International Transport Forum

Ready for Take-Off? Integrating Drones into the Transport System

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Research Report
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The International Transport Forum

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In December 2018, the International Transport Forum (ITF) at the OECD convened more than 30 distinguished international experts to form a Working Group "Drones in the Transport System: Acceptability and Integration" discussing the integration of drones into the overall transport system and the prerequisites for public acceptance of regular drone transport.

The group assembled renowned practitioners and academics from areas including aviation regulation, transport modelling, innovation policy and urban planning. It was first chaired by Laura Ponto, then Counsel at Hogan Lovells, and later by Richard Cross, Manager Strategic Policy and Innovation, New Zealand Ministry of Transport – Te Manatū Waka.

The Working Group was facilitated by Katja Schechtner, Advisor for Innovation and Technology at ITF and Visiting Scholar at Massachusetts Institute of Technology (MIT), and Elisabeth Windisch, Team Lead Empirical Policy Analysis, ITF. They would like to thank Ombline De Saint Leon Langles, Andrew Lombardi and Vatsalya Sohu (all ITF) for their support on compiling this report and Edwina Collins (ITF) for her support in the publishing process. The group brought together knowledge from 14 countries and three international organisations to provide insights on one of the most discussed issues in aviation today.

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Table of contents

Figures

Boxes

Abbreviations and acronyms

AAM	advanced air mobility
ANS	air navigation services
ANSP	air navigation service provider
ATC	air traffic control
ATM	air traffic management
API	application programming interface
DOT	U.S. Department of Transportation
gCO_2	grams of CO_2
GDP	gross domestic product
GHG	greenhouse gas
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IPP	Integration Pilot Program
KPI	key performance indicator
LCA	life-cycle assessment
MaaS	Mobility as a Service
PPP	public-private partnership
UAM	urban air mobility
UAS	unmanned aircraft systems
UTM	unmanned traffic management
VTOL	vertical take-off and landing

Executive summary

What we did

Recent years have seen rapid developments in drone technology. Today, drones have the potential to become a reliable technology for civil, commercial and leisure use. However, existing policy frameworks are often lagging behind technological advances, causing reluctance among potential adopters or hampering new developments.

This report presents policy options for integrating drones into the wider transport system while reaping their opportunities and limiting any potential risks. It focuses on standard public concerns related to the introduction of new transport services, such as their acceptability, efficiency and sustainability. It therefore goes far beyond the frequently debated safety and security issues of drones. The report considers the use of drones for different scales of payloads and autonomies, mainly used in freight and passenger transport. It also looks at drone use cases in the transport sector that go beyond the transport of passengers or goods, such as their use in the maintenance of transport infrastructure.

The insights and policy options presented in this report build on the collective knowledge of the Working Group on Drones in the Transport System: Acceptability and Integration by the International Transport Forum. The group included more than 30 renowned practitioners and academics from 14 countries with expertise in aviation, transport regulation, mobility systems and urban planning.

What we found

Drone technology – including related research and development, manufacturing and operations – enables significant economic activity. It offers many potential use cases that can ultimately deliver substantial economic, social and environmental benefits. Countries should recognise these potential benefits and work towards safely integrating drones into their aviation and overall transport systems. However, various public concerns about the large-scale deployment of drones have not yet been thoroughly addressed. There remain substantial knowledge gaps about how to respond to such concerns as there is only limited research on the potential impacts of drones that goes beyond assessing safety, security and privacy concerns. In parallel, policy makers continue to assess the appropriateness of existing regulations (e.g. for aviation) and how best to adopt new policies and rules for drone use to ensure their market potential can be leveraged and societal benefits realised.

What we recommend

Establish clear objectives and priorities for the introduction of drone transport by identifying the best first use cases

Like all new technologies, drones will have both positive and negative impacts. To keep up with the developments of new technologies and enable future research within the sector, authorities should clarify priorities for drone integration by identifying initial use cases that align with the overall transport policy goals. Where possible, early trials of drones should also focus on use cases that have clear public benefits, such as transporting medical goods and improving access to remote communities. Industry claims concerning, for example, the efficiency or sustainability of drones should be objectively evaluated.

Design a communication strategy that directly addresses public concerns

Public acceptance will have a major impact on the speed of drone development. Authorities can enhance acceptance by directly addressing concerns such as about safety, privacy, noise, visual disturbance, equitable access related to drones. This can be accomplished by ensuring that the public is informed about, for example, accident and incident rates, methods of reporting and addressing grievances, rules that govern the flight and take-off and landing procedures of drones, and the benefits provided by drone operations.

Clarify and develop drones' status within the broader framework of aerospace regulation

Drone transport services may be subject to the same market access restrictions as manned aviation under the Chicago Convention (1944) and associated aviation licensing and traffic rules. Restrictions on operations could especially constrain the development of drone companies that engage in the carriage of goods or people. Authorities wishing to exempt drone operations from restrictive rules, such as the prohibition on cabotage, need to determine how to distinguish drone services from manned aviation and whether to distinguish transport drones from those performing other commercial services (such as aerial surveillance).

Co-ordinate with the drone industry to inform investment, development, and equitable policy making

Governments can establish mechanisms to address issues related to regulation, governance, and the funding of drone infrastructure. Such mechanisms can consult different levels of government and industry stakeholders as appropriate and on an ongoing basis, taking into account national, regional or local characteristics. Private industry is currently spearheading most drone technology developments, thus gaining the expertise and insights that can inform and support policy development. Where appropriate, governments are encouraged to actively collaborate with industry to develop policies to support drone development and deployment in ways that increase public acceptance.

Foster the emergence of civil aviation authorities with interdisciplinary competencies and capabilities in order to integrate drones into the transport system

The emergence of drone applications will fundamentally transform the aviation industry by attracting many new players with different backgrounds, characteristics and requirements. To ensure that authorities can keep their active role in integrating drones in the airspace in accordance with this transformative ecosystem, they need to transform themselves too. Thus, civil aviation authorities should promote more flexibility, by investing in interdisciplinary competencies that may far exceed expertise in aviation and transport.

Support the design and implementation of a robust Unmanned Air Traffic Management system

Unmanned Air Traffic Management (UTM) will be essential for managing drones, especially as they increase in volume. UTM can ensure the physical separation of aircraft, allocate airspace, and optimise route planning, especially in densely populated areas with crowded air corridors. There is no one-size-fits-all approach to UTM, and a number of different governance approaches are currently being trialled. Any future UTM system must prioritise safety, security, interoperability, and equitable access to airspace. Drone registration and remote identification are key building blocks that will support the development of UTM in order to increase transparency and public accountability.

Develop methods for assessing the impact of drones' full life cycle on the environment

Policymakers should focus on the total energy consumption and emissions generated from drones, including those associated with the manufacture and disposal of the drones. The net impact on carbon emissions will, among other parameters, depend on the source of energy used and on the activities that drones perform. Other environmental impacts, including noise and vibration, will also vary greatly depending on the drone use case, and comparisons of impacts with manned aviation will not always be appropriate.

Incorporate drone operations into long-term urban planning strategy using data and predictive models

Drone operations will likely have a small infrastructure footprint compared to manned aviation, at least initially, but could be deployed in combination with existing modes of transport. Cities should incorporate drone operations into their long-term planning, and leverage data and research to identify areas where drones may be most suitable. The best environments for initial drone deployment include areas where noise and visual disturbance can be minimised, where new or more efficient transport links can be created, where the value of existing land use and properties is maintained, and drone operations (both passenger and cargo) can be seamlessly integrated with other modes of transport to reduce transfer times.

CHAPTER 1
Introduction

For several years, drones have been transforming the way many businesses operate. Initially, the limited range and payload of drones meant that they were best suited to conducting tasks that were costly or impractical to perform using traditional (manned) aircraft, such as aerial photography, surveying and mapping. However, as drone technology has advanced, the use cases for drones have rapidly expanded. It is now evident that in the decades ahead drones will play an increasingly important role in all aspects of the transport system, including transporting both goods and people.

Drones are no longer limited to the small, electric rotor aircraft commonly used by photographers, tourists and hobbyists. The term *drone* is used throughout this report as it is more commonly understood by the public. It is an umbrella term that encompasses all flying vehicles without a human operator on board.* The underlying technologies used in drones can be fitted to virtually any conventional aircraft, and there is wide variation in their size, weight, level of automation, design features and method of propulsion.

Like all new technologies, drones bring both benefits and risks. Drones are expected to improve safety by automation (hereby limiting the degree of human interaction and related possible human error) and create economic benefits by reducing costs and improving efficiency, resulting in new business processes and opportunities. However, drones will also introduce new risks and externalities. Technology developers will naturally highlight the benefits of drones while tending to understate or overlook risks and challenges; mitigating these risks will be crucial for building public acceptance, which will ultimately determine where and how drones are used in the future.

Although drones have unique characteristics, they are still aircraft, and they will need to fit into an existing aviation system to ensure ongoing safety and public acceptance. This system has been established over many decades and is supported by a myriad of regulations and standards, which are set out in international conventions and mirrored in domestic legislation, regulations, and operator practices throughout the world. Integrating drones into this system without compromising the safety or security of the aviation system will be a significant challenge for many years to come. There are extensive trials underway, and significant resources and literature dedicated to evaluating safety and security issues. These issues are not discussed here, but their importance is by no way overlooked by the authors of this report. There is far less dialogue and research identifying possible approaches to integrating drones into the economy and society with a high level of public acceptance.

Realising the full potential of drones will require new tools and new ways of working. The private sector will have a key role to play, not only in developing the drones themselves, but also in developing the technologies needed to support their integration into the transport system. Drones will need to integrate into not only the aviation system, but also into the transport system and society more broadly. This will require input from experts in new technology fields and other transport sectors beyond aviation; and experts from both aviation and from outside the sector will need to understand the regulatory

* Other, more technical terms are also used to discuss drones in many countries and aviation. The most frequently used terms are *remotely-piloted aircraft system* (RPAS) and *unmanned aircraft system* (UAS). Literature also refers to *unmanned aerial vehicle* (UAV), *autonomous aerial vehicle* (AAV) and *remotely piloted aerial vehicle* (RPAV).

environment and culture of both aviation and other transport policy fields, such as urban transport planning.

Unmanned traffic management (UTM) systems will be an essential part of the drone ecosystem. UTMs enable deconfliction of air traffic and real-time identification of drones in flight; they can also identify the most efficient route for a given flight based on its origin and destination, weather, other air traffic, and a number of other factors. In the future, UTMs are likely to be an important tool both for managing the environmental impacts of drones (allowing flights to be planned to take into account restrictions on noise or visual disturbance) and for ensuring equitable access to take-off and landing areas in areas of high demand. Regulators and policy makers around the world will need to work closely with industry and other stakeholders to establish performance-based standards for UTMs that are interoperable and interact with existing air traffic control systems.

A key message of this report is that although drones have the potential to improve many aspects of our society and economy, the realisation of these benefits will depend on policy makers putting into place a good foundation. With careful management, drones could improve access to places of opportunities (such as jobs, health care, education) and contribute to a safer, more efficient and more sustainable transport system – but if they are not managed carefully, they have the potential to increase emissions, noise and other environmental impacts while exacerbating inequality in the transport system. This report is a call to action for policy makers to look beyond the most obvious potential impacts of drones, and to consider how they can shape some of the less-obvious potential impacts of drones through the policies they develop.

Drones will have positive economic impacts, but will also create economic risks

There is a wide range of potential use cases for drones. These include networks of small drones carrying parcels and/or medical goods over short distances, larger cargo drones carrying heavier payloads over long distances, and drones transporting passengers. Passenger drones may be used within large and sprawling urban areas, or to connect cities with regions that are either difficult to access by surface transport or lack the infrastructure or scale necessary to support traditional forms of aviation.

The economic benefits of drones are significant. Drones are expected to expand access to goods by allowing for faster and less expensive air transport, unbound by the expensive and expansive infrastructure traditional aircraft require. Drones are likely to increase productivity and create new manufacturing and technology development streams, which will create jobs throughout the economy. In the more distant future, they may also shift or eliminate jobs within portions of the transport sector.

Over time, drones can also be expected to affect land use and property values, both positively and negatively. Where drones are perceived to provide benefits, property values are likely to increase, but where they are perceived to be an annoyance (e.g. due to noise, visual disturbance or privacy concerns), property values are likely to decrease. Drones may also affect land use patterns, as improved accessibility may create an incentive for people or businesses to move away from dense urban areas.

The development of new markets for drones will depend in part on regulation. In particular, as drones are generally considered “civil aircraft”, they are likely to fall within the Convention on International Civil Aviation, or Chicago Convention (1944). They may also be subject to national licensing frameworks which limit the ability of foreign investors to participate in the aviation industry. In facilitating the integration of drones, policy makers will need to consider whether the economic regulation of drones under these frameworks is beneficial or necessary.

To build social acceptance, drones will need to provide clear benefits to the general public

Drones, particularly passenger carrying drones, have the potential to significantly reduce costs compared to traditional forms of aviation. If these cost reductions can be realised, they have the potential to create new markets and significantly improve connectivity – both within large metropolitan areas and in remote or geographically isolated regions which are poorly served by other modes. This in turn may lead to changes in commuting patterns and/or urban development. While this will bring benefits for some people, it may also raise significant sustainability issues by incentivising urban sprawl and increasing the ecological footprint of the existing population.

A key risk with drones used for passenger services is that, at least initially, services may be priced to recover high investment costs, and therefore reach levels that are appealing only to passengers with high incomes. The benefits of these services could largely be confined to wealthy citizens, while their externalities (such as visual disturbance or noise) would affect the general public. Drone delivery services may result in similar equity concerns if they are perceived to be catering primarily to wealthy citizens, particularly if they are delivering non-essential goods. If drone services are not affordable to a majority of citizens, social acceptance will be low, and large-scale drone innovation and deployment may be impeded from the outset. Policy makers and drone companies will have to think carefully how to address social acceptance and ensure that drones are seen as providing value to the public at large.

Drones will create new environmental challenges

Traditional aviation has a significant impact on the environment, but these impacts are generally well understood, and a range of policies, standards and operational procedures have been developed to ensure that these impacts are addressed. In contrast, the environmental impacts of drones have received comparatively little attention. The huge variation in both the size and physical characteristics of drones, and the environments in which they operate, mean that the mitigations that have been developed for traditional forms of aviation are unlikely to be sufficient to manage the environmental impacts of drones, and new approaches will be required.

Noise is a key factor which could be a major obstacle to drone integration if it is not carefully managed. This is due not only to the actual noise drones produce (often a high-pitched tone that is typically between 20 and 70 decibels), but also to the ways in which noise is perceived – such as people's familiarity with and acceptance levels of drones, or surrounding noise levels. In cities, the ambient noise levels of conventional vehicles may make drone noise less apparent. However, their proximity to residential areas, and the increasing uptake of quieter electric vehicles, may make drones more noticeable.

Although most drones produce zero tailpipe emissions, this does not mean they do not contribute to net greenhouse gas emissions. All drones will consume energy. The amount of energy used will depend on the design of the drone, its payload, the energy mix used for electricity production, and the method of electricity transmission to the battery. The production and scrapping of drones at the end of their lifespan will also consume energy and produce emissions. The net emissions of drones compared to traditional modes of transport will depend on the specific use case and the local context. In some cases (such as carrying lightweight packages in sparsely populated areas that would have otherwise required a delivery van), drones may reduce emissions. In other cases, drones may result in a net increase in emissions.

Drones will also have other environmental impacts, both positive and negative. They are likely to help alleviate air pollution in urban cities, as the majority of drones are electric powered. Drones may also have impacts on wildlife and generate visual disturbance, however, and these impacts will need to be carefully managed.

Policy makers will need to support the development of physical and digital infrastructure while ensuring equitable access

In order to operate safely, drones will rely on infrastructure. This includes both physical infrastructure (such as charging stations and designated take-off and landing areas) as well as digital infrastructure (such as UTM services and associated communications infrastructure).

Most drones are smaller than traditional aircraft. Their ability to take off and land vertically with a high level of precision means that they typically occupy a smaller spatial footprint. The specific characteristics of the physical infrastructure will depend on both the location and its intended use cases. In rural areas, infrastructure for drones is likely to be relatively inexpensive. In dense urban areas, suitable take-off and landing areas (particularly for larger, passenger carrying drones) are likely to be scarce, and will require careful planning in order to comply with zoning and other regulations. In some cases, demand for landing sites in a given area may exceed supply, and in these instances there may be a case for either public funding or regulations to ensure fair and equitable access to take-off and landing sites.

Currently, in most countries, drones are able to fly at low altitudes in uncontrolled airspace without authorisation or communication with air traffic control. However, in the future, drones are expected to regularly operate in other classes of airspace as they become larger and fly at higher altitudes, and there are likely to be an increasing number of aircraft in the skies. New UTM systems will be required to enable seamless communication between drones, other aircraft, and air traffic control. To date, the development of UTM has been led by the private sector, with the public sector helping to establish and ensure compliance with performance-based standards. This creates a risk that private sector actors may prioritise certain operations (including their own commercial operations) or apply fees that have the effect of commercialising public airspace. This, in turn, could lead to the emergence of a UTM structure that is dominated by a handful of private monopolies. To mitigate these risks, policy makers will need to have a better understanding of the way data is produced, collected, stored, analysed and repurposed within the UTM ecosystem. They will also need to keep the risks in mind as they establish regulatory frameworks to support UTM systems, emphasising interoperability.

Policy should emphasise filling gaps in the network while supporting broader goals

Drones will not operate in isolation. Rather, they will be integrated into a larger, inter-modal transport system. For example, freight may travel by boat, rail, or truck, and then be transported by airborne drone to its final destination; and passenger drones may transport people to airports or rail stations as just one leg of their journey. In some cases drones may act as a complement to existing modes, helping to fill gaps in the network and making it more viable for people to get around without the need to own a private vehicle. In other cases, drones may act as a substitute, or induce demand for new trips which otherwise would not have been made or that were not previously possible to make.

Although most drone services are likely to be provided by the private sector, governments can still influence how and where they are used. For example, through planning policy, governments can encourage the integration of drone services into existing transfer hubs to provide seamless connections to other transport modes. Other tools – such as establishing flight corridors, or using drone registries and geofencing to prevent flights over certain areas – can also help to ensure that drone services are supporting public policy goals.

CHAPTER 2
Drones for transport: Potential market and economic impacts of drones for transport

Drones have the potential to unlock a wide range of economic benefits by improving the efficiency of supply chains and offering a new mode of passenger transport. However, as with all technologies, drones also create economic risks that must be considered and mitigated to allow for their successful development.

This chapter discusses promising use cases for drones in the transport sector and provides policy recommendations that can help materialise the drones' market potential. The chapter also assesses the impacts of drones on competition and employment in the transport sector, as well as on land and property values, and proposes policy actions that can help mitigate any unwanted, related effects.

Impacts on transport operations

Drones in the transport sector may be used for freight and passenger transport operations. Policy makers should pursue policies that ensure this market potential materialises and provides for the economic development of the transport sector, while minimising any potential externalities (as discussed throughout this report). Use cases in transport may also go beyond the transport of goods or passengers and benefit the sector as a whole (such as when deployed to aid the maintenance of transport infrastructure).

Drones for freight transport

Consultancy firm Roland Berger (2020) identifies four different cargo-drone use cases that can be differentiated by the drone's payload and degree of autonomy. In all applications, the aim is to automate the transport of goods to provide faster, more flexible, and less expensive services compared to traditional means of transport:

- Automation of intralogistics (in factories and warehouses): Drones may be deployed to deliver single items directly to the production line or to help in warehousing activities (refilling of depleted shelves, etc.). For example, carmaker Audi has been piloting an indoor drone at its Ingolstadt plant. It travels at up to 8 km/h and transports automotive parts up to 2.0 kg to the required step in the manufacturing process.
- Delivery of medical goods (often to remote places): Drones can be a fast and reliable transport option for urgent medical goods, especially where existing transport infrastructure (or a lack thereof) does not allow for efficient deliveries. For example, Zipline – a US company that designs, manufactures, and operates delivery drones – has been operating a medical supply drone service to 25 hospitals and clinics in Rwanda since 2014, primarily to deliver blood samples and blood products. Similar services have since expanded around Africa and beyond, and have seen increased interest during the Covid-19 crisis (see Box 5 in Chapter 3 for further examples). The delivery of medical goods is closely related to the concept of first/last-mile parcel delivery (see the next bullet point) as the payload and range of the respective drones can be very similar. For

many drone operators and/or manufacturers, the delivery of medical goods is a start, with the aim of expanding operations to also provide first/last mile deliveries.

- First/last mile parcel delivery (often in/around urban areas): Drones can bring significant increases in productivity and profitability (and hence cost savings) for logistics companies in first/last mile operations. Often this part of the freight transport chain constitutes the most expensive and least efficient part of a delivery, requiring significant manpower, vehicle numbers and time (especially where poor traffic, poor roads or geography impede existing delivery methods). Delivery drones could also be combined with other new technologies, such as driverless vehicles. Driverless vehicles loaded with parcels could dispatch multiple delivery drones when they near the most efficient point from which to complete their deliveries. Such a vehicle would serve as a base station for the drones, providing charging and payload swapping as required (PwC, 2018). See Box 1 for examples of drone delivery applications.
- Transport of air cargo (for longer-distance applications): Cargo drones could allow the transportation of goods more flexibly than truck or train transport allows; they could also provide an effective means of balancing out stock across different warehouses. For example, US start-up Elroy Air has been developing a drone that can carry up to 225 kg within a maximum range of 500 km (Elroy Air, 2020); US-based Yates Electrospace Corp. (YEC) has announced a new widebody cargo delivery drone with a payload of 567 kg (Air Cargo News, 2020); Natilus, a California-based start-up, is developing a 60m-long drone with a 100-ton capacity (Jordan, 2019); and in May 2020 Sabrewing Aircraft Company unveiled a drone with a payload of more than 2 000 kg (when taking off and landing from a runway) and a range of almost 2 000 km (Harry, 2020; Hsu, 2020). To date, commercial applications of such high-payload cargo drones have not started.

Alternatively, cargo drone use cases could also be categorised into intralogistics, short-range/last-mile delivery, and long-haul/large-payload delivery services.

The parcel delivery sector's existing use of automation, broad network, and high visibility have led to early adoption of drone technology by many firms, including new-entrant technology providers and existing freight and logistics companies. Today, parcel delivery is the among the most prevalent drone use cases in the transport sector (especially when combined with the related use case of medical supply transport). For firms that ship millions of packages per day, small reductions in the cost of transporting packages improve profitability, and improvements to margins and new business models will likely develop over time as automation is successfully introduced. Delivering goods to customers more quickly can increase competitiveness and network coverage as well.

A 2016 study (Sudbury and Hutchinson, 2016) conducted a hypothetical analysis of the cost reductions that Amazon could achieve through drone deliveries while accounting for factors such as labour, capital, maintenance and regulatory costs, and weather delays. The analysis predicted that a network of drones in Chattanooga, Tennessee, would reduce costs by one-third or more, compared to ground-based delivery methods. Amazon's drone technology intends for drones to replace traditional forms of package delivery which are both labour and capital intensive. It is envisioned that one drone operator will monitor multiple drones simultaneously.

Another study (Aurambout, Gkoumas, and Ciuffo, 2019) undertook modelling, using EU-wide population and land use data, to consider the potential economic viability of "drone beehives" (a type of consolidation centre, patented by Amazon, that accommodates landing and take-off of drones in densely populated areas) as a last-mile delivery solution in urban areas. The study finds that drone beehives are economically viable in many European urban areas (reaching 7-30% of EU citizens, depending on the scenario). The study concludes that such drone activities are likely to develop quickly when regulatory limitations are overcome.

In addition to bringing efficiencies to large supply chain firms, drones can provide small businesses with greater access to the on-demand delivery market, reduce delivery times, and increase access to goods, especially for time-sensitive products. This could foster competition and increase economic growth.

However, parcel deliveries with drones will also face a number of limitations. They are likely to be restricted from operating in adverse weather conditions, such as high winds, icing or heavy rainfall. In some circumstances they may also be less efficient than other modes of transport for delivering goods, e.g. when direct drone delivery to a household or specific address is impossible given the availability of drone infrastructure and/or potential flight or landing restrictions. They may also not be preferred by some customers. As a result of these limitations, it is likely that drones in the freight transport sector will be a complementary or optional mode of transport versus more conventional modes.

Box 1. Examples of drone delivery trials and applications

Drone delivery trials have taken place all over the world, employing various types of aircraft and delivery models. Some trials involve delivering packages to a specific landing spot or locker in a given area, where the consumer collects the goods. Others deliver directly to a consumer's home, potentially even without the need to land. Lyons Place, a London residential complex designed by architect Sir Terry Farrell, will be the first in the United Kingdom to implement rooftop "vertiports", encouraging drone delivery services (Stouhi, 2019).

In 2016, Amazon carried out its first successful drone delivery operation in Cambridge, UK. In 2019 it unveiled the latest version of its Prime Air delivery drone and announced that it wanted to launch a delivery service using drones in "the coming months" (Vincent and Gartenberg, 2019).

In March 2018, The People's Republic of China-based logistics giant SF Express became the first company to be issued with a commercial license by the Civil Aviation Administration of China (CAAC) that allows them to drop off products using their drones. The company aims to use drones for delivering goods to rural and sparsely populated areas in China. JD.com, China's second-largest e-commerce company, has also been testing drones and wants to build 185 droneports in China's mountainous southwest region, with the aim of cutting its logistics costs there by more than half (Huang, 2018).

In May 2018, Matternet, a California-based manufacturer of drones, was selected to carry out drone logistics operations for U.S. hospitals under the Federal Aviation Administration's (FAA) drone integration program. In partnership with WakeMed Health (in North Carolina) and UPS, they have completed over 1 000 medical deliveries (UPS, 2019) (Matternet, 2019).

In April 2019, Wing Aviation, a cargo drone specialist owned by Google-parent Alphabet, was awarded the first U.S. FAA air-carrier certificate licensing commercial deliveries using cargo drones. The permissions allow multiple pilots to oversee numerous simultaneous flights making commercial deliveries to the public. In October 2019, the first commercial flight took place in Christiansburg, Virginia. Using a smartphone app, customers can make an order at one of the partnering retailers; the delivery drone then takes off within a few minutes (or when scheduled) and delivers the parcel directly to the customer's home (by lowering the package within a small, designated area of the homeowner's property) before returning to Wing's "Nest" in North Christiansburg (Murphy, 2019).

Drones for passenger transport

There is now an emerging consensus that drones will eventually play a future role in transporting passengers. Over the past few years, an entirely new industry segment is emerging, with companies around the world competing to develop drones capable of carrying passengers and taking off and landing vertically. The development of this segment has been partly driven by new start-ups that see an opportunity for these aircraft to revolutionise urban mobility. However, all of the major aircraft manufacturers – including Airbus, Boeing and Embraer – are also developing variants of drones. Many of these drones are expected to carry a pilot on board in the early stages of the business plans. In the short term, passenger drones would be used mainly for short-distance trips (in and around, but not limited to, urban areas) where air or surface transport is either not feasible (e.g. due to infrastructure constraints) or very expensive (given its labour-, fuel- and capital-intensity). Drones may eventually also be used for longer-distance passenger trips. See Box 2 for examples of passenger drone trials.

Box 2. Examples of passenger drone trials and ambitions

Passenger drone trials are still rare and have not yet gone beyond single test flights. Furthermore, as of June 2020, fully remotely-controlled test flights with passengers have not been carried out to the knowledge of the authors.

In 2017, Lilium, a Munich-based start-up, launched its two-seater prototype drone. In 2019, this was followed by a first flight of a five-seater drone. The company envisions offering drone passenger services to the public in various cities around the world by 2025, initially with a human pilot on board (Lilium, 2020).

Volocopter, also a German-based drone start-up, conducted its first piloted flight with its two-seater drone in Singapore in October 2019. The event marked the end of a long period of trials and engagement with the local government. At the same occasion, it also unveiled its vertiport design, called “Voloport” – the physical infrastructure required for the vertical take-off and landing of the drone (Future Travel Experience, 2019). The company hopes that its “air taxis” can launch in Singapore as early as 2021, also with a pilot on board at first (Elangovan, 2019).

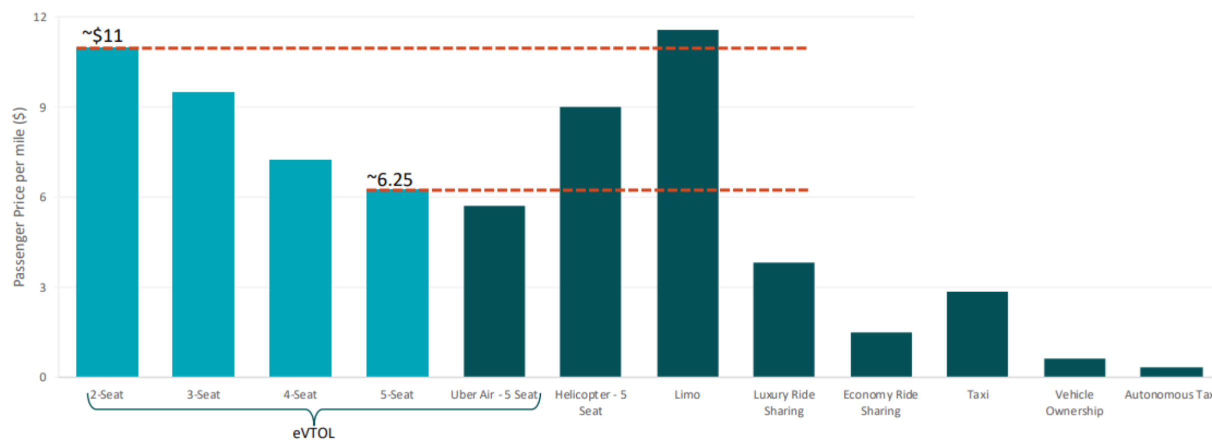
In May 2018, Airbus created Airbus Urban Mobility. The goal is to offer passenger drone flights across congested cities and from suburbs to city centres at a cost that is competitive with traditional ground taxi service (Downing, 2019; Airbus, 2020).

Uber Air plans to be able to provide shared air taxi services to their customers by 2023, with test flights planned in the cities of Dallas, Los Angeles, and Melbourne in 2020 (Uber, 2020).

The costs for transporting passengers by drone are still highly uncertain. However, those developing the technology have suggested that it will be affordable to the wider population. In the longer run, they expect prices to become similar to those of normal taxis (for short trips) or high-speed rail or economy flights (at longer distance), or even below the costs of using your own car and viable for daily commuting (Uber, 2016; Hader, 2018; Downing, 2019; Wakefield, 2020).

An analysis carried out for the US National Aeronautics and Space Administration (NASA) in 2018 (Booz Allen Hamilton, 2018) estimated a passenger price per mile of USD 11 for a two-seater drone (comparable to current limousine-type services) and USD 6.25 for a five-seater drone (cheaper than limo services, but more expensive than luxury ride-sharing services) in the first years of operation (see Figure 1). This is based on the assumption that, in these first years of operation, drone services require one full-time-equivalent pilot per drone and one full-time-equivalent ground crew member. The ground crew is expected to serve multiple roles including passenger check-in, security check and any other customer-related service. The assessment also accounts for capital and insurance costs, energy costs, battery costs, infrastructure costs, maintenance costs, route costs (for the use of airspace) and indirect operating costs. It also defines premiums, likely profit margins, and taxes and fees to convert cost estimates into likely consumer prices. Once air taxi services become fully automated, labour costs would decrease, putting downward pressure on the prices offered to consumers (assuming a competitive environment).

Figure 1. Price comparison of passenger drone services with other modes of transport during first years of operation (USD/mile)



Source: Booz Allen Hamilton (2018).

Uber (2016) believes that in the long term, drones will be an affordable form of daily transport for most people, and even less expensive than owning a car. This may be due to economies of scale in manufacturing as drones become more akin to automobiles than aircraft; and also to their ridesharing model, which could amortise vehicle cost efficiently over paid trips. The pooling of trips would also achieve higher load factors and thus lower the prices for each individual. This would then drive demand for the services and the drones themselves, lowering manufacturing costs further.

Based on these estimates, there are several ways in which the so-called Urban Air Mobility (UAM) or Advanced Air Mobility (AAM) market could evolve. It could complement existing ground-based, short-distance transport modes or develop its own unique offering – either helping to extend existing networks or providing an alternative. The first mode-choice studies addressing UAM/AAM show that trips by active modes (walking and cycling) are unlikely to be substituted, while people currently using private cars, car sharing or taxis are more likely to consider using UAM/AAM providers for some of their trips. Depending on price levels and service design, some public transport trips may also be substituted (Fu, Rothfeld, and Antoniou, 2019).

With further technological improvements in battery technology, reliability of communication links, and certification processes for automation, it is possible that drones may eventually become capable of making medium– to-long–distance trips, competing with rail or traditional aviation models. They could open new inter-city or inter-regional markets on routes which currently have little demand, and could make passenger transport easier across natural barriers such as lakes, rivers, mountains and bays. There are also hybrid and fossil fuel powered drones under development.

Other drone uses in the transport sector

There are many drone use cases that are relevant for the transport sector and that go beyond the transport of goods or passengers. For example, drones equipped with cameras may be used for the inspection or monitoring of transport infrastructure (such as railway lines, roads or bridges) or aircraft. They may also be used for the surveillance and monitoring of traffic or peoples' movements (such as at mass events or during times of crisis), and they could offer efficiency gains and improved outcomes for emergency and search and rescue operations which are currently performed by conventional helicopters. Drones often offer a means to carry out respective tasks more safely, more efficiently and/or more accurately than what would be possible by more traditional means, especially where humans are put in harm's way. As a result, such, and related, drone use cases are of increasing interest in the respective industries.

Box 3 provides several examples of drone uses that are relevant to the transport sector but that go beyond the transport of passengers or goods.

Box 3. Examples of non-transport applications of drones related to the transport sector

Under the Unmanned Aircraft Systems (UAS) Integration Pilot Program (IPP) launched by the United States Department of Transportation (DOT) in October of 2017, the City of Memphis deploys **drones for aircraft inspections,** airport warehouse and security fence inspections, security patrols of ramps, and perimeter security of the Memphis International Airport (FAA, 2019; Memphis International Airport, 2019).

An engineering firm in Minnesota uses **drones to inspect bridges** to save time and costs, while increasing the accuracy and frequency of inspections. The drone requires no traffic control to transport and no additional time to reach the site, and can be operated by a single inspector compared to the two or more personnel that would be required otherwise. The drone also allows the inspector to see normally inaccessible areas like the spaces between beams (Hayley, 2018).

In Germany, **drones are being used for highway maintenance and rebuild operations**. Using photogrammetry software, the drones can deliver 3D models and respective data to analyse vegetation, vehicles or on-site resources (Hayley, 2019).

During the Covid-19 crisis, many relevant drone uses have emerged, ranging from contact-free deliveries to the **disinfection of large areas**. For example, in China, more than 900 km^2 in 20 Chinese provinces have been disinfected using a total of 2 600 drones. In Korea, drones used in the city of Daegu sprayed an area of 10 000 m^2 in around ten minutes (Sinha, 2020). See Chapter 3 for examples of contract-free deliveries during the pandemic and ITF (2020) for further examples.

Resulting market potential for drones in transport applications

The market potential for drones in the transport sector remains uncertain at this point in time. As with other new technologies, market development will highly depend on, for example, the regulatory framework and potential supportive measures put in place, technological advances, related costs of drones and their services, etc. The societal acceptance of drones as a means of transport – whether for freight or passengers – will also be a key determining factor for the drones' market potential.

Furthermore, studies on the market potential for drones in key transport applications (i.e. the transport of passenger and goods) are limited. Often, the market potential for drones is assessed across the whole economy. For example, research by PwC suggests that the global value of businesses and labour that could have been replaced by drones in 2015 is USD 127 billion – this, however, includes services in sectors such as transport, infrastructure, insurance, media & entertainment, telecommunication, agriculture, security and mining (PwC, 2016). In the United Kingdom alone, drones could lead to a GDP uplift of GPB 42 billion (or 2%) by 2030 (PwC, 2018).

Looking more specifically at the global drone transport and logistics market, available studies suggest that this sector could grow from USD 11 billion in 2022 to USD 29 billion by 2027 (or to USD 27 billion by 2030 when looking at the drone package delivery market alone) (MarketsandMarkets Research, 2018). In the UK, the transport and logistics sector could be responsible for around 11 000 drones, increasing the productivity of the sector by 8.4% by 2030, and resulting in cost savings of around GBP 2.8 billion. They would contribute to a GDP increase in the sector of around 1.5% by the same year (PwC, 2018).

Roland Berger (2018) provides an outlook specifically for passenger drone applications in the UAM/AAM market. They see around 100 000 passenger drones in operation by 2050 (across 100 cities) that are either used as airport shuttles, air taxis or for intercity flights. The base case of another study suggests a market potential of USD 21 billion and USD 11 billion for intra- and inter-city passenger drones, respectively, by 2035, relying on a global passenger drone fleet of 23 000 vehicles (Porsche Consulting, 2018). A study carried out for the US government suggests that the air taxi market has a potential demand of around 55 000 daily trips (or around 80 000 passengers) that can be served by around 4 000 passenger drones in the first years of operation. The corresponding annual market value would be USD 2.5 billion (Booz Allen Hamilton, 2018).

What can policy makers do?

It is in a policy maker's interest to pursue policies that seize the opportunities and market potential that a new technology and related industry may provide. To seize the market opportunities provided by drones, policy makers should consider:

- **Recruiting experienced personnel from the drone and information technology industries** to recognise drone innovation and its associated potential in the early stages.
- **Defining responsibilities across public authorities and levels of government** (e.g. with regard to enforcement of rules and regulations) to create clarity for policy makers but also for industry stakeholders.
- **Assessing how much economic regulation is necessary for the drone industry** and whether existing approaches to economic regulation (e.g. in the area of air transport) could impede the development of new drone services. Where obstacles arise, they should be addressed appropriately and in consultation with citizens and industry.*
- **Fostering developments with public-private partnerships to overcome the initial uncertainty that usually accompanies investments in new technologies.** This could help kick-start drone research and deployment.

Policy makers should further **consider all risks and public concerns that may come with drone deployment** (as outlined in this report) **and address them adequately**, to limit any potential adverse effects of drones

* For example, policy makers should carefully assess the adequacy of national regulations developed under the Chicago Convention (1944) establishing the core principles for international air transport that are likely to apply to international drone services. If applied in their current form, they could put significant restrictions on foreign drone operators to operate in domestic markets or transoceanic transport business models. This may unnecessarily constrain the growth of drone services, the industry and their market potential overall.

as much as possible. In this regard, policy makers would do well to incorporate lessons from the development of similar industries, i.e. traditional aviation and telecommunications.

Impacts on competition

The effectiveness of transport services relies on competition among firms as well as accessibility and quality of infrastructure. In the case of manned aviation, services could not be provided on an industrial scale without the existence of aerodromes, aeronautical telecommunication, and air traffic services, among others.

Drone-based services will be reliant on similar infrastructure and may therefore follow a similar trajectory to manned aviation. Drone applications will give rise to a new “second” economy – the data economy – whose economics have yet to be worked out. Nevertheless, it is clear that this economy will trigger new business models, shift competitive dynamics, redefine market structures, and attract new players in the transport industry and far beyond. These developments will have significant implications for competition in the industry and may turn into regulatory challenges that policy makers should note.

Impacts of drones

Markets involving transport infrastructure may present competition issues. Usually, duplication of transport infrastructure is not feasible technically or viable economically. Consequently, natural monopolies that have sole access to respective infrastructure may develop. They give producers or service providers the ability to surcharge their outputs, because incentives to control costs of, or develop, new products or services are limited.

Critical components of drone infrastructure could also be susceptible to monopolies – in particular, ground-based equipment(such as drone charging stations or vertiports) and UTM systems and the data they collect. When addressing competition concerns, policy makers may be able to emphasise the differences in drone infrastructure requirements compared to manned aviation. For instance, drone operating sites are less expensive and require less space than manned facilities, which could allow for more new players. However, spatial, regulatory or environmental constraints, especially in densely populated areas, may lead to the natural monopoly of ground-based facilities such as charging stations or vertiports. The susceptibility of UTM to monopoly may depend on the types and compatibility of technologies deployed, how data is distributed among actors, and the nature of airspace allocation (e.g. its fragmentation into urban drone corridors, drone highways etc.).

Competition problems may also occur outside the scope of natural monopolies, such as the vertical integration of supply chains. Where upstream or downstream markets do not provide adequate services, the strategy of an enterprise may include self-supply of these services. For instance, a drone service provider may wish to introduce its own UTM system and ground-based operating sites, or a drone manufacturer may choose to offer some UTM services. In some forms, these strategies have already been applied in the drone sector, and to an extent they may be necessary to foster the economic and technical advancement of this young industry. However, in the long run, some types of vertical integration of supply chains may bring about anticompetitive effects. This is because they may enable firms to exercise market power or to exclude competitors.

Solutions for other means of transport

To reduce the risk of natural monopolies developing, governments have increased market regulation, including price controls. For instance, airport services have regularly been subject to laws on user charges (Directive 2009/12/EC). Further, specific access rules may apply to critical infrastructure, especially where they are subject to capacity or environmental constraints. Well-known examples of such policies in aviation are the allocation of slots at airports among air operators (Council Regulation (EEC) 95/93) or the guaranteed non-discriminatory access to some parts of ground-handling equipment at airports (Council Directive 96/67/EC).

In several network industries (e.g. telecommunication), lawmakers have explicitly introduced requirements for technical interoperability to ensure third-party access (Directive (EU) 2018/1972). Regulation can also ensure the unbundling of activities related to infrastructure management and operating services. For instance, unbundling of infrastructure and services has been introduced for rail (Directive (EU) 2016/2370), while airlines have traditionally been separated from airports and Air Traffic Management (ATM) services.

Where necessary, natural-monopoly problems may also be addressed through public service obligations (obligations imposed on an organisation by legislation or contract to provide a service of general interest) or universal service regulations (a combination of regulations on price, regularity, quality and user access).

What can policy makers do?

A fully developed drone industry may require a sound economic policy that promotes competition. However, at the current stage, regulatory action on competition may be premature. Overregulation of a newborn industry could be harmful for market growth and technological development. At this stage, policy makers should therefore:

- **Be aware of common competitive issues and of specific regulatory tools** to address them.
- **Recognise that local authorities may positively or negatively affect competition** through their policies in areas such as UAM/AAM, if franchises or restrictions are applied.
- **Carefully monitor the expansion of the drone industry as critical components of drone infrastructure could be susceptible to competition concerns** – in particular, UTM systems and ground-based equipment such as drone charging stations or vertiports. More specifically,
    - With regard to UTM, some forms of competition policy may be helpful to secure the technical interoperability of drone-related facilities or services;
    - With regard UTM systems data, there may be a need to build appropriate mechanisms and institution in order to regulate the data economy; and
    - With regard to ground-based equipment and UTM, there may be a need to develop and define the role of public ownership, as some authorities may be interested in public investments in drone-related infrastructure, especially where the private sector shows no interest in providing these facilities. (See Chapter 5 for more details.)
- **Consider sector-specific oversight where general antitrust laws do not adequately address the risk of monopolies** and abuse of market power.

When taking any regulatory actions with respect to drone activities, policy makers must also be aware that transport of people and goods by air has been regulated for years. Under the Chicago Convention framework (1944), as a matter of economic policy, international air carriage is handled distinctly from trade in the goods and services of other industries. Commercial and recreational drones are “civil aircraft”, which implies that their international operation would be governed by the Chicago Convention and that states may regulate drone services within their borders in the same way they regulate manned aviation.

Economic regulations for aviation are included in bilateral or multilateral air services agreements that result from the architecture of the convention, although some drone services (often categorised as “specialty air services”) are authorised by trade agreements. The international framework is reflected in national aviation laws which also may apply to the drone industry. These regimes need to be carefully considered by states when enabling new drone operations.

Article 6 of the Chicago Convention requires operational authorisations for international scheduled air services. Additionally, under most air services agreements, such authorisations are granted subject to ownership and control restrictions – which limits the ability of foreign investors to participate in the aviation industry. Non-scheduled commercial flights are exempt from the authorisation requirement but may still be subject to any regulations, conditions or limitations that the host State may consider desirable (Article 5 of the Chicago Convention). What is more, any unmanned international operations will still require special authorisation under Article 8 of the Chicago Convention. Finally, Article 7 of the Chicago Convention authorises limitations on “cabotage” (services between two points within the territory of the same State) and many States rely upon that provision to prohibit cabotage (though this is not required by the convention).

These regulations were designed many decades ago for manned aviation and do not take into account potential differences in the structure of the drone industry versus the traditional airline industry. However, the consequence of these restrictions is that the growth of scheduled drone services may be constrained by geopolitical considerations that have in many cases constrained the growth and development of the manned aviation industry. For the time being, there is significant flexibility in the regime and States may choose not to introduce new and unnecessary regulations.

Impacts on employment

Automation, in its various stages – from software enhancements to future deployment of machine learning and artificial intelligence – is likely to have a multi-faceted impact on employment. In the future, the effects may be positive or negative, or likely both, with the balance of economic benefits and employment status yet to be determined and dependent upon the state of cooperation between industry and government. Drones in transport and logistics applications are expected to enhance productivity by ultimately automating many tasks that are currently undertaken by humans (see earlier section on the use of drones in freight transport). In passenger transport applications, drones are also likely to take on tasks that are currently carried out by transport workers. On the other hand, drones will create new tasks that were not previously performed and will require new workers to oversee. In any event, the development, implementation and oversight of automation will require human intervention and employment of humans for the foreseeable future.

Taking a long view, policy makers may wish to consider how drone deployment is likely to result in job losses or changes in the transport sector. This will allow them to take action, where appropriate, to mitigate risks associated with workforce changes. At the same time, understanding which skills are required for a thriving drone industry will allow policy makers to fill potential skill gaps that may hamper the development of the industry and open paths to robust employment in their country.

Impacts of drones

Given the uncertainties around the market potential of drones, their impact on the job market also remains highly uncertain. PwC (2018) estimates that there will be 630 000 jobs in the UK drone economy by 2030; however, information on how this might affect the transport sector specifically is not provided in this assessment (or any other assessment that could be identified by the authors).

In general, the interest in drones for transport applications (as for many other applications) comes to a large degree from expected productivity improvements and cost reductions. These expected impacts of drones can be attributed to expected labour cost savings, route optimisation, and access to new customer bases resulting from the automation of tasks. If drones become a substitute, rather than a complement, for other mobility modes, labour demand in the transport sector, especially with regard to drivers, is likely to decrease. On the other hand, drone operations in the transport sector are likely to require workers. For example, staff will be required to operate drones from a distance (where not fully automated) or for ground-based passenger- or freight-handling activities at vertiports. Where there might be labour shortages, automation could enable continuity of operations and growth to support the existing employment base.

Taking a sceptical view, the amount of new jobs that drones may create in the transport industry may not balance job losses in that same industry, especially where drones will replace existing services rather than provide additional services. This could occur in drone applications in the transport sector where cost reductions are unlikely to increase overall demand for transport to a significant degree.

However, jobs are likely to be reallocated to other industries, rather than eliminated (as is a likely scenario for the impact of automation across the economy in general; see IPPR, 2017). In the case of drones, such jobs may, for example, be reallocated to drone manufacturing; to drone operating firms; to firms specialising in maintenance, repair and overhaul of drones or their infrastructure; or to insurance companies. Drones are also likely to open up possibilities for entirely new business activities where new job opportunities will arise (Straubinger et al., 2020). Existing firms may be able to expand their operations due to increased productivity, requiring more workers, or launch new products and services to complement existing offerings. Finally, drone delivery applications could also indirectly drive employment in the production and distribution of goods by expanding consumer markets. This may be a result of increased competition in local markets thanks to improved connectivity and accessibility of such markets. Drones providing high-speed passenger transport services could potentially expand access to employment opportunities, giving companies access to more potential employees, and residents access to more suitable employers – thus creating benefits for both sides.

What can policy makers do?

The effects on employment due to the increased usage of drones in the transport sector are not yet known. To avoid a potential resulting rise of unemployment of traditional transport workers, policy makers should:

- **Create understanding about the skills needed for a thriving drone industry that employs humans** – whether the respective skills refer to providing transport services itself (e.g. drone operators or traffic controllers), to manufacturing or maintaining the vehicles (e.g. technicians), or to any other industry or business activity that enables drone services (e.g. insurance providers);
- **Develop programmes to equip the workforce with skills and capabilities needed for the drone industry**, e.g. via establishing new, or revising or re-focusing existing, educational programmes, ranging from vocational training to post-graduate degree courses; and

- **Incentivise the up-skilling or re-skilling of displaced workers** from the traditional transport industry to mitigate the risk of unemployment in that industry. This may, for example, include the provision of educational loans or financial support for educational leave, either for employees or employers, or both, etc.

Taking these actions will also enhance the attractiveness of the local market for the development of the drone industry as the demand for required skills may be better met than in other markets. This, in turn, can boost overall employment opportunities in the drone industry in the respective market.

The proposed actions are in line with general best practice in the broader context of how to manage potential shifts and changes in the employment market due to the uptake of new technologies – whether in the transport sector or elsewhere.

Impacts on property/land value

Drones and droneports are expected to have a range of positive and negative impacts on land use and property values. Jurisdictions will have to plan carefully to integrate drones and drone infrastructure into existing land use plans. Where drones are perceived to be an annoyance (e.g. due to noise, visual disturbance or privacy concerns), property values close to droneports or close to drone activity may decrease; conversely, where drones are perceived to provide benefits (e.g. enhanced access to goods or services, or enhanced access and connectivity to opportunities), property values are likely to increase. Policy makers should take the impacts of drones on property values into account when deciding on the build of drone infrastructure and/or possible drone routings. This will help anticipate and mitigate potential opposition to drone developments – be it because of property or land value losses, or because of the potential secondary effects of value gains, such as gentrification effects.

Impacts of drones

Traditional transport infrastructure has been shown to have varying effects on property and land values. For example, the literature on airport noise and housing prices (e.g. Cohen and Coughlin, 2008) shows that in areas close to airports, land is up to 20% cheaper than in comparable locations that do not suffer any noise disturbance. In contrast, literature on train stations shows that proximity to a train station increases housing prices, even though proximity to railways has a negative impact due to noise (Debrezion, Pels, and Rietveld, 2011). This suggests that proximity to infrastructure increases land rents if the infrastructure benefits residents on a regular basis and/or does not have a negative impact (e.g. noise from a railway or subway). On the other hand, if an individual uses the infrastructure infrequently but suffers from noise or visual pollution, transport infrastructure can have a negative impact on land rents.

To understand whether drone activity and droneports are likely to have a positive or negative impact on land value, it is essential to assess:

- the potential accessibility gains that they might offer the neighbouring communities – this can be done by (a) identifying target markets for drone services and (b) considering expected pricing schemes, service quality and drone-network design aspects; and
- the extent to which residents (a) might object to noise or visual disturbance or (b) have privacy concerns due to flights in proximity to (or directly above) their premises.

This will allow policy makers to better judge the trade-off between the positive and negative effects of drone activity on land and property values.

However, increased accessibility thanks to drone deployment may also result in indirect land and property value losses. This may be the case where improved accessibility levels result in businesses or residents choosing to move away from denser areas rather than remaining close to infrastructure and services (Rothfeld et al., 2019). Similarly, an increased access to goods thanks to drone deliveries may reduce the desire of many to live close to dense areas. (See Chapter 3 for a discussion of the impacts of drones on accessibility and the associated risk of urban sprawl).

It is also important to consider that land value gains, not only losses, can lead to a backlash against drone deployment. This may be the case where land value gains result in gentrification effects (i.e. a displacement of the less affluent) that have been documented as results of transport infrastructure developments (e.g. Lagadic, 2019).

Solutions for other means of transport

Policy makers usually strive to anticipate the effect that the building or upgrade of traditional transport infrastructure or services may have on property and land values. In the case of traditional transport infrastructure, impacts on land or property value can typically be assessed thanks to empirical studies of the impacts of similar infrastructure or service developments in the past. Such assessments then allow policy makers to define whether the neighbouring community should be compensated (in the case of value loss), or whether there are grounds for so-called “value capture” policies that can bring new funds to the public purse (in case of value gains).

In the case of value loss, some laws allow or require affected property or land owners to obtain financial compensation. The exact level of compensation will usually have to be determined based on a case-specific assessment of the adverse impacts that the new infrastructure or service has on the specific household claiming compensation (Highways England, 2015).

In the case of value gains, policy makers have a range of value capture options to choose from (OECD, 2020). For example, property tax rates, tax rates for businesses, or purchase tax rates for property/land in the vicinity of the new developments may be increased (where these are not already dependent on the value of the property/land – for example, where they are defined as a flat fee). Policy makers may also allow direct development above or around new infrastructure (e.g. public transport stations) and sell development rights to capture the value gains of land owned by public authorities prior to the infrastructure development (or its announcement) (TfL, 2017). Monetary streams resulting from value capture policies could, for example, finance the new infrastructure or the services being developed, or compensate for environmental (or other) adverse effects that the new developments may bring.

What can policy makers do?

To avoid a potential backlash against drone deployment due to changes in property values in/around drone infrastructure or drone activity, policy makers should:

- **Consult with affected property owners and residents** to identify concerns and understand future development options being considered in which drones will be deployed in their communities.
- **Develop a strong understanding of the potential impact of drone infrastructure (vertiports) and drone activity on land and property values in surrounding areas** before embarking on the building of, or approving, respective developments. Such understanding may be gained via:
    - thorough empirical assessments of the impacts of past transport infrastructure and service developments on land/property value in similar settings, and/or

    - specific impact assessments that analyse (a) the likely benefits (e.g. increases in accessibility to opportunities and access to goods) and detrimental effects (e.g. noise and visual disturbances) of drone infrastructure and services and (b) the resulting location choices of residents.

- **Where relevant, consider value capture strategies,** e.g. to fund new infrastructure (or to compensate for externalities of new services). However, applicable policies must also be assessed in light of potential gentrification effects (e.g. the displacement of the less affluent) that often come with transport infrastructure and/or service improvements. This could, in turn, drive public backlash against drone deployment despite value gains.

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CHAPTER 3
Societal impacts and acceptance of drones

Throughout history, there are numerous examples of new transport technologies delivering significant societal change. The most obvious example is the motor vehicle. It changed the way people move, how far they travel, where they choose to live and how they spend their time.

The societal impacts of drones are difficult to predict, but they could be equally profound. This chapter discusses some of the potential societal impacts of drones, notably impacts on the equity of the transport system, on privacy, on connectivity to remote regions and on accessibility in urban or sub-urban environments. It also provides recommendations for policy action for each of them.

Impacts on the equity of the transport system

The right to travel is a human rights concept that is enshrined in Article 13 of the Universal Declaration of Human Rights as the freedom of movement (UN, 2015; first published in 1948). Functioning transport infrastructure and services are the cornerstone to enabling such free movement of people. It is hence the policy makers' responsibility to provide functioning infrastructure and services and related benefits to all. This will provide people with access to opportunities that fulfil their basic needs and aspirations – regardless of their age, income and potential special needs (VTPI, 2020). In the same vein, costs and externalities of transport infrastructure and services – such as environmental impacts, congestion or barrier effects (e.g. delays for non-motorised travellers due to roads or railroads) – should not affect a specific population group any more than others. Where this can be achieved, an equitable transport system will bring benefits to people in terms of social stability, well-being and economic growth.

New transport services, such as those offered by drones, should follow this equity principle – especially at a time when creating inclusive mobility systems has become an increasingly important objective for policy makers around the world (Corwin, 2019; EC, 2019). Policies related to drones could thus seek to ensure that the services offered are fair and inclusive, and contribute to the development of a fairer and more inclusive transport system overall. If this principle is followed, public acceptance of drone services will increase, which, in turn, will support their mass deployment and make it economically easier to provide services for all.

Impacts of drones

A key challenge with drones for use in passenger services is that (at least) initial services may be priced at levels that are appealing only to passengers with high incomes instead of to the general public. Drone services would then be similar to those of helicopter services that developed in heavily congested metropolitan areas such as in Sao Paulo, Mexico City and San Francisco (Airbus, 2020). The benefits of such services are largely confined to wealthy citizens who can afford them, while their impacts (such as visual disturbance and noise – see Chapter 4) affect the general public that lives in the respective areas. Such a use case scenario for drones would be clearly in contradiction with the equity principle for the provision of functioning transport services.

Studies have estimated that costs for drone services could substantially reduce over time and provide an affordable means of transport for many people (see Chapter 2). This may allow passenger drone services to become an equitable transport alternative, and to contribute to a more equitable transport system overall. Drone services may also allow new participants into the aviation sector (WEF, 2020). This can increase competition and may reduce costs for air-born transport services or transport services further.

The potential cost reductions for drone services will rely mainly on operators achieving economies of scale. These economies of scale will, in turn, depend on the specific business model of the drone operator and on the regulatory landscape that will define operator costs – such as potential limitations to landing/take-off infrastructure, constraints on access to airspace, regulatory requirements that cause costs for businesses (UAVAIR, 2020), or potential public subsidies for the provision of drone services. The level of public acceptance and resulting use of the drone service will play a decisive role as well; this will depend on the societal concerns discussed in this chapter, as well as on environmental, safety, security, and other concerns the public may have and how/when they may be overcome.

Freight drones will also affect the public. Benefits may, for example, stem from a potentially increased accessibility of goods (i.e. increased levels of e-commerce, perhaps in areas that were not previously served by other modes) or reduced delivery costs and hence prices for consumers. On the other hand, the externalities of freight drones (e.g. noise emissions, visual disturbance or privacy concerns) will also affect the public. Depending on their service area and routing, freight drones may therefore benefit certain areas or groups of population more than others.

Solutions for other means of transport

Whenever new transport infrastructure or services are established, or the set-up or service level of existing ones is revised, transport agencies and respective policy makers should, at least in theory, carry out an equity impact assessment. Whether and to what degree such assessments happen in practice will vary widely across different jurisdictions, and depend on the specific infrastructure/service that is being put in place or the extent of the alterations that are envisaged (Fan, Guthrie and Van Dort, 2019).

A factor impeding equity assessments of transport infrastructure and services is that they are inherently difficult to carry out and require vast amounts of data – at least where all dimensions of equity are to be accounted for (e.g. all types of positive and negative impacts, across all categories of people). Impacts are, furthermore, often difficult to quantify and hard to compare to each other, and measurement units are frequently difficult to establish. Often there is also a trade-off between equity objectives and other objectives. For example, improving traffic safety for all transport users may reduce efficiency (e.g. in terms of transport speeds) and therefore economic productivity (VTPI, 2020). In such cases, it may not be obvious how to value equity impacts against other outcomes. In the case of drones, equity impacts could also be overlooked as jurisdictions seek to capitalise on the economic benefits associated with being an "early mover".

Where obvious equity issues of transport services arise, policy makers may choose to intervene. For example, financial measures may balance apparent equity concerns. These may, for instance, take the form of providing subsidies or discounts for transport user charges/fares (e.g. for the use of public transport for certain user groups) or imposing tolls, fees or taxes (e.g. for the means of transport that result in relatively more externalities than other transport alternatives). Such instruments have to be used very carefully to ensure that they do not have adverse equity effects (e.g. taxes or fees that make transport overall more expensive may result in a higher detriment to lower-income groups) (Lawrence and Kornfield, 1998; Guzman and Oviedo, 2018; Zhao and Zhang, 2019).

What can policy makers do?

The idea and definition of equity are both strongly shaped by a given environment. Different societies with different cultural values may judge differently what is appropriate, reasonable or customary in a given situation (Young, 1995). Policy measures targeting equity concerns will therefore be highly influenced by the respective societal context. The following proposed policy actions to address potential equity concerns may therefore be more or less relevant in different jurisdictions:

- **Assess the potential equity impacts** of new drone services that are proposed and see if the business model in place allows (at least in the mid-to-long term) an equitable means of transport. These equity assessments should be as comprehensive as possible in terms of the positive and negative impacts that are being assessed, and the groups of impacted population that are considered. The UTM system could serve here as a crucial tool for providing relevant data for such assessments (e.g. on noise levels, human mobility, traffic density) – not least where such assessments are carried out following the introduction of new services. It could also provide relevant ground traffic data to aid in determining the areas in which drones bring greatest public benefits in terms of mobility improvements.
- Where relevant, **consider policy measures, such as financial measures, that have the potential to counter inequitable service provisions**. For example, governments could consider levying taxes to account for externalities of the services, or providing (or asking service operators to provide) subsidies or discounts for certain user groups. The type of incentives and their potential impacts must be assessed thoroughly upfront to avoid any unintended equity impacts. Again, the UTM system could play an important role, e.g. by facilitating the charging of drone operators.
- **Enhance the public acceptance of drone services by:**
  - **Addressing public concerns** raised in this chapter, especially with regard to privacy, and in other chapters of this report. This will help accelerate the mass use of drone services while driving the emergence of business models that achieve economies of scale. This may allow the provision of equitable services for "all" in the mid- to long-term, despite potential user charges to compensate for the externalities of drone services.
  - **Engaging the public through "co-creation" processes** that allow both users and non-users to actively participate in service and infrastructure design. This will endorse equitable services, bringing benefits to all potential user groups.
  - **Launching public information/communication campaigns** that focus on the benefits of drones and promote positive use cases. They should also address risks of drone use and specifically how public concerns are being addressed. Campaigns could also inform the public about:
    - existing drone research and continuous research efforts to close research gaps;
    - how drone use is regulated (i.e. what drone operators are / are not allowed to do) and how existing regulation may change in the future; and
    - how the public can report illegal drone activity and what actions are taken to enforce the rules.

    Such campaigns will provide the public with transparency about how drones are being used and how policy issues are being addressed, and foster a sense of trust among the public.

- **Raise awareness among drone operators regarding the public's concerns** and how the operators could address them – for example, by outlining their necessary qualifications and certifications as part of their company's information, or by informing neighbours or people in the area that a drone may be flown.

Impacts on privacy

The public's biggest concerns with regard to drones are related to how drones may be mis-used for privacy breaches or surveillance (DfT, 2016). The successful uptake and scale-up of drones services will therefore heavily rely on whether such concerns are adequately dealt with and whether public trust towards the use of drones can be established (PwC, 2019).

Impacts of drones

Many of today's technologies allow the surveillance and monitoring of people. For example, CCTV in many urban areas can track people's movements, and satellite systems have the potential to monitor people around the globe (Antunes, 2018). The specific privacy concern regarding drones comes from the fact that drones occupy a space not currently occupied by anything else human-made. Often they also fly at low altitudes and have access to airspace not used by larger aircraft. As such, drones are often perceived as "intruders" that have the potential to collect large amounts of data, especially when equipped with cameras (McNeal, 2014).

Even drones whose primary purpose is not to take photographs or record videos may use cameras to facilitate navigation. In doing so, they can capture data that must be protected. Professional drones may also be equipped with a range of other sensors and data collection devices. This contributes to the public's feeling of being "watched" when a drone is present. Finally, drones are often perceived as "faceless": when a drone flies over the park you are sitting in, you may not be able to locate the pilot, and as such, may not be able to understand their intentions.

Existing research (Rice, 2019; Bajde et al., 2017; Chang, Chundury and Chetty 2017) finds that privacy concerns regarding drones are contextual and depend on

- the specific **drone use case** (e.g. concerns are higher when the drone is used by law enforcement than when the drone is used by hobbyists – and are especially high when the purpose of a drone use is unknown);
- the **frequency** of the drone use (e.g. concerns are lower when a drone is known to be used for a specific mission, rather than on a continuous basis);
- the **location** of where the drone is used (e.g. concerns are less in public places (parks, streets) and respectively higher in relation to private spaces, especially where drones offer a direct view into dwellings);
- the **speed** at which the drone flies – in general, the faster the movement, the lower the privacy concern (e.g. concerns are higher if a drone is hovering over one's dwelling/garden for a longer period of time, which may enable the drone to film and take pictures, compared to a drone that merely flies by);
- many **characteristics of the drone** itself, such as its colour, size, and sound; and

- the **characteristics of the person or community affected** (e.g. women are typically more concerned than men).

Concerns about data collection and misuse by drones are amplified by the fact that drones may easily gather information about people who have not engaged in any drone service and who cannot be easily made aware of potential drone recordings.

Solutions for other means of transport

Privacy concerns in more traditional means of transport have mainly emerged with the use of travel "smart cards" in public transport, which facilitate payment and interchanges between different services. Many of such cards allow public transit companies to store users' private information, such as addresses, next to their travel patterns (Dempsey, 2008; Essers, 2012). In general, the smarter the card, the more useful it is, yet the more intrusive it becomes (Dempsey, 2015). In view of further advancements and increasing use of smart cards in (especially urban) transport systems around the world, and increasingly "smart" transport systems, privacy issues around the use of transport services is set to increase. Travellers may also be recorded via CCTV systems installed in (public transport) stations or vehicles.

Regulations can protect travellers' privacy in various ways. They may limit the type of information that can be gathered; they may limit the persons and/or organisations who have access to it. They may also entirely protect information against external dissemination. Information collected can be encrypted, and firewalls built against external access. The information collected can be prohibited from distribution except by court order (Dempsey, 2008).

In Europe, an example of such a regulatory framework is the European Union's General Data Protection Regulation (GDPR) (see Box 4). It provides principles relating to data protection and privacy and aims primarily to give control to individuals over their personal data. In general, personal data can be processed under the GDPR only if the data subject gives their explicit consent (however, exceptions exist). In the case of CCTV systems, a privacy notice must inform data "subjects" that they are being recorded. The notice must include information on contact details, the purpose of recording, the existence of data subjects' rights etc. (Champion, 2018).

Box 4. General Data Protection Regulation principles relating to processing of personal data

Article 5 of the General Data Protection Regulation stipulates the following:

1. Personal data shall be:
   a. processed lawfully, fairly and in a transparent manner in relation to the data subject ("lawfulness, fairness and transparency");
   b. collected for specified, explicit and legitimate purposes and not further processed in a manner that is incompatible with those purposes; further processing for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes shall, in accordance with Article 89(1), not be considered to be incompatible with the initial purposes ("purpose limitation");
   c. adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed ("data minimisation");

d. accurate and, where necessary, kept up to date; every reasonable step must be taken to ensure that personal data that are inaccurate, having regard to the purposes for which they are processed, are erased or rectified without delay ("accuracy");

e. kept in a form which permits identification of data subjects for no longer than is necessary for the purposes for which the personal data are processed; personal data may be stored for longer periods insofar as the personal data will be processed solely for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes in accordance with Article 89(1) subject to implementation of the appropriate technical and organisational measures required by this Regulation in order to safeguard the rights and freedoms of the data subject ("storage limitation");

f. processed in a manner that ensures appropriate security of the personal data, including protection against unauthorised or unlawful processing and against accidental loss, destruction or damage, using appropriate technical or organisational measures ("integrity and confidentiality").

2. The controller shall be responsible for, and be able to demonstrate compliance with, paragraph 1 ("accountability").

Source: EU Parliament (2016).

What can policy makers do?

To enhance trust in drones operations and ease privacy concerns, policy makers should:

- **Adapt/expand existing legal frameworks addressing data protection and privacy** to address drones that collect data.
- **Advise drone operators on how to mitigate privacy concerns** – e.g. by avoiding certain zones like private dwellings or property more generally; or by adapting speeds, frequencies or specific drone characteristics.
- **Consider static and dynamic no-fly zones** above dwellings or private property, e.g. through the provision of UTM geofencing services.
- **Consider a requirement for mandatory registration and remote identification of all drones**, to allow members of the public to assess information about a drone that they might have seen fly by, e.g. through the provision of the registration and e-identification services.
- **Develop communication strategies to foster public acceptance of drone services** in general (see previous section on equity for specific recommended actions).
- **For a specific proposed drone service,**
    - **assess what data a drone is allowed to collect** and what specific data collection equipment the respective drones are therefore permitted to carry;
    - **assess potential privacy concerns and how they may be mitigated**, in collaboration with the drone operator, e.g. by advising on potential re-routing of the service or on adapting frequencies, drone speeds or other characteristics of the drones used; and

- inform members of the public who reside or work in the vicinity of the drone service – or the public more largely – about the drone service and its purpose (or require or encourage the drone operator to inform the public accordingly).

Impacts on connectivity to remote regions

Ensuring sufficient levels of connectivity in remote regions is important to governments for economic, social and strategic reasons. Residents in sparsely populated regions often have insufficient access to goods and essential services such as medicine, health care or education. Also, these regions and their inhabitants frequently suffer from comparatively high unemployment rates, structural weaknesses (e.g. reliance on primary industries), isolation and lower wages. Where commercial transport struggles to deliver, governments often decide to step in.

Achieving the transport service levels required to deliver the needed connectivity is, however, often difficult. High transportation costs and lack of sufficient demand often deter private-sector providers from serving connections to remote areas. Low demand, often subject to seasonality, combined with high upfront costs to provide resilient and reliable transport networks throughout the whole year, make it difficult for operators to achieve returns on their investments (ITF, 2021).

Drones may provide a relatively low-cost, effective means of improving connectivity to remote regions or isolated areas such as island communities.

Impacts of drones

Drone services have increasingly shown they are able to supply access to goods in, and connectivity to, remote areas and islands. As such, they could potentially reduce the need for both extensive transport infrastructure and the investments required to finance it.

For example, in Africa, one-third of the population lives within two kilometres of an all-weather road. Providing similar access to the other two-thirds would cost more than USD 50 billion (SAP, 2019). Drone services could potentially provide the required access and connectivity for these regions at a fraction of such costs if they are used to leapfrog traditional land-based transport operations (OECD, 2019).

A recent study for the New Zealand Ministry of Transport estimated the economic benefits of drones connecting passengers from small communities to larger airports at NZD 1.4 billion over 25 years. These benefits stem from passenger time savings, as well as from resulting changes in trade and airport activity. For island communities or communities with poor land-based transport alternatives, the benefits of such drone services could be substantially higher (m.e consulting, 2019). Increasing connectivity for such remote regions can foster economic growth and might even decrease brain drain in rural regions and decrease urbanisation tendencies.

Many countries now acknowledge the potential benefit of drone-based services over land-based (or traditional aviation services) in this regard, and have begun trial drone services to remote regions and islands. For the time being, these operations are often related to humanitarian aid programmes, where remote communities are provided with essential medical supplies. Such services have seen a rapid increase during the Covid-19 health crisis (see Box 5), during which "contactless" deliveries have become increasingly important – partly because traditional means of transport have been unable to operate.

In the longer run, drones may well be used to transport a growing range of products – and potentially also passengers – to and from such regions in an effort to connect the regions to bigger economic centres, and ideally to secure related social and economic benefits. Although this initiative will have its own infrastructure requirements (e.g. droneports, potential monitoring systems), they will be significantly less than those normally required for traditional transport services.

However, while autonomous drone operators are less reliant on large volumes of passengers to cover operating costs, services to remote areas could still be economically challenging compared to services in dense urban areas. Hence, drone operators could also shy away from providing these services, resulting in a market failure. Adequate public policies have to be put in place to make respective operations economically interesting for drone operators.

Box 5. Examples of drone trials in and to remote regions to deliver medical supplies

In Africa, a consortium comprising logistics company DHL, German drone manufacturer Wingcopter, and the German development agency GIZ recently ran a pilot drone-delivery project called "Deliver Future" to carry medicine and blood samples between a hospital and an island in Tanzania; thanks to the success of the project, the project partners have decided to expand the service area (GIZ, 2018). Meanwhile, drone-maker Zipline has been running drone delivery services in Rwanda to increase the speed of health-related deliveries to hospitals (Zipline, 2020).

Similarly, the Pacific island country of Vanuatu is working with UNICEF and two drone companies to deliver vaccines to rural areas. Vanuatu is composed of 83 islands spread over an area of 1 600 kilometres. To deliver vaccines to rural communities, health workers often have to walk for hours, or drive and take boats for days (Moon, 2018).

In the United States, between the Alaskan communities of Indian and Hope, the main road connection is consistently impacted by avalanches. The Alaska Fairbanks Drone Test Site has begun investigating drone "long-haul" operations that could cover the required 160-kilometre distance between the two communities, potentially delivering much-needed medical supplies between the two communities (Davis, 2019).

More recently, in response to the Covid-19 crisis, the United Kingdom has started using drones to carry medical supplies from Hampshire to the Isle of Wight. The timing of the drone trials was moved up after ferry crossings to the Isle of Wight were reduced due to the spread of coronavirus (BBC, 2020). Similarly, in April 2020, the Irish Aviation Authority approved drone operator Manna Aero's proposal to deliver crucial medical prescriptions to roughly a dozen households under confinement in the rural town of Moneygall (Chandler, 2020).

Zipline made a concerted effort in spring 2020 to assist the Ghanaian government in its fight against Covid-19 where it has prioritised the connectivity of rural residents. In April 2020 alone, the "contactless drone delivery" service collected and transported Covid-19 test samples from 1000 rural health facilities to labs in Accra and Kumasi (Reuters, 2020).

Solutions for other means of transport

Public authorities often decide to use public funds to improve connectivity to/from remote regions or islands to stimulate economic and social development in the concerned areas.

Public funds may be used to build and maintain relevant transport infrastructure such as roads, railways, ports or airports. To ensure connectivity provision by private entities, public support may also take the form of either public service provision or subsidies, such as budgetary and tax expenditures, or transfer of risk from the private sector to the government (ITF, 2020).

Governments have adopted different approaches to determine the level of public support for enhancing the connectivity of remote and sparsely populated regions. Decision-making relies on a variety of factors, ranging from value-for-money considerations to requirements to meet specific equity goals or minimum access thresholds. For example, Greece assesses the needs and potentials of concerned islands in a connectivity index that provides guidance on what funding should go into which ferry connections (Lekakou, 2019); Chile follows a similar approach (Céspedes, 2019). Scotland assesses a long list of potential transport infrastructure projects against environmental, safety, economic, accessibility, affordability and acceptability criteria (among others). The business case of the project has to be clear in terms of its alignment with public policy objectives, value for money, commercial viability, financial affordability and achievability (Laird, 2019).

ITF (2020) provides an extensive review of public policies put in place to support the connectivity of remote regions, and outlines related challenges.

What can policy makers do?

Policy makers who consider spending public funds on improving the transport connectivity to remote regions islands (e.g. because private operators cannot find a viable business model and service levels are therefore insufficient) should:

- **Consider drone services as a possible alternative for providing improved connectivity** when assessing different options; and
- **Avoid altering assessment criteria and appraisal processes already in place** to the benefit (or detriment) of drone services. This will ensure that funding is allocated for the most adequate and cost-efficient solution at the required level.

Policy makers may also consider **a system where drone operators are encouraged and incentivised to carry out a mix of transport services in light of the services' expected profitability**. For example, an existing drone operator that operates a profitable service could be encouraged to operate additional services that are in the public interest. Such mechanisms may also be relevant for areas other than remote regions or islands, such as within the same urban area.

Impacts on accessibility in urban and sub-urban areas

Adequate access to opportunities (e.g. employment, education, health care, goods, services, family and friends) is a fundamental condition for well-being. However, transport policy is often still more focused on generating physical movement than in guaranteeing access to opportunities. This has often resulted in induced demand (i.e. the phenomenon wherein increasing transport capacity leads to an increase in traffic volumes) and related increases in the externalities of transport (e.g. congestion, pollution and greenhouse gas emissions). The level of accessibility in, for example, a metropolitan area is a combination of the performance of the transport network (i.e. the time required to reach a destination or place of opportunity) and the "performance" of land use (i.e. the proximity of people to destinations) (ITF, 2019a; ITF, 2019b).

Drones may have the potential to improve accessibility to opportunities in urban or sub-urban areas by increasing the performance of the transport network. However, they may also have an adverse effect on land use.

Impacts of drones

As with new (public) transport infrastructure and services, drones could open up new possibilities for land use and land development in and around urban areas. These new developments could help relax pressure on house prices, which have been rapidly increasing in many cities around the world (UBS, 2019), and hence bring a significant societal benefit. This may even happen while maintaining or even improving current accessibility levels in and around urban areas, thanks to likely significant travel-speed increases when using a drone compared to land-based transport alternatives (Rothfeld et al., 2019).

At the same time, however, the new land developments that could be driven by this new, high-speed transport mode, combined with the prospect of lower housing prices, could mean an increased risk of urban sprawl. Urban sprawl often comes with severe adverse environmental, economic and social impacts. Because changes usually occur in a gradual manner, they are often not perceived as significant by the general public for some time (EEA, 2016). For example, urban sprawl frequently leads to a loss of farmland and/or habitats for native species, reduced groundwater regeneration, higher energy consumption and GHG and pollutant emissions per capita, and higher light and noise emissions – to name only a few of the adverse environmental impacts. Higher public service costs and higher expenditure per capita for construction and maintenance of infrastructure, and greater segregation of residential development based on income, are examples of economic and social impacts respectively (EPA, 2016).

Drones in urban or sub-urban areas could also alleviate congestion. For example, there are claims that in the Australian Capital Territory (ACT), drone delivery services could reduce traffic congestion by up to 35 million vehicle kilometres each year by 2030 (AlphaBeta, 2018). Alleviating congestion would come with significant benefits for the economy, the environment and, again, society. People would benefit from the improved performance of the transport system overall, and hence increased accessibility levels.

However, it is not clear that any independent research exists to support such claims. It is also possible that virtually-instantaneous delivery by drones may simply change consumers' buying habits and have little effect on overall congestion. With regard to passenger transport, simulation results and mode-choice studies suggest that the mode share of drones is unlikely to be high enough to have significant impact on road congestion (Balac, Vetrella and Axhausen, 2018; Fu, Rothfeld and Antoniou, 2019). Besides that, as mentioned earlier, literature on transport upgrades or investments typically shows that decreasing the flow capacity ratio on roads leads to induced demand rather than decreasing congestion (e.g. Cervero and Hansen, 2002). People may also tend to move further away from city centres thanks to travel time gains. This, in turn, would again risk urban sprawl, as discussed above. Drones may even put additional pressure on urban space and hence traffic, as (public) space for the build of physical drone infrastructure (i.e. droneports) will be required (see Chapter 5).

Solutions for other means of transport

Reaping accessibility benefits from the upgrade or set-up/introduction of new transport infrastructure services has been a significant challenge for policy makers. The effects of urban sprawl that often result from new transport services can easily counteract any efforts made, and cause many adverse impacts in the long term.

Several options to mitigate the risk of urban sprawl have been identified, largely related to land-use and urban planning policies. EPA (2016) provides an overview of possible options for controlling urban sprawl and provides best practice examples. For example, policy makers can try limiting the total extent of designated building zones; restricting settlements by setting settlement boundary lines; or setting targets, limits and benchmarks for sprawl. Measures outside the sphere of traditional land-use planning policies may also help, such as abolishing tax deductions for commuting between homes and workplaces or introducing road tolls; this would encourage people to live closer to their work places due to increased transport costs. Such measures need to be carefully designed, though, to avoid adverse equity impacts.

Transport authorities and planners should give preference to mixed-use developments. Most importantly, they should also integrate transport and land-use planning methods to foresee potential urban sprawl due to changes in the transport system.

What can policy makers do?

Policy makers need to ensure the deployment of drones results in accessibility benefits, while working to avoid potential adverse effects that new transport infrastructure or services have frequently caused, especially urban sprawl. With this in mind, they should:

- **Follow best policy practices with regard to controlling urban sprawl**, as established for traditional transport modes and well reported in the existing literature, and adapt them to the specifics of drones, if/where required; and
- **Focus on accessibility indicators** (instead of sole transport system-based performance indicators, such as speed or traffic capacity) when assessing the impact of a new drone service. These will be a better measure for assessing the impact of drones on the well-being of the inhabitants in a given urban area or region.

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CHAPTER 4
Environmental impacts of drones

Existing studies suggest that drones may have the potential to reduce energy use in transport and hence CO_2 and other transport-related emissions (Linchant et al., 2015). On the other hand, there are clear environmental challenges relating to the deployment of drones. These relate to noise and vibration impacts, as well as light pollution that will affect humans and wildlife (ITF, 2018). Policy makers need to ensure that the deployment of drones comes with environmental benefits for the transport system, and that adverse impacts are limited as far as possible.

This chapter tackles the following impacts of drones in turn, and discusses how policy makers may limit potential adverse effects while reaping the potential benefits of each:

- Noise impacts
- CO_2 impacts (across the whole life-cycle of drones)
- Air pollution impacts
- Wildlife impacts
- Other environmental impacts including
  - Visual disturbance
  - Soil sealing

Noise impacts

The World Health Organization (WHO) has identified noise from transport as the second-most significant environmental cause of ill health in Western Europe, after air pollution (WHO, 2010). Noise exposure can lead to annoyance, stress, sleep disturbance, poor mental health and well-being, impaired cognitive function in children, and negative effects on the cardiovascular and metabolic system (Fons-Esteve, 2018). If not managed adequately, drones will contribute to the problem of noise pollution in urban areas and elsewhere.

Impacts of drones

Drone noise characteristics depend on a variety of factors, including a drone's design and size (both of which define the engine power required) and its propeller configurations and spinning speed (Intaratep et al., 2016). Most currently available drones have moderate to quiet noise levels in the range of around 20-70 decibels (Intaratep et al., 2016). In comparison, the noise level of a typical busy road is around 80 decibels. The noise *frequency* of drones, and especially of smaller drones, is typically higher than that of road traffic, meaning the noise is higher-pitched; the noise characteristics of larger drones are still uncertain and remain largely unexplored (Uber Elevate, 2016). Noise is considered *vibration* if it is mainly transmitted through ground and buildings at frequencies below 200 Hz (Leventhall, Pelmear and Benton, 2003). The frequency spectrum of typical drones shows peaks at multiples of the blade passing frequency above 200 Hz (Cabell, Grosveld, and McSwain, 2016). Therefore, drones, and especially small drones, are not expected to contribute to vibrational emissions.

However, the perception of noise is often very different to actual noise levels. For example, perceived noise levels vary with the sound source, the characteristics of the person exposed to the noise and the noise environment. As such, parameters like the type of noise (consistent vs. fluctuating), frequency of noise (high vs. low), sources of noise (nature vs. human activities), time of noise (day vs. night; weekday vs. weekend), surroundings of the noise source (residential area vs. industrial zone) or the information content of noise (e.g. children crying vs. cars honking) will influence the perception of noise. The characteristics of the person exposed to the noise (e.g. familiarity with, and attitude towards, the sound source; general or current mood) will also influence how a noise is perceived (BEPA, 2019). Noise propagation is further highly dependent on factors such as weather, wind, temperature and the built environment near the sound source (Hannah, 2006a; Hannah 2006b).

As a result, perceived noise levels of drones diverge from their actual noise levels. Recent studies on the societal acceptance of drones (e.g. Eißfeldt and Vogelpohl, 2019) show that drone noise is one of the main concerns of the public regarding drone applications besides violation of privacy, misuse and transport safety. A study by NASA Langley found that people perceive small drone noise as more annoying than the noise of cars in residential neighbourhoods (Christian and Cabell, 2017). This may be due to the noise characteristics of drones (such as their high pitch), but also due to peoples' lack of familiarity with, and acceptance levels of, some drone applications. Potential differences between (the perception of) the noise of a single drone and the cumulative impact of multiple small drones remain largely unexplored so far.

Ambient noise levels can make the noise of drones less noticeable. For example, in cities, ambient noise levels of conventional vehicles may make drone noise less apparent. However, drone noise may be a specific challenge in such areas given the proximity of dense residential areas. Further, the increasing (or envisaged) uptake of electric, automated and shared vehicles as well as of active travel in cities is expected to make conventional traffic more efficient and hence silent. Many cities are also developing sustainable urban management plans with the specific objective of reducing noise levels to improve health and quality of life. The urban land- and soundscape in the city of the future may therefore be very different to today's. It is likely that such developments will put increasing challenges on noise levels of drones where deployed in urban environments.

Overall, it is likely that drone noise levels will give rise to opposition to drone operations – even where operations replace and are not louder than, for example, conventional package delivery operations (Christian and Cabell, 2017). This is because drone noise levels may be perceived as louder and/or more annoying than they actually are. Similarly, passenger drones will need to be significantly quieter than, for example, current helicopters to gain acceptance in urban environments (Uber Elevate, 2016; Porsche Consulting, 2018; Roland Berger, 2018) – not least because the latter are often banned from operating in urban environments due to their noise levels.

Solutions for other means of transport

Noise from transport is a recognised issue and has been tackled in different ways. For example, noise from ground transport is often mitigated by noise barriers (e.g. on motorways or railway lines), speed limitations, noise emission standards or vehicle use bans (e.g. during the night). The latter measures are particularly relevant for dense urban areas, where physical noise barriers are usually not practical. Noise from aircraft is one of the main issues that the sector is facing. It is particularly challenging around airports and is tackled by measures such as noise standards for aircraft (e.g. standards that encourage manufacturers to deploy low-noise engines, operating restrictions, improved ground operations, and noise protection walls and land-use management around airports (e.g. Regulation (EU) No 598/2014).

In the EU, the Environmental Noise Directive (END) is the main instrument used to monitor and tackle land-based noise emissions from road, rail and air traffic, and from sites of industrial activity. EU member states are obliged to assess noise levels and provide action plans for areas where noise thresholds are surpassed. With regard to aviation specifically, EU Member States are also required (by Directive 2002/30) to limit noise emissions by:

- reducing aircraft noise levels (e.g. via low-noise engines) and limiting sound propagation (e.g. via noise protection walls around airports),
- planning and managing land use to prevent airport locations near densely populated areas, and
- providing noise-reducing flight routings for approaches and departures to airports (e.g. bypassing villages or approaching with a steeper descent).

Further, Member States are also required to assess noise levels, determine noise level maps and provide actions plans for areas with high noise levels. These requirements are closely monitored and, where required, further regulation, such as restrictions on night operations, is put in place.

What can policy makers do?

In general, policy makers should assess the potential of existing noise reduction measures that have been implemented to alleviate noise emissions from conventional means of transport. Many of them have proven to be effective and are likely directly applicable to drones as well. More specifically, policy makers should envisage the following measures to mitigate noise impacts of drones:

- **Support further research on actual and perceived drone noise emissions and their propagation,** related annoyance levels, and drone-noise reduction measures. This may, for example, include research on technical solutions that reduce noise levels and/or change characteristics of drones' noise emissions (such as their frequency). Such research will support both the establishment of strategic noise maps and the defining of adequate noise mitigation measures for policy makers (Eißfeldt and Vogelpohl, 2019; Bakx and Nyce, 2016).
- **Put in place adequate drone-noise monitoring and reporting procedures** to enable regulators to define appropriate means to reduce noise to an acceptable level. This should include:
    - Defining a process that measures actual drone noise levels,
    - Defining acceptable drone noise levels, while accounting for differences in local surroundings and resulting differences in perceived drone noise levels (accounting for the national and local stakeholder groups),
    - Establishing strategic noise maps (similar to noise level maps required from airports, and specifically for urban areas) to identify the number of people exposed to noise emissions from transport or industrial activities, and
    - Implementing an ambient-drone-noise measurement and reporting system to be able to influence and monitor emerging noise peaks.

- **Stimulate low-noise flight procedures and drones by**
    - publishing respective information for drone operators and manufacturers, and/or
    - implementing noise emission standards
    - implementing drone restrictions or registration fees that are dependent on a drone's noise emissions.
- If any jurisdictions decide to regulate flight based on the results of this defined process, they should ensure that the decision-making process accords with national laws and balances economic risks and benefits. With this principle in mind, they could **define drone operating restrictions**, where required, based on the results of strategic noise maps**.** Such restrictions could take the form of time and/or space restrictions. They may also depend on drone noise levels and/or differentiate between drone landing/take-off operations and drones in flight mode. For example, no-drone zones (where drones are entirely prohibited) or drone corridors (where drones are allowed to operate) could be defined.
- **Support a staged approach to drone integration**, in which regular drone flights are first planned on routes with low annoyance levels. Based on experience and acculturation with this new technology in the course of time, drone volumes and routes could be gradually expanded to meet market demands (see Chapter 3 for further recommendations on how to carry out the integration of drones in stages). Any staged approach will have to consider the political and cultural context of area where the drones are to be deployed.

CO_2 impacts

Decarbonising transport remains a major challenge for mitigating climate change in the decades ahead. Fuel combustion from transport is responsible for around one-quarter of greenhouse gas (GHG) emissions globally; the sector remains dependent on oil for 92% of its energy demand. The ITF's "current ambition" scenario projects that the sector's CO_2 emissions, the main GHG in transport, will grow by 60% between 2015 and 2050. This is despite all present and currently foreseeable future mitigation efforts (ITF, 2019). Drones, a new means of transport that has the potential to reduce the use of more conventional vehicles, may be able to reduce CO_2 emissions from transport. This will, however, depend on many factors.

Impacts of drones

Most currently available drones run on electricity. As such, they do not emit any tailpipe emissions. A meaningful comparison of the CO_2 impact of drones with that of other means of transport should therefore rely on a so-called "well-to-wheel" analysis (or "generator-to-propeller" analysis in the case of drones) – regardless of their energy supply or the service they provide. This type of analysis accounts for both the emissions caused during the vehicle-use phase and those caused by the production, transportation and distribution of the electricity or transport fuels.

A full life-cycle assessment (LCA) for a drone, from "cradle" to "grave", is also required to account for the emissions impacts of the vehicle itself. An LCA accounts for CO_2 emissions that stem from the extraction of resources required for manufacturing the vehicle; for CO_2 emissions from producing, recycling (or disposing of) and transporting the vehicle (and its battery, where applicable); and for CO_2 emissions caused by vehicle maintenance and service activities. Also, the emissions resulting from the construction and use of enabling drone infrastructure, or from the potential need to replace a battery during the life cycle of a drone, need to be accounted for (Stolaroff et al., 2018; Asaithambi, Treiber and Kanagaraj, 2019; Dai et al., 2019). The energy efficiency of a drone is the main determinant of a drone's CO_2 emissions during its use phase. Measured either in gCO_2 per vehicle-kilometre (vkm) or gCO_2 per tonne-kilometre (tkm), this is typically the most relevant factor for determining the total life-cycle emissions of a drone (Bachmann, Hidalgo, and Bricout, 2017).

When comparing the life-cycle CO_2 emissions of drones with other means of transport, it is also important to consider that the distances travelled (e.g. in vkm or tkm) will vary across the different means of transport. For example, a drone will often use more direct routes than a delivery truck, and thus use fewer vkm or tkm to reach its destination. At the same time, a delivery drone, which is often limited by range and payload, may require more return trips to a base for recharging and/or reloading than a delivery van. Further, the energy consumption of a drone is, for example, higher for take-off or landing operations than for cruising operations. As such, the energy consumption of a drone's trip will greatly depend on the number of landing operations it has to carry out in the course of a return trip to its base. Comparisons between different means of transport need to account for such differences. This may be done by defining a meaningful unit of comparison, such as CO_2 emissions per delivered package (Goodchild and Toy, 2018; Figliozzi, 2017; Stolaroff et al., 2018; Kasliwal et al., 2019).

Figliozzi (2017) compare the well-to-wheel (or "generation-to-propeller") energy use and CO_2 emissions of delivery drones with those of diesel vans, electric vans and electric tricycles for different delivery scenarios. Results indicate that, on a per-distance basis, drones are more CO_2-efficient for small payloads than conventional diesel vans. More specifically, in the scenario of one-to-one deliveries (i.e. a single delivery is made with one return trip), a drone is around 47 times more energy-efficient and 1000 times more CO_2-efficient than a diesel van (assuming that the drone emits around 23 times less emissions per energy unit used). Drastically different results are obtained when customers can be grouped in a delivery route (i.e. in a one-to-many route setting). Here the higher payload of vans (assumed to be 380 times more than drones) allows for more efficient deliveries. Although a drone is eight times less energy-efficient than a typical U.S. van, it is still almost 2.8 times more efficient in relation to CO_2 emissions. Electric trucks and vans are much more efficient than a conventional van; as a result, a drone is not more efficient than electric ground-based vehicles in delivery scenarios with more customers per route.

Figliozzi (2017) also assesses the life-cycle emissions of drones, accounting for emissions from materials extraction and processing, manufacturing, distribution, and vehicle disposal or recycling. Results show that such emissions are significant for drones and must be taken into account. Drones have more processors, sensors, electronics, and other aircraft materials that are more energy intensive to produce and recycle than the materials needed for ground-based vehicles. Considering such life-cycle emissions, an electric tricycle is likely to be more CO_2 efficient than a drone. Hence, in dense urban areas, where tricycle deliveries are economically feasible, tricycles are likely to outperform drones in terms of both energy consumption and life-cycle CO_2 emissions. Overall, drones appear to cause less CO_2 emissions than ground-based vehicles only in sparsely populated areas with a low number of customers where payloads are relatively small.

Stolaroff et al. (2018) compare the life-cycle CO_2 emissions from two different types of drones (a small quadcopter designed to carry loads up to 0.5 kg and a large octocopter that can carry up to 8 kg) with those of trucks (running on diesel, natural gas or electricity), vans and passenger cars (running on gasoline or electricity). All vehicles are assumed to be used for the final delivery of goods in an urban area. The analysis provides results for GHG (greenhouse gas) emissions per package delivered. It includes emissions from fuel production and combustion, as well as from battery production and electricity production required for transportation and warehousing. The range of the emissions intensities of electricity in the

United States is represented by comparing results from low-carbon California to relatively high-carbon Missouri. The study assumes that drones require additional infrastructure in the form of warehouses because of their limited range, increasing the energy consumption and related emissions for the whole delivery system. Results show that small quadcopter drones have lower life-cycle GHG emissions than conventional trucks (powered by diesel and natural gas) and electric vehicle (EV) trucks in most regions. Large octocopters have lower GHG emissions than diesel and natural gas vehicles, but only when charged with low-carbon electricity. However, improving technology for delivery trucks and vans will reduce emissions per package for such ground-based delivery services and influence the life-cycle emissions comparison between such vehicles and drones.

Chiang et al. (2019) investigate the sustainability impact of pairing drones with traditional delivery vehicles into a last-mile delivery routing model. The authors find that if the introduction of drones is carefully planned and the routing and coordination of vehicles and drones are controlled properly, drones have the potential to realise environmental benefits.

Kasliwal et al. (2019) compare the well-to-wheel energy use and related GHG emissions for passenger drones with conventional and electric cars. They find that a point-to-point service for one passenger is 35% more GHG-efficient than a conventional car, and 28% less GHG-efficient than an electric car. Higher load factors would increasingly favour drones compared to the car alternatives. Overall, they find that drones might be a more sustainable transport solution when replacing ground vehicles that operate on congested, indirect routes or that face other geographical barriers. Drones might therefore have a niche role in the mobility system, especially for travellers with a willingness to pay for predictability and time-saving.

Overall, reviewed studies show that CO_2 emissions comparisons between drones and other modes of transport depend on many factors. They include the drone technologies and their respective energy efficiencies, the assumed load factors of the vehicles, the specific transport services being assessed, and the carbon-intensity of the energy powering the vehicles. Because a comparison will also depend on the technological development of alternative modes and their carbon footprints, the results of such assessments will be subject to change over time (Park, Kim, and Suh, 2018). A generic conclusion that applies to all drones and their applications cannot be made. So far, available assessments mostly focus on electric drones used for delivery applications. How the (CO_2) efficiency of passenger drones or larger freight drones (that may not be able to rely exclusively on electricity) compare to more conventional transport services remains to be explored.

Finally, as with any other new means of transport or technology, it is important to consider that drones bear the risk of creating additional travel demand (as discussed in Chapter 3). Where this happens, drones cannot possibly reduce emissions from transport. On the other hand, drones may help reduce overall travel demand (in pkm or tkm) as direct connections (e.g. to remote areas) can be established, and as the detours required by other means of transport can be avoided.

Solutions for other means of transport

Transport is a major contributor to global CO_2 emissions. As such, efforts across the sector to reduce CO_2 emissions have recently increased, with solutions being sought and developed by policy makers and industry alike (see ITF (2020) for a non-exhaustive overview of such measures).

The so-called Avoid-Shift-Improve framework allows such efforts to be classified (e.g. SUTP, 2011). The *avoid* and *shift* categories comprise measures designed to do two things: (a) reduce transport demand, e.g. through land-use management measures or technology that can help to reduce travelling overall (tele-presence, web-conferences etc.); and (b) to encourage people/companies to use more sustainable, i.e.

more (CO_2) efficient, transport modes. The *improve* category of measures aims at enhancing the CO_2 efficiency of a specific transport alternative itself (or the infrastructure it uses) – for example, by making the vehicle (i.e. its use or other stages of its lifecycle) more efficient, by switching to more sustainable fuels, by increasing its utilisation rate (load factors) and/or by optimising its routes.

Regarding *improve* measures, clear policy intervention has proven to be necessary to ensure that vehicle manufacturers and operators pursue the production and use of more (CO_2) efficient vehicles and fuels. This is mainly because upfront development or investment costs for such measures may surpass potential cost savings or competitive advantages in the short or even longer term for vehicle manufacturers and users alike, if an adequate policy landscape is not put in place. A well-known example of a policy measure designed to encourage efficiency improvements of road vehicles is the vehicle efficiency standards (or CO_2 emission standards) that have been put in place around the world (Yang, 2018). These standards typically prescribe minimum energy-efficiency levels (or, inversely, maximum CO_2 emissions levels) for vehicles. In the case of aircraft, standards will apply to new aircraft type designs globally from 2020 (ICAO, 2017a). So far, such standards have typically been based on the energy-efficiency of use phase of the vehicles (and their respective tailpipe emissions). Given the uptake of electric vehicles in road transport (and potentially aviation), more-holistic approaches to standard-setting (e.g. based on life-cycle assessments) will be increasingly relevant in the future. Policy intervention is less critical concerning the other mentioned improve measures, i.e. the increase of utilisation rates (load factors) and the optimising of routes. This is because such efficiency improvements are in the clear interest of transport providers. They can help reduce costs and can therefore help increase the competitiveness of a transport provider.

Economic measures – such as the uptake and gradual increase of a carbon tax, the inclusion of transport operations into an emissions trading system, or a carbon-offsetting scheme (like the Carbon Offsetting and Reduction Scheme for International Aviation, CORSIA) – are a means of encouraging actions across all three *avoid*, *shift* and *improve* categories. They also contribute to establishing a level playing field across different transport modes and alternatives. This is achieved by relating the costs of transport (and hence for the user) to the carbon footprint of transport operations. In the road transport sector, well-known examples of economic measures also include road taxes or congestion charges that can be based on the CO_2 performance of the vehicles.

What can policy makers do?

To improve the CO_2 efficiency of drones and their operations, policy makers can revert to measures that have been put in place for more traditional means of transport and for other industries. For example, they should:

- **Consider introducing drone efficiency standards** that are made increasingly stringent over time. These could be similar to standards that have been introduced for other means of transport (e.g. passenger vehicles, heavy-duty freight vehicles or aircraft). However, they should account for vehicle life-cycle emissions. In this context, ideally new life-cycle-based standards, including relevant measurement processes, would be established for *all* means of transport, to facilitate the comparison of transport alternatives on a like-for-like basis. Lessons learnt from existing efficiency standards for transport vehicles (such as loopholes in the regulation or potential perverse effects regarding vehicle weight developments) should be taken into account when designing such standards (ITF, 2020). The introduction of efficiency standards requires the set-up of respective efficiency measurement procedures and related vehicle testing facilities.
- **Consider introducing CO_2-based charges for airspace use** that drone operators must pay in order to access airspace. This could be managed via the UTM system and rely on drones' CO_2-efficiency

values (which would also need to be determined for setting up drone efficiency standards – see above).

Further, policy makers should:

- Where resources allow, **carry out (or require certified) CO_2 assessments of proposed drone operations and/or proposed drone corridors** – similar to the environmental impact assessments that are often carried out for (transport) infrastructure projects. Such assessments should account for the life-cycle emissions of the drones and their operations, consider the impact of potential alternative transport options, and evaluate the extent to which the specific drone service might create additional transport demand that would undermine any potential CO_2 emissions reduction of the proposed service.
- **Consider whether CO_2-related policies for drones should be part of an economy-wide policy framework that encourages the mitigation of transport CO_2 emissions**. This way, all transport modes will compete on a level playing field regarding their environmental performance.

Air pollution impacts

Some 3.8 million premature deaths annually are attributed to outdoor (ambient) air pollution. According to WHO's most recent survey of 4300+ cities worldwide, only 20% of the urban population surveyed live in areas that comply with WHO air quality guideline levels for PM2.5. Average particulate air pollution levels in many developing cities can be 4-15 times higher than WHO air quality guideline levels, putting many at risk of long-term health problems (WHO, 2020). Fuel-powered drones will contribute to air pollution.

Impacts of drones

In general, drones have great potential to alleviate air pollution in urban areas. This is especially the case where they operate on electricity, as most of the currently available drones used or tested for freight transport in urban areas do (Chiang et al., 2019; Goodchild and Toy, 2018). As such, they do not cause any local air pollution. Where such electric drones replace the use of more conventional, fuel-based means of transport, drones will help alleviate air pollution in urban areas. Larger drones, such as those used for (urban) passenger transport services or larger freight movements, may at least partly rely on more conventional fuels. In these cases, they would contribute to local air pollution.

What can policy makers do?

To avoid the aggravation of air pollution problems in urban areas, policy makers should

- **Consider prohibitions and/or high fees for the use of drones running on fossil fuels in urban areas** (e.g. similar to low emissions or vehicle restriction zones targeting road-based vehicles that are increasingly deployed in cities across the world). As suggested above regarding the charging of use of airspace, respective fee collections or prohibitions could be facilitated via the UTM system.
- **Consider air-pollutant-specific emission standards that define the acceptable limits for exhaust emissions of new drones that burn fossil fuel**. These standards should be inspired by, and meet at least, the stringent criteria currently in place for ground-based vehicles (e.g. those defined in the "Euro" series of exhaust-emissions standards in the European Union). Respective emissions-test procedures for drones would have to be developed. Energy-efficiency (or CO_2) standards that

encourage a reduction in fuel use (as described in the section above) will also contribute to limiting tailpipe emissions of air pollutants.

Wildlife impacts

Wild animals mixing with any form of transportation leads to confrontations that can be fatal to both human and animal. Several recent studies indicate that wildlife-vehicle collisions are a serious problem in many of the OECD member states (Colino-Rabanal et al., 2012; Neumann, 2012; Markolt et al., 2012). The consequences are profound and include significant socio-economic, traffic safety and environmental costs. The Traffic Injury Research Foundation (TIRF) in Canada found not only that wildlife collisions result in death and serious injuries, but also that certain species have become endangered and are at risk of disappearing altogether, which is a threat to biodiversity (TIRF, 2012). Traditionally, wildlife strike prevention has focused on keeping birds off airport perimeters. Bird strikes mostly happen during take-off or landing, or during low-altitude flight in airspace below 3000 metres (McKee et al., 2016). Therefore, options to expand the horizon of wildlife strike prevention beyond airport boundaries are currently being investigated (Hale, 2017; Metz et al., 2019). Although birds try to avoid aircraft, the high speed of planes can cause a delayed reaction that makes it too difficult for the bird to react and avoid the aircraft in time (DeVault, et al., 2014; DeVault, et al., 2015; Doppler et al., 2015; Blackwell et al. 2016).

Because most drones will operate at low altitudes, they will therefore also interfere with the natural environment, in the form of disturbing wildlife or risking collisions with wildlife (Mulero-Pazmany et al., 2017).

Impacts of drones

Wildlife reactions to drones will depend on both the vehicle's attributes (especially drone size, flight pattern, and engine type) and the characteristics of the animals themselves (animal type, life-history stage, and level of aggregation). For example, fuel engines – which are generally noisier than electric engines, especially when combined with changes in noise intensity (e.g. caused by speed or trajectory changes or wind alterations) – will disturb wildlife. Larger drones will impact wildlife at higher altitudes than smaller ones, as the size of the threat increases an animal's perceived risk and the probability of detecting it. Quieter drones, on the other hand, or drones operated at higher altitudes (e.g. over 100 meters above ground level), where noise is attenuated, may not be heard by wildlife and are therefore likely to be less distressing.

Among different animal types, birds, especially in larger groups, are the most sensitive to drones. Flightless birds and large birds are more likely to be disturbed than smaller ones. Terrestrial mammals are overall less reactive to drones than birds. Given the low altitude at which small drones operate, drones may also interact with local fauna, generating a new type of anthropogenic disturbance that has not yet been systematically evaluated (Mulero-Pazmany et. al., 2017).

Solutions for other means of transport

Measures to increase a bird's ability to detect and avoid an aircraft have been demonstrated to enhance the chances for a successful escape and thus to prevent a collision (Lima et al., 2015; Bernhardt et al., 2010). For example, pulsing light on aircraft has been shown to reduce the risk of bird strikes (Blackwell and Bernhardt, 2004; Blackwell et al., 2009; Blackwell et al., 2012). Similar results can be achieved by applying patterns to the propellers of turboprop aircraft (FAA 1978; Aas and Johansen, 2016). Aircraft with a higher contrast to the sky experience fewer bird strikes (Fernández-Juricic et al., 2011). In ground-based transport, measures like flashing road signs that warn car drivers about wildlife crossings or sensors inside cars that enable the detection of wildlife in the direct vicinity have proven effective. Overall, different species of animals react differently to vehicle encounters on the ground and in the air, making very dedicated counter-measures necessary (Lima et al., 2015).

What can policy makers do?

In line with findings from Hodgson and Koh (2016) and Mulero-Pázmány et al. (2017), the following recommendations for policy makers can be drawn to limit the disturbance of wildlife due to drones:

- **Enable local authorities to react immediately when wildlife becomes significantly affected**, for example by defining additional no-fly zones or restricting access to specific areas;
- **Publish information on bird concentrations, bird movements, seasonal animal movements etc**. together with associated guidelines for drone operations in those areas;
- **Publish recommendations for drone operations in sensitive areas** to produce the lowest possible levels of noise, vibration and light pollution;
- **Introduce requirements for drones to be equipped with additional lights and visual patterns** on the propellers to help birds see and avoid drones; and
- **Publish technical and operational guidelines on how to use drones in the vicinity of wildlife**, such as
    - prefer straight flight paths over unpredictable flight manoeuvres,
    - favour quiet drones over noisier drones (e.g. electric propulsion), and
    - position ground stations at an appropriate distance from wildlife habitats.

In urban areas, dedicated urban infrastructure measures (e.g. fences, acoustic warnings or pulsing lights) can help avoid disturbance of, or collision with, birds. They can also prevent birds from entering drone hubs or interacting with ground infrastructure like antennas or surveillance systems.

Other environmental impacts

Visual disturbance

Drones can cause visual disturbance which may impact people’s well-being and health. Similar to noise emissions, perceived visual disturbance may be different to actual visual disturbance. Studies originating from different fields indicate that perceived disturbance is often strongly correlated with the uncertainty related to the actual situation. In this context, drones may more often be perceived as disturbing when their purpose, flight legitimacy or estimated height and distance are uncertain. Research shows that a drone that flies sufficiently far away and has a clear and legitimate purpose does not cause people to interrupt their activities, and is not seen as problematic (Bakx and Nyce, 2016). On the other hand, a drone that hovers over public or residential areas with no visible legitimisation will most likely be perceived as disruptive or intrusive. Similarly, drones that access areas that are considered either private (e.g. residential areas, schools, kindergartens), sensitive (e.g. industrial, governmental or military buildings) or protected (e.g. natural reserves, historical places and buildings) are more likely to cause distraction and distress (Lidynia, Philipsen, and Ziefle, 2017).

Policy makers should consider the following measures to reduce the general public's uncertainty about drones, and thereby reduce (perceived) visual disturbance (see Chapter 3 for further recommendations on how to improve the public perception of drones):

- **Implement drone e-registration and e-identification processes and make information on drone flights available to the general public**, who could then instantly verify the drone's origin, destination and purpose.
- Where appropriate, **define no-fly zones above private or sensitive areas and require drone manufacturers to equip their vehicles with appropriate geofencing and remote identification technologies** to effectively enforce such zones.
- **Improve public perception and awareness of drones**, e.g. by launching awareness campaigns that highlight the opportunities presented by drones.
- **Support further research on tolerance levels with regard to visual disturbance of drones** to identify further measures for mitigating such disturbance.

Soil sealing

The term *soil sealing* describes the problems related to large-scale sealing of natural soil – that is, the covering of the ground by an impermeable material. A major amount of soil sealing can be attributed to the construction of housing, office and industrial buildings. Transport infrastructure also contributes to soil sealing, and droneports may eventually contribute to soil sealing in a future scenario of mass deployment of drones.

Soil sealing prevents rain from draining into the soil and thus lowers the overall ground water level. At the same time, surface drains can cause local sewers to overflow and ultimately contribute to river floods. Further, sealed soil cannot carry plant life, which has negative effects on the microclimate such as overheating effects in summer. Soil sealing also reduces animal diversity, both on the surface and underground; and it can play a role in climate change by hindering natural CO_2 absorption by soils. Efforts to renature sealed soil require huge amounts of technology and money and often leave contaminated soils behind (Umweltbundesamt, 2019; European Commission, 2013).

The amount of soil sealing that may be attributed to drone traffic will largely depend on the drone application scenario. In principle, drones will not require sealing of significant amounts of soil; they do not require sealed traffic areas like railways or roads, and they can take-off and land in smaller, confined places requiring only minimal surface area. Passenger drones used for urban air mobility applications may imply the construction of air hubs similar to bus terminals. However, especially in urban areas, existing roof tops or legacy industry or traffic infrastructures may be used for this purpose. Thus, in urban areas the impact on soil sealing is expected to be low. In sub-urban and rural areas, drone delivery and cargo applications may require the construction of separate logistics infrastructure to couple drone traffic to other modes of transport. Each specific drone use case will require a different degree of soil sealing and, to a greater or lesser extent, may revert to already existing infrastructure.

Policy makers should keep the issue of soil sealing in mind when planning future urban landscapes or drone operations in general. Where possible, they should ensure that drone operations make use of soil already sealed by existing built infrastructure or buildings, instead of requiring additional soil sealing.

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CHAPTER 5
Infrastructures for drone deployment: Droneports and Unmanned Air Traffic Management

This chapter will address the infrastructures needed for widespread drone deployment as well as potential governance and funding models for those infrastructures.

In the context of drones, both physical and digital infrastructures are relevant. Drones will require physical spaces to land and take off (called “droneports” throughout this document), which, depending on the types of drones using them, may also include facilities to connect passengers and cargo to their destinations. Digital infrastructure, like new Unmanned Air Traffic Management (UTM) systems, which co-ordinate and monitor drone flights, will also be needed. These UTM systems will need to be closely linked with existing Air Traffic Management (ATM) systems to ensure safety and to monitor adherence to other policies and regulations.

Upgrades and additions to both the ground infrastructures and air navigation services will be necessary:

- New drone stations and droneports, as well as changes to existing airports and heliports, must be able to seamlessly connect drones and their passengers/cargo to their destinations and other transport modes.
- UTM systems, which co-ordinate and monitor drone flight activity, must become a part of Air Navigation Services and be closely linked with Air Traffic Management (ATM) systems to ensure safety and the ability to monitor adherence to policies and regulations beyond safety (Deloitte, 2019).
- Both physical and digital drone infrastructures require governance and funding models that are integrated with manned aviation and the transport system overall.

The chapter concludes with recommendations for policy makers regarding drone infrastructure.

Ground infrastructures – The future of droneports

Ground infrastructure may pose a significant challenge to widespread drone adoption (Deloitte, 2019). Requirements may include adequate space to safely land and take off, the capacity to load/unload passengers and cargo in compliance with legal protocols (i.e. customs), adequate space and resources for maintenance and storage, access to other modes of transport, and connection to communication networks.

Similar to other transport infrastructures, the location, size, and shape of drone ground infrastructure may be influenced by the scope of drone activity (i.e. passengers and/or cargo, small or large drones), the physical conditions of land, proximity to other transport networks, density (i.e. urban vs. rural), land regulations (i.e. zoning), price, and the nature of land ownership (public vs. private). These factors will likely also determine where and how sites are procured and maintained. However, the comparatively small size and potential Vertical Take-Off and Landing (VTOL) capabilities of drones may allow for more spatial flexibility and a smaller footprint than traditional airports and helipads. The global drone industry is currently exploring designs for droneports atop residential buildings, along highways, in parking lots and atop skyscrapers.

How will droneports be designed?

An *aerodrome* can be defined as an "area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft"; they comprise ground infrastructures for aviation, such as airports and heliports, of all sizes and purposes (ICAO, 2018). Today there are approximately 42 000 airports (CIA Factbook, 2016) and 6 500 heliports (CIA Factbook, 2013) worldwide, ranging from international commercial hubs to small rural installations.

Most airports are currently designed as a vast movement area extending from a runway, along taxiways and onto an apron. Today's large, modern aircraft require a more exacting design of these facilities. Specifications for their physical characteristics (e.g. width, surface slope and separation distances from other facilities) form a principal part of the Chicago Convention's annexes. Specifications for facilities (e.g. runway end safety areas, clearways and stopways) are all articulated. Terminal buildings and maintenance facilities are required to enable adequate processing of passengers/freight transport and provide energy servicing.

Regarding ground infrastructure for helicopters, most heliports in the United States (home to 81% of the world's heliports) are privately owned and poorly documented by the Federal Aviation Administration (FAA), and many are located on the rooftops of valuable real estate in the central business districts of urban areas (Walker, 2019). Due to the smaller size and VTOL abilities of helicopters compared to airplanes, heliports require less surface area – allowing them to be closer to city centres and reducing travel time in many cases, but increasing the complexity of traffic management.

Drones are likely to require smaller and simpler ground infrastructure than airplanes or helicopters, allowing for some flexibility in the design and location of droneports, particularly if they serve drones with VTOL capabilities. However, drones will still need a sufficient surface area, as well as being positioned at a suitable distance from other structures after factoring in wind and trajectory. Droneports will also require charging/fuelling capacity for drones that run on battery, hybrid and/or conventional propulsion energy. Adequate spaces for security processing, loading/unloading, and lounge/storage are necessary for both passengers and cargo as well (Deloitte, 2019). Provisions for connections to other modes of transport, including pedestrian and surface modes, will be important considerations.

Light drones with low payload are likely to require less intensive servicing at ports. Thus, depending on the cargo and local regulations, a "port" for a small drone could just be a demarcated space on a rooftop or parking lot or a small drone station similar to other urban furniture, e.g. like the Matternet (2020) drone station. However, ports that exclusively service small drones may still require a certain economy of scale as a port that can only process one small drone at a time may be too expensive to maintain, especially in high-land-value areas.

Midsized passenger drones designed to carry 1-5 passengers could potentially still be accommodated on existing urban infrastructure, including rooftops and other surfaces located near transport hubs and places of interest (e.g. central business districts). However, locating droneports in urban areas will require adherence and/or adaptation to zoning regulations and airspace restrictions stipulating e.g. noise levels or minimum distance from adjacent buildings. Rooftops retrofitted as droneports may require broader changes to a building's infrastructure and security as well. Additionally, permission procedures must be established for non-residents to use a residential building for drone services. Existing helipads may serve as examples of how to design, manage and regulate urban passenger droneports. Midsized passenger drones could also cover the first and last miles of a rural/urban commute, while midsized cargo drones are well-suited to serving low-access areas with sparse population, poor transport infrastructure and/or difficult terrain.

Rural droneports might be more feasible in the near term, considering that land is more affordable and low density means less conflict with other infrastructure. Whereas the premium on space in urban areas might translate to more limited use cases in the near term, the potential cost-savings and additional space of droneports in less dense regions could more easily allow for well-equipped facilities there.

Large drones the size of a small conventional aircraft without VTOL capabilities will likely require droneports that resemble small conventional airports. It is possible that the most feasible ground infrastructure for large drones already exists – in the form of traditional airports that can be updated to provide the types of services needed to support a fleet of large drones.

Governance of ground infrastructures: airports, heliports and future droneports

Currently the governance of civil aviation ground infrastructure varies widely depending on the legal jurisdiction. There has historically been a “lack of clear guidance within the aviation industry or for governments on ownership and operating models for airports, and the appropriate regulatory framework to govern them” (IATA, 2018). Generally, the selected model for ground infrastructure is determined by the regulatory parameters and property law in force in each jurisdiction. In some cases, a public entity may own land and develop transport infrastructure there as a public good. In others, states may exert eminent domain and acquire private land in order to do so. Regulatory tools, such as zoning, limiting the size (i.e. height, density) and function (i.e. manufacturing, residential) of ground infrastructure may be established by governments at the municipal, regional, or national levels, depending on context.

Under Article 28 of the Chicago Convention (1944), States are primarily responsible for the provision of airport and air navigation facilities and services to facilitate international air navigation. As such, countries are ultimately responsible for safety, security and economic oversight of airport and air navigation operations. However, this international obligation does not necessarily need to translate into direct provision of these facilities and services by governments. The following aims related to the establishment of autonomous infrastructure operators in aviation can be identified:

- Reduce the financial burden on governments;
- Increase efficiency and service quality;
- Encourage commercial development, through a focus on revenues and expenses, quicker decisions and market forces;
- Establish a clear separation between regulatory and operational functions; and
- Enable access to private capital markets and encourage private investment.

Although government or public ownership and control of airports was once a common form of organisation, many countries have established autonomous or publicly-chartered entities in order to separate the provision of airport services from strictly governmental functions. Furthermore, public sector priorities such as financial sustainability, maximised financial gains, access to new sources of private finance, and more efficient management have led to an increase in public-private partnerships (PPPs) or outright privatisation for airports around the world. Accordingly, the number of airport entities with

private participation has grown in all regions of the world in recent decades: the proportion of passenger traffic handled by airports with private sector participation has reached 75% in Europe, 60% in Latin America and 45% in Asia-Pacific (Graham, 2020).
The International Civil Aviation Organization (ICAO) has recommended that the public sector consider PPP models in order to optimise airport performance, but also clarifies that "States are ultimately responsible for safety, security, and economic oversight" over aviation ground infrastructure (ICAO, 2012). The International Air Transport Association (IATA) recently outlined the trade-offs of various governance models for such infrastructure, ranging from public to non-profit to fully private. The choice of governance model typically depends on the preferences, goals and resources of the government involved, i.e. whether the airport is envisioned as a global, regional or local hub in an established or emerging market (IATA, 2018).

A massive proliferation of private drone fleets will require additional infrastructure and real estate for landing, take-off and servicing. This need may result in a race to acquire rights to rooftop spaces in urban areas, affecting real estate markets and creating incentives for firms to exclude rivals. For example, a start-up in the United Kingdom named Skyport has already bought the rights to 15 rooftops in London that it plans to convert to droneports, with plans to purchase 85 more in the near future, plus expand to Los Angeles and Singapore (Deloitte, 2019).

In some areas the potential high costs of outfitting urban space for drone use – including real estate acquisition, construction and engineering – may necessitate the engagement of the private sector. Indeed, the cost, ownership and location of droneports will likely have a direct impact on governance structure.

In the absence of any regulation, exclusively private ownership and operation of droneports could complicate transport policies and undermine public authorities' likely preference that drone service remains available to a wide range of the population as a public good. Without proper public planning, real estate intended for droneports could, in theory, be exploited by private real estate speculators, or purchased and developed by firms that limit port use to their own fleets. While the former model could result in the selling of slots, the latter could lead to monopolistic practices which might undermine public sector goals for equitable access and deployment of drones. Jurisdictions should weigh these factors in their policy making.

Depending upon how the market develops, it might ultimately become necessary to legally unbundle the vertical integration of upstream services, i.e. separate the fleet management from providing droneports. Regulations concerning third-party access and technical interoperability of ground infrastructures may also be welcome (see also Chapter 2). Manned civil aviation standards may point to other possible regulatory solutions for the drone industry. At the global level, regulators and industry stakeholders have developed best practices regarding the levying of services for use of aviation infrastructure. These best practices were refined on the basis of feedback from operators and regulators, and officially adopted as *ICAO's Policies on Charges for Airports and Air Navigation Services* (ICAO, 2012). These key charging principles include transparency, consulting with users, non-discrimination and cost-relatedness.

Funding for ground infrastructure

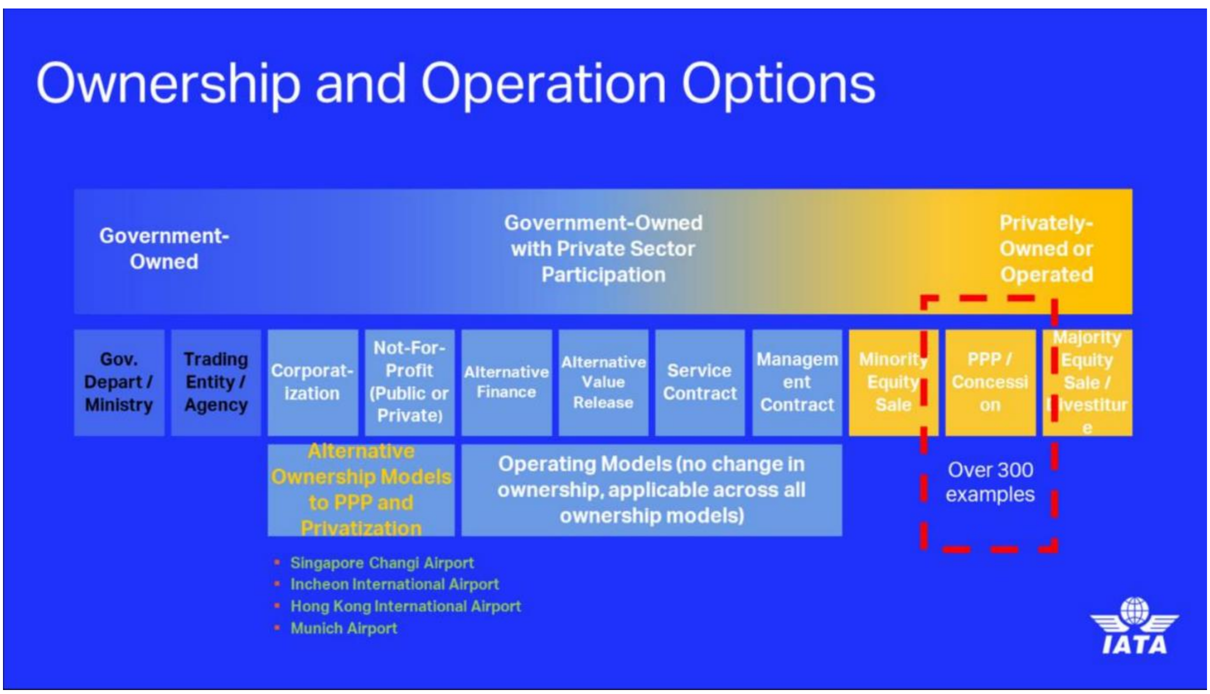
The history of airport development, operation, and governance offers lessons for what can be expected for drone infrastructure. In particular, decisions made regarding the governance of aviation infrastructure are often deeply related to issues of funding.

Potential sources of funding for aviation infrastructure vary from country to country. Traditionally, the main source of funds for airport development has been governments, including both direct government funding and funding from government-owned or -sponsored institutions. Airports also generate around 40% of their revenue from non-aeronautical activities such as concessions, rent and parking (ACI, 2019).

IATA attributes the transition towards some level of privatisation of ground infrastructures to a shift in public sector priorities, chiefly those related to the pursuit of financial stability for both governments and the aviation industry they oversee. These priorities included financial sustainability, economic diversification, maximised financial gains, access to new sources of private finance and technical expertise, and more efficient management (IATA, 2018).

Though there is little information available on public or private efforts to develop droneports so far, public-private partnerships that "utilise a range of cost-sharing and revenue-sharing models may lower cost barriers and provide a balanced approach to development" (Deloitte, 2019). The range of airport governance models described by IATA (Figure 2) could serve as a template for policy makers, who must then adapt the models to their local context (e.g. zoning restrictions, urban/rural, existing infrastructure).

Figure 2. Airport ownership and operation options



Source: IATA, 2019.

The consistent increase in PPPs, commercialisation, and outright privatisation of airports around the world has yielded both success stories and cautionary tales. The decision to incentivise the private sector to invest needed funds in aviation infrastructure in exchange for the rights to profits has yielded "efficiency gains associated with greater specialisation in the airport industry, access to new sources of private sector investment, and stimulation of aviation-driven economies" (IATA, 2018). Without competition and/or regulatory oversight, however, an over-reliance of the State on private funding can lead to abuse of market power.

At least part of the funding for the ground and airspace infrastructure needed for mass drone deployment is likely to come from the private sector. For example, Google, Amazon and other leading firms have already invested significantly in the development of drone technology, including ground infrastructure design. Similarly, other private firms have demonstrated interest in developing droneports: Uber has identified development of drone infrastructure as having "significant cost advantages" over conventional transport (Uber Elevate, 2016).

Overall, the private sector may be willing to cover a significant portion of upfront costs by way of investment. A recent report estimated that bringing drone infrastructure to 74 cities would cost USD 32 billion, but could produce revenues of more than USD 244 billion. Considering recent trends, plus the anticipation of both expensive upfront infrastructure costs and highly profitable market opportunities, a significant private sector role in the funding of drones is likely (eVTOL, 2019).

To date, governments have not invested resources in creating ground infrastructure for drones. Deloitte (2019) found that "neither government agencies nor private sector firms—in engineering, procurement, and construction—are widely discussing how to proceed with ground infrastructure." If the private sector creates and funds this infrastructure it may do so for their own exclusive use, or they may control access to ground infrastructure in a manner that limits access to the airspace. As mentioned above, regulators may need to address these concerns.

While it is logical for the public sector to leverage the financial and technological resources of the private sector, it may want to heed the lessons of commercialisation of traditional infrastructure and ensure that the benefits won by early-adopting private actors are passed on to the public at large.

In addition, policy makers should note that any straightforward application of airport governance and financing models to drone ground infrastructures may prove to be inadequate. Drone technologies, applications, operational standards and value chains are still under development and may ultimately require customised policies and approaches to address economic concerns.

Unmanned Air Traffic Management (UTM) systems

New digital infrastructures for unmanned aviation are just as crucial to establish drone economies at scale as novel ground infrastructures: drones must be able to communicate with both manned and unmanned aircraft while occupying airspace. New digital systems that are interoperable with all other systems are necessary to avoid collisions, ensure the smooth flow of drone traffic, allow for identifying unauthorised drones and/or use of airspace, and avoid social disturbances.

The current air traffic management (ATM) system is defined by ICAO as the management of airspace and air traffic in order to facilitate safe, economic and efficient aviation practices through collaboration and integration with all airborne and ground-based parties. The main objectives of air traffic control services are to prevent collisions between aircraft and with other potential obstructions, and to maintain a fast but orderly flow of traffic (ICAO, 2016).

Considering the trends toward private participation in the governance of both ground and airspace infrastructure, plus the early interest in UTM system development demonstrated by major tech and mobility firms, the governance of such infrastructures for drones will likely depend on significant public and private collaboration. While the public sector is directly responsible for overseeing aviation safety, the private sector has more resources and expertise concerning the technological aspects of UTM development.

There is certainly no "one-size-fits-all" solution for governance of future drone infrastructure; different States have different approaches to governance of existing aviation infrastructure. However, the fundamental principle is that, regardless of the governance model adopted, States are ultimately responsible for the ensuring safety and security of the aviation system. In addition, market access and non-discrimination will be important considerations. Players that are willing to become infrastructure service providers should be accommodated as long as they meet critical safety, security, and efficiency requirements.

In practical terms, this may mean that governments at various levels will need to adopt regulatory parameters and standards for UTM services used by drones that private industry must comply with. If so, lawmakers will need to ensure that those private actors will have sufficient freedom to pursue innovative applications of drone use.

Development of Unmanned Air Traffic Management (UTM) systems

Unmanned Air Traffic Management (UTM) systems are envisioned as a part of ATM systems to manage drone operations safely, economically and efficiently through the provision of facilities and a seamless set of services in collaboration with all parties and involving airborne and ground-based functions.

Although consistent systems-level requirements for UTM systems have not yet been established, core principles that exist in the current ATM structure remain applicable for the development of UTM services. These may include:

- Oversight of the service provision remains the responsibility of the regulator for both ATM and UTM.
- Existing policies for aircraft prioritisation, such as aircraft emergencies and support for public safety operations, should remain applicable, and practices unique to UTM should be compatible with these policies.
- Access to the airspace should remain feasible and equitable, provided each aircraft is capable of meeting the appropriate conditions, regulations, equipage, and processes defined for the specific airspace in which operations are proposed.
- The drone operator should be appropriately qualified to meet the established normal and contingency operating procedures defined for the specific class of airspace in which operations are proposed.
- To meet their security and safety oversight obligations, States should have unrestricted, on-demand access to drone operators and the position, velocity, planned trajectory and performance capabilities of each drone in the airspace through the UTM system.

In order to enable drone transport at scale, UTM services may include: activity reporting; aeronautical information; airspace authorisation; registration service; flight planning; separation (including strategic deconfliction, tactical separation and conflict advisory/alert); tracking and location; and weather. This scope of suggested services is consistent with the approach national governments have already taken in their concepts of UTM operations, e.g. the Swiss U-Space Concept of Operations (FOCA, 2019).

Managing access to airspace, drone identification and registration as part of UTM

Recent reports of unidentified drones above a small town in Colorado, as well as in the airspaces of Gatwick Airport and Los Angeles International Airport (LAX), have frightened communities, disrupted major transport arteries, and confounded authorities. In Colorado, Nebraska and some residential areas, citizens and officials alike have been unable to identify the operators of the disruptive drones (Smith, 2020). The drone sighting near Gatwick resulted in hundreds of flight cancellations (CANSO, 2019). Despite observing over 200 drones near LAX since 2016, officials have managed to identify and contact the operator of only one.

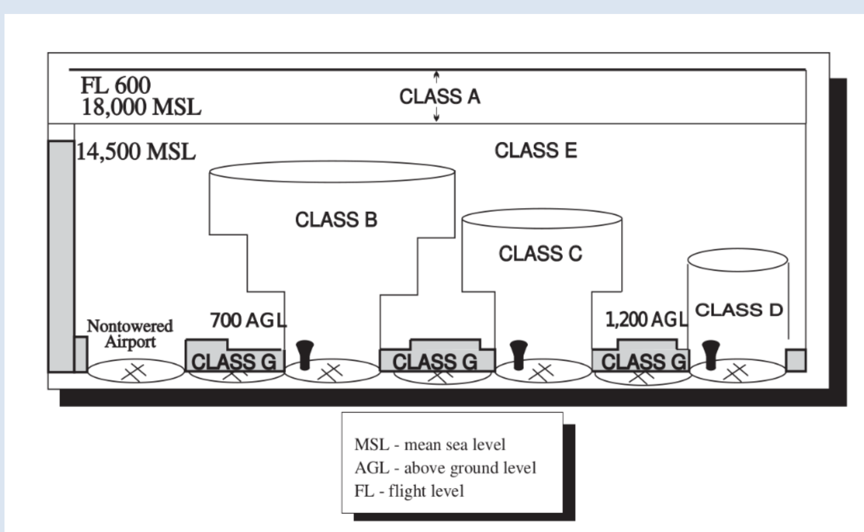
In order to monitor access to airspace and address non-compliant drone activity, administrative and technical tools to register and identify drones must be developed and implemented. For this purpose, UTMs will have to rely on electronically defined/transmitted identification techniques, which can incorporate a range of tools to decode and share this information, while respecting the need for security and personal data protections.

Box 6. Access to airspace

Currently, the sky is divided into different regulatory sections of "air space classes", each of which is accompanied by obligations and entitlements overseen by air traffic control (ATC). This system of airspace management is based on a complex and decades-old regulation enshrined in an international treaty, the Chicago Convention. Adopted in 1944, the treaty established a delicate balance of power between different forms of manned aviation, the respective air volume, and the designated service provider – normally a dedicated air navigation service provider (ANSP) within a given territory deriving its authorisation from the respective government.

In most countries, drones can fly at low altitudes in the uncontrolled airspace, Class G. By contrast, Class A, B, C, D and E airspace is all controlled airspace and includes airspace near airports and airways. Small drones currently primarily operate within Class G airspace. From an economic standpoint, there is great value in capitalising on the largely unused airspace at low altitudes. In the future, drones are expected to operate within other classes of airspace as they become larger and fly at higher altitudes. Already today, military drones such as the "Global Hawk" use the services of Air Traffic Management (ATM) in controlled airspace to get to their cruising altitude in Class A.

Figure 3. Airspace classes in the United States



Source: FAA (2017)

Several aviation groups, led by the Civil Air Navigation Services Organisation (CANSO), have argued that drones should be integrated into common airspace with other aircraft rather than be confined to a segregated section of the sky, which they believe would undermine drones' impact. In order to achieve this, the aviation partners have called for "a consistent flow of information between all actors who may need to use the airspace", as well as between ATM and UTM systems (CANSO, 2019).

The allocation of airspace will continue to be an important issue in aviation as more diverse users take to the skies. Drones must be incorporated into the existing airspace system in a way that is safe, efficient, sustainable and equitable. As a new form of airspace use, drones will either continue to occupy airspace below the current minimum flight height or be integrated into existing airspace classes used by manned aviation.

International aviation law, i.e. Article 21 of the Chicago Convention, already requires States to maintain a registry of all aircraft registered in their State. In most cases, these registries have not been yet expanded to include small unmanned aircraft, but the existence of the requirement provides a foundation on which to base drone-related registration laws.

However, any updates should consider technological advances already made, as well as potential future changes. This may include flexibility regarding the nature of data access and sharing – i.e. application programming interfaces (APIs) and Mobility as a Service (MaaS) – as well as the potential implementation of machine-readable law (i.e. geofencing). A possible solution for drones includes the creation of an encompassing aircraft registration network to connect national registries in order to facilitate voluntary exchange of information.

Seamless communication between drones, other aircraft and ATM and UTM systems via interoperable digital infrastructure will be essential to a safe and equitable allocation of airspace.

UTM systems and governance models currently being developed

States remain ultimately responsible for the provision of airports and air navigation services in their respective territories (Chicago Convention, 1944). The ownership and management of airports and air navigation services (ANS) may be delegated to the private sector, but delegation of ANS to the private sector has different implications than for airports.

First, unlike airports, which are localised, air navigation services often extend over the territory of entire countries, or even beyond such national territory. Second, by reason of each country's sovereignty over its airspace (as articulated in Article 1 of the Chicago Convention), air navigation services have national defence and external relations implications, which is mostly not the case for airports. Third, in many countries, air navigation services are provided by a single entity, traditionally the national civil aviation administration.

Historically, air navigation service providers (ANSPs) have been integrated within the governmental structure, but governments around the world are increasingly commercialising their ANS (IATA, 2020). More than 40 countries have done so, including Australia, Canada and the United Kingdom. Yet the United States has kept ANS within the public sector. The nature of ANS governance can have a major impact on aviation, including costs, service quality, and competition. While IATA, and the airlines it represents support greater autonomy for ANSPs for the sake of more efficient management it also warns that commercialisation "can have a negative outcome when the principal objective is to maximise shareholder profits", and that some past attempts have caused an increase in ANS costs without any corresponding improvement to efficiency. IATA recommends that any commercialisation is precipitated by independent regulation and government oversight that clearly establishes the authority of all stakeholders and the applicable financial models (IATA, 2020). Further, any ANSPs granted monopolistic service status must provide full transparency.

The current system of airspace control does not have the capabilities to cover very low altitude airspace, where drones will likely operate most frequently. Moreover, the integration of drones into other airspace already occupied by existing aircraft remains an outstanding challenge. Considering that drone traffic in urban air space is expected to increase rapidly, and airspace capacity is finite, a framework must be established to govern and manage low-level airspace.

At the same time, emergent UTM systems must strive to be interoperable with existing ATM systems, thus minimising the burden placed on the incumbent system and improving safety and economic outcomes. Regulators may want to facilitate the formation of consortia with UTM and ATM operators and other private firms in the tech, aviation, and security sectors in order to establish a fast, pragmatic approach, as is being done in Singapore (Box 2 in Chapter 2). IATA's proposed guidelines for the responsible commercialisation of ANS with public sector oversight could guide the governance decisions of UTM as well (IATA, 2020).

In the absence of any universal UTM system, which is unlikely, various UTM systems are currently being developed. Those developments are often driven by private firms - which may lead to disparate UTM designs.

Some private UTM developers are agnostic as to who will be the future UTM operator (be it a state agency, an ANSP, a region or metropolitan area, etc.) and basically aim to sell the technical capabilities to the entity vested with this authority. Others are proprietary systems which are intended to remain privately-owned systems specifically catering to the fleet of a specific entity and also including additional functionalities such as fleet management. Large companies such as Amazon or Google, for example, are known to be working on their own UTM systems.

In Rwanda, the State has traded prescriptive regulations on drone operation that stifled their development for performance-based rules that ensure drone operators meet the necessary safety standards (WEF, 2019). By making this change, authorities have given operators the space to experiment with technologies more rapidly (rather than precluding development based on equipment specifications), thereby accelerating drone integration and deployment. Though not specifically focused on UTM, Rwanda's regulation requires integration and compliance while allowing private sector innovation. This type of approach can serve as a model for other UTM developments.

In Singapore, the Civil Aviation Authority and Ministry of Transport have formed the Future Flight Consortium, which brings together tech industry and academic leaders to establish a "connected urban airspace management system for unmanned aircraft" (Deloitte, 2019). This UTM system would ensure that any operator in Singapore wanting to fly a drone can communicate with all relevant airspace operators. However, the limitations of this system underscore the need for wider UTM development. A UTM system such as Singapore's would only ensure interoperability and enforcement within the city, meaning that unauthorised drones could still enter the airspace without compliance. Conversely, compliant drones would no longer be able to rely on the interoperability of the UTM system once outside Singapore. This may not be a grave risk in the near term, as drones are most likely to operate over short distances. Nevertheless, this question needs to be anticipated, as longer-range drones are likely to emerge in the future.

The U.S. FAA has proposed "wide-sweeping regulations that would require all but the tiniest drones [to] incorporate technology that would enable them to be tracked at all times while flying in United States airspace" (Murphy, 2020). The regulation would require certain digital infrastructure compliant with FAA-compliant systems to be incorporated into drones, including remote ID technology so that authorities are able to identify drones flying within their jurisdiction. The proposed regulation may partly be in response to increased drone complaints across the United States – which, while the drones "may be perfectly legal", currently lack the digital infrastructure to be identified either by concerned citizens or authorities (Smith, 2020).

Similarly, the European Commission has launched the U-Space initiative, which aims to establish regulatory policy for drones across Europe (CANSO, 2019). Such a regulatory framework could increase safety and equity for both airspace operators and citizens on the ground by ensuring – among other things – interoperability of drone data and communication systems. In order to implement its U-Space initiative, the European Commission is developing a UTM regulatory framework, which it describes as "a set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones" (SESAR JU, 2017). The services will require a high level of digital infrastructure capable of automated functions, integrated into both drones themselves and corresponding ground infrastructure. The UTM services proposed through the U-Space framework are not intended to replicate ATM functions, but rather to ensure interoperability between UTM and ATM systems that service unmanned and manned aircrafts respectively.

U-Space has identified the establishment of basic digital infrastructure as the first step to safe drone deployment that is interoperable with both existing ATM systems and other UTM systems for drones. That digital infrastructure includes e-registration, e-identification, and geofencing (SESAR JU, 2017). Likewise, a group of 19 European and international aviation associations ranked the integration and open exchange of data as the number one principle for successful drone regulation. Interoperable data exchanged between drones and conventional aircraft via ATM and UTM systems is essential to create "a common and shared picture of the airspace, and any operations taking place within it at any given time", in order to guarantee safety and security (CANSO, 2019).

In a similar vein, various governments are, cooperating through the ICAO, to develop Standards and Recommended Practices (SARPs) supporting instrument flight rules (IFR) operations for drones in controlled airspace and at controlled aerodromes. ICAO's SARPs are currently focused on airworthiness, operations, operator certification, air traffic management, detect and avoid (DAA), safety management and security. For those unmanned aircraft which are not expected to be operated internationally in IFR – which is, for the moment, the majority of drones guidance material is available to help States begin their regulatory processes (ICAO, 2019).

Any future airspace management will either need to accommodate a multitude of these UTM providers within a given territory ensuring a real-time exchange between these systems or establish one sole UTM system used by all airspace users like today's system based on officially designated air navigation service providers as stipulated by the Chicago convention (1944).

While the public sector may prefer the private sector's pursuit of UTM solutions given the latter's technological and financial advantages, states may nonetheless want to adopt regulations that guarantee interoperability between independent UTM (and existing ATM) systems. A few governments have already taken steps in this direction.

Considering the trend in many regions toward private sector commercialisation already apparent in aviation infrastructure, as well as demonstrated private sector interest in the drone industry from major tech firms, governments should be prepared for the proliferation of drone operators. Gone unplanned or potentially unregulated, these private UTM may deny fair access to other market participants and refuse to share necessary information with key stakeholders (i.e. ANSP). Such practice would prevent the development of a robust drone market, undermine competition, and increase the risk of airspace accidents. Policy makers must therefore adopt clear regulations that require private firms' UTM systems to be interoperable with other UTM, any existing ATM systems operated by ANSPs as well as any national and local civil aviation authorities' systems.

Thus, considering the likelihood of several private UTM systems operating simultaneously, one main challenge for establishing clear digital infrastructure governance will be to clarify what information UTM systems must provide to other UTM systems and to the ANSP or any other involved aviation authority. On the other hand, private UTM systems must have access to any information from local or national entities on restricted flight zones and events that might impact or be impacted by drone traffic. While the regulation of airspace is the authority of civil aviation authorities, the establishment of no flight zones will involve a variety of state actors such as defence forces (next to military bases), ministries of justice (next to prisons or penitentiaries), ministries of foreign affairs (next to embassies), ministries of interior (next to police stations) and more. Other concerns may arise, including updating definition of highly populated versus scarcely populated areas in consideration of drone-related risks — for example, the "ground risk" of a person being struck by a drone in case of malfunction is severely higher in metropolitan areas (JARUS, 2017).

Europe's proposed U-Space framework may also provide some guidance in this area. It is intended to enable a "clear and effective interface to manned aviation, ATM/ANS service providers, and authorities", not just for the lowest airspace but for "the smooth operation of drones in all operating environments, and in all types of airspace" (SESAR JU, 2017). Rather than insisting on exclusively public governance of UTMs or relinquishing regulatory authority to private UTMs, the U-Space framework recommends regulations that ensure the integration and interoperability of data between all stakeholders.

In practice, this would likely mean a public-private partnership that establishes a universal set of standards, so that drones and conventional aircraft can communicate with both public regulators and private operators in any airspace. The initial step may be to form a consortium that, informed by private expertise, develops these standards and enshrines them in public regulation. For its part, U-Space recommends that the foundation to an integrated airspace that supports open, clear data exchange between all parties is the establishment of electronic registration, e-identification and geofencing systems for all airspace users. This would require transparency from the private sector, and technical capabilities from the public sector. It is possible that authorities may need to use regulation to "force" data transparency – much like what has been happening in the private e-scooter industry, where authorities have required scooter operators to provide location data of their scooter fleets (Hawkins, 2019).

Funding air space navigation services for drone fleets

There are major differences between airports and airspace navigation infrastructures with respect to funding and financing models. As organisations within governments, air navigation system providers (ANSPs) have historically been funded by the government, sometimes from taxation revenues. An additional feature is that the ANSP service provider may be exempt from taxes.

As with airports, air navigation services (ANS) have been continually commercialised around the world over the last 40 years, with mixed results. Mutually beneficial and sustainable commercialisation of ANS is possible, but requires a well-defined commercialisation policy agreed upon by customers, a robust institutional environment, clear roles for all stakeholders, a clear financial model, full transparency for operators (especially ANSP monopolies), a systematic performance review process, and alignment with international agreements and ICAO policies (IATA, 2020).

When ANSP commercialisation has been implemented accordingly, the subsequent increase in autonomy has led to more efficient operations. Proper execution of ANS commercialisation has been pivotal, considering its financial impact on the aviation sector. However, there are many models of commercialisation, and the specific needs of a given regulator may dictate the type of model chosen (Button and McDougall, 2006). A major lesson has been that private funding for airspace infrastructure (in exchange for profit-sharing) poses challenges without clearly defining mechanisms of responsibility, evaluation and outcomes. This lesson might usefully inform thinking on how to approach funding models for UTMs.

The same holds true for the provision of UTM services. If UTM systems are operated by private entities, it will be important to identify a framework for the allocation of the fundamental public resource at issue – the airspace. Some private UTM developers, such as Google, might offer UTM to the public, but also intend to deploy their own fleets of drones for package delivery or other functions at low altitudes. If a private entity has the capability to allocate and control the access to the airspace while being able to handle its own unfettered access, there is a risk of unbalanced access to airspace.

The key players in this arena – ANSPs, regulators, UTM providers – must also collaborate with other entities. That may include local authorities (particularly if they have passed their own laws governing drone operations at low altitudes), military, law enforcement and national security agencies.

UTM services may cover two aspects:

- Public duties, like flight authorisation and the safe integration of drones into the existing airspace while considering other airspace users; and
- Other services related to drone operations, such as fleet management, flight software, and accounting.

While the price for services provided by a private operator should be charged competitively, some countries may wish for the price for public duties to be set by the regulator. In this case, UTM providers act like an ANSP in the airspace the drone is using and are not competing with respect to these minimum requirements. Any "race to the bottom" should be prevented.

Options for covering UTM costs

The costs for a future UTM could be covered in several ways, for example:

- Costs are borne by the users of drones or those who benefit from the use of drones.
- Costs are borne by regional or national governments, which see drones and the accompanying infrastructure wholly or partly as a public, socially desirable good.

The first option, where drone users or those who benefit from the service (e.g. a person who ordered a parcel delivered by a drone), will be the most likely in the near future. Nevertheless, for operations with a social aim, like transporting medical goods, governments could provide funding, perhaps via national health care systems.

Cost-recovery mechanisms

In terms of cost-recovery mechanisms, the key charging principles of transparency, consultation with users, non-discrimination and cost-relatedness (ICAO, 2012) provide a set of guiding principles, which have been developed and refined over decades of experience by regulators, service providers and users. The most relevant cost-recovery mechanisms which can also be applied to UTMs currently seem to be the following:

1. Non-recurring costs for infrastructure like operating sites and air traffic control (ATC) are borne by the providers, be they governments, private companies or a combination of both. The providers can recoup (part of) these costs by adding a supplement to user charges or, in the case of governments, taxes or fees. Fees can be levied for possession of drones (either a single payment when someone buys a drone or a yearly fee); if this is done, a drone registration system must also be set up. This registration system may in any case be necessary to allow ANS to identify drones and track down offenders. Different mechanisms for recovering the cost of providing infrastructure may be envisaged. The costs of setting up registration systems will have to be addressed and covered, depending on the governance model adopted for such infrastructure.
2. Recurring costs like providing handling and ANS can be borne by the users in the form of, for example, a rate based on flight time. They can also be borne by the government for certain classes of drones, if drones are seen as an essential public good or if the cost of collecting fees is not worth the effort. The latter can also be an argument for private service providers. It may be the case, for example, that recreational drones make so little use of UTM services that the provider decides to cover these costs via an increase in rates for professional users. When recurring costs are levied on users, this can be done on the basis of the number of flight movements, flight distance, duration of use of ANS services, maximum take-off weight of the drone, the number of ANS areas crossed during the flight, the type of service provided (e.g. ground handling). Drone operators can then choose whether to pass on the costs to their clients.

The above mechanisms are not substantially different from those used in manned aviation. The main issue may be the greater number and variety of users, with their variety of service and quality requirements and buying power. It may be wise to look at other mass consumption goods and services besides aviation when developing business models. Based on the above, key questions when developing business models are:

- Identification of recurring and non-recurring costs,
- Deciding to what extent to pass on costs to users (drone operators),
- Deciding whether to pass on non-recurring costs as a supplement to rates for recurring costs, and
- Deciding which criterion to use as a basis for rates (e.g. number of flight movements, distance).

For large drones to be fully integrated into the existing aviation system for international flights in a manner comparable to commercial airlines, existing practices serve as references. The traditional charging method for en-route services is based on aircraft weight and distance overflown, “or other commonly agreed distances” (ICAO, 2012). This has worked well for regular airline operations. However, it may be more challenging to apply this method to flights by unmanned aircraft, which often fly circular routes or do not follow direct tracks from A to B. In that case, charging would perhaps be better based on flight time and on airspace congestion.

What can policy makers do?

Unmanned Traffic Management (UTM) systems will be an essential part of the drone ecosystem. UTMs enable deconfliction of air traffic and real-time identification of drones in flight, and can identify the most efficient route for a given flight based on its origin and destination, weather, other air traffic, and a number of other factors.

In the future, UTMs may also become an important tool for managing the environmental impacts of drones (allowing flight planning to take into account restrictions on noise or visual disturbance) as well as equitable access to take-off and landing areas in areas of high demand. Regulators and policy makers around the world will need to work closely with industry and other stakeholders to establish performance-based standards for UTMs that are interoperable and interact with existing air traffic control systems.

Integration of drones into government policy

- Governments should ensure that the infrastructure required for drone deployment is resilient and should consider drone operations to be an integral element of all government policy.
- Governments should ensure that all drones are part of a UTM system that is able to communicate autonomously with air navigation service providers (ANSPs) that govern controlled airspace for manned aviation, as well as all UTM systems used by other drones. In order to ensure full interoperability between different ATM and UTM systems, UTMs "will require highly reliable and available communication, predictable and consistent navigation, and accessible and trusted surveillance" systems (Deloitte, 2019).

Cooperation and consultation processes for drone infrastructure

- Governments and industry should continue cooperating at the global level to develop operational solutions, regulatory standards and guidance for drone infrastructure, especially for UTM systems. They should also support the safe and co-ordinated implementation of aviation activities at very low altitude, particularly in urban and suburban environments.
- Governments should support the creation of specific consultation mechanisms for addressing the development, governance and funding of unmanned aviation infrastructure – convening different levels of government and industry stakeholders as appropriate, and taking into account national, regional and local characteristics. To facilitate public acceptance, new mechanisms should be defined, with city-level authorities involved in the decision-making.

Promotion of business opportunities associated with drones

- Governments may wish to take more proactive measures to develop unmanned aviation, such as funding research and development (R&D), supporting start-ups that develop new drones and applications, investing in drone infrastructure, and promoting the use of drones for commercial applications. Where applicable they might also act as "launch customers" (i.e. the first recipient of a new drone).
- Governments, when planning for infrastructure governance and financing, should take into account existing manned aviation best practices, but should also be aware of the economic and technical distinctiveness of the drone industry
- Governments should ensure that service providers apply management best practices and seek efficiency and cost-effectiveness in the provision of an appropriate quality of facilities and services.
- Governments should also take note of the emergence of large drones – as the applications for these aircraft, which have payloads upwards of hundreds of kilograms, have the potential for considerable economic growth and societal impacts.

- Governments should collect and share information regarding very-low-altitude operations, including on UTM systems. States, ANSPs and industry stakeholders should co-operate with a view to collecting and analysing relevant data regarding financial charging practices for existing unmanned aircraft flights.

Development of registration systems for drones

- As a matter of priority, governments should support the development of registration services that allow drone operators to register their drones. Such systems should also provide a query function allowing authorised stakeholders (e.g. regulators, police services) to request registration data.

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CHAPTER 6
Drones as part of the transport system

The emergence of drone technology offers an opportunity for a planned integration of this new mode of transport with existing modes, which can lead to better, more efficient, higher-quality transport services. By introducing drones into transport networks, they will increasingly interact with other modes of transport. This could unveil positive effects since drones may be complementary to other forms of transport if they offer a solution for currently unmet mobility needs, both for goods and people. In order to leverage the positive aspects of competition (such as the substitution of more-sustainable transport options through drones) while avoiding conflicts, it is important to review the context and ongoing developments of mobility systems.

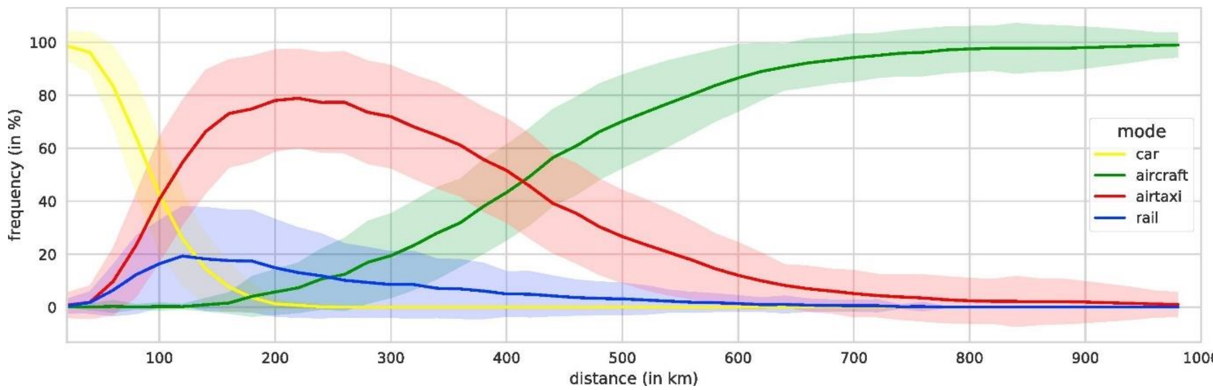
Existing relationships between transport modes

Improving the intermodality of urban transport and thus promoting public transport and non-motorised modes (walking and cycling) is an effective measure for tackling the challenges of congestion, low accessibility, climate change, high energy consumption, and poor local air quality while working towards more sustainable mobility (Cervero, 2013). Pourbaix (2011) projects that daily trips in urban areas by private cars will increase by 80% from 3.5 billion in 2005 to 6.2 billion in 2025, with a big share of this growth occurring in developing countries. According to Cervero (2013), fostering sustainable mobility in future will require a paradigm shift that compels a re-ordering of priorities to promote inherently resourceful forms of mobility, frames investments in more holistic (and less mobility-focused) terms, and – importantly –seizes opportunities to integrate transport infrastructure and urban development when and where they present themselves. The potential of drones in this respect lies in filling gaps that currently cannot be addressed by existing services due to technical or economic limitations. For instance, air travel is currently less available for domestic interurban journeys under 300 km (European Commission, 2016).

Transport modes operating in a similar market and level of service compete for customers, passengers and freight (Teodorovic and Janic, 2016) based on several factors such as travel costs and time, safety standards, comfort level, capacity, frequency and reliability of the service, and accessibility of the terminals (Prussi and Lonza, 2018). Fearnley et al. (2018) demonstrate that bus services compete with both rail on longer trips and light rail on shorter trips. Depending on the particular service and market, drone operations can attract passengers and/or cargo away from public transport, private cars, taxis and ride-share services, and to a lesser extent from traditional air travel, thus adding a new level of competition.

The estimated operation range for air taxis is illustrated in Figure 4, which shows they would mainly compete with cars on journeys of 80-130 km, with railway service on journeys of 130-220 km, and with aircraft on journeys of 220-340 km (Sun, Wandelt and Stumpf, 2018). Fostering transport interoperability and shifting away from modal split and competition to a system-wide transport solution can support the introduction of drones as a complementary mode.

Figure 4. Competition of transport modes as a function of travel distance



Source: Sun, Wandelt and Stumpf (2018).

To better plan the integration of drones into a transport system, one must consider the implications of its current evolution with respect to new services, such as on-demand mobility services. Ride-hailing services provided by companies such as Uber and Lyft have emerged as a strong option for urban transport of people. Their introduction has influenced people's mobility behaviour and their usage of other modes of transport, raising the question of how on-demand services either complement or act as a substitute for public transit (Hall, Palsson and Pricec, 2018). On the one hand, on-demand mobility services can be seen as competing with more sustainable transport modes, such as walking, cycling and public transit, by providing a higher level of comfort and efficiency (Rayle, Dai, and Chan, 2016). On the other hand, on-demand services can also increase the reach and flexibility of transit's fixed-route, fixed-schedule services and could help to meet the rising and evolving demands placed on the region's networks (Hazan et al., 2019).

The use of drones can also contribute to the increasing popularity of shared mobility, which includes services such as ride-sharing, bike and scooter sharing, and car sharing. While people have long prioritised ownership, millennials and younger generations are more willing to pay for access and have a preference for collaborative consumption that is also reflected in the growing shared economy (Hwang and Griffiths, 2017). This form of consumer behaviour is facilitated through ongoing digitalisation (Standing, Standing and Biermann, 2018). There are numerous drivers of sharing related to transport for participants and providers such as reduced costs, convenience, environmental friendliness, the appeal of engaging with non-traditional companies, and higher independence. There is potential to improve mobility as collaboration can reduce the number of vehicles on the road while decreasing congestion, demand for parking, and car ownership rates in cities (Santi et al., 2014).

Going forward, Mobility as a Service (MaaS) can offer added value through the use of smartphone applications to provide access to mobility, with a single payment channel instead of multiple ticketing and payment operations (MaaS Alliance, 2019). Drones and air taxis can be integrated into MaaS applications. In addition to the usage of drones as an on-demand, point-to-point service (similar to current ride-share services for cars), such integration will allow drones services to be combined with other modes of transport. This would allow the full range of drone service advantages to be achieved by supporting more flexible trips, filling transport gaps, and avoiding disjointed mobility chains (Roland Berger, 2018). The framework of MaaS can support the introduction of drone services as it creates a level playing field through the definition of mandatory standards for different operators to compete (Hensher et al., 2020). See Box 7 for an example of how Maas has helped integrate and improve mobility services in Helsinki.

Box 7. Mobility as a Service: The Helsinki example

Mobility as a Service (MaaS) is designed to provide riders with mobility solutions based on their personal travel needs at the exact time the service is needed. It is also possible to combine different modes of transport along a travel chain, and the mostly app-based services are convenient to book via smartphones.

For example, the start-up MaaS Global has developed the app Whim (https://whimapp.com). Whim is a meta-portal through which most of the mobility services in the greater Helsinki area can be booked via a smartphone. In addition to public transport, taxis, rental cars and bike-share operators are integrated within one app.

For route selection, all transport alternatives are displayed. After selecting their preferred choice, users can pay via the app; an internal algorithm determines the price of the available alternatives. In addition, various flat-rate payment models are offered via Whim.

The entire app is cloud-based. In Finland, all transport companies, taxi operators and car-sharing services are obliged to disclose relevant mobility data such as timetables and the real-time location of buses and available taxis. There is also an obligation for open programming interfaces to enable riders to purchase tickets or to make payment for trips through a single window.

Drone operators expect that one key factor driving a wide acceptance of drones or air-taxi services will be their integration into MaaS environments. This would enable drones to become part of multimodal journeys to get from point A to point B, while giving the user an experience that is as simple as taking a bus or booking a shared car (Karpowicz, 2018).

Potential impacts of integrating drones with other transport modes

The impact of drone operations on other transport modes depends on the specific setting, e.g. urban or rural transport, and competing transport modes along the intended route. The introduction of drones in the transport system could lead to conflicts with overall transport policy goals, including economic prosperity, environmental protection, climate impact, and equity. For instance, drones could replace other transport modes with a lower environmental impact or even increase flows of motorised individual traffic (for persons as well as for goods) instead of reducing traffic flows, as is the overall aim, especially in densely populated cities (Sun, Wandelt and Stumpf, 2018). For trips up to 35 km, where cars have a high modal share, passenger drones have higher energy consumption and GHG emissions than ground-based vehicles (Kasliwal et al., 2019). However, trips beyond 35 km, where drones are more sustainable than conventional cars, account for only a small fraction of total trips travelled on the ground, e.g. less than 15% of all vehicle trips in the United States (Oak Ridge National Laboratory, 2017). Passenger drones could allow cities to use their existing resources more efficiently by sharing and pooling trips (Martinez and Viegas, 2017), and by integrating them in MaaS applications (Kasliwal et al., 2019). Drones may be a part of a passenger's multimodal trip, executing the first/last mile of their journey and connecting them e.g. to transport hubs like airports or train stations. With the proper integration, passenger drones can serve as "feeders" to the "trunk" systems of mass transit while offering a congestion-free commute (Kasliwal et al., 2019).

Drones will likely compete with traditional air transport, for instance, in the application of domestic interurban journeys. For interurban operations, however, drones can also help to overcome poor integration between two separated urban mobility systems (e.g. traveling from Brooklyn to Jersey City in the New York area), thus adding value by mitigating weak spots in existing transport networks. Similar to the function of ferries that cross urban rivers, the use of drones to overfly waterways can be more advantageous in terms of time, and convenience and reduced infrastructural footprint (Whyte, 2020). For instance, a drone conveyed Covid-19 samples from Estonia's second-largest island, Hiiumaa, for testing in Tallinn (Threod Systems, 2020). Whereas a ferry journey would have taken over an hour, the drone accomplished it in 27 minutes.

Drones and the traditional aviation sector share some of the same capacity limitations, both in the air and on the ground. Until now, helicopters have distinguished themselves from airplanes by their flight flexibility and their ability for vertical take-off and landing. Drones not only have similar capabilities, but have the advantage of being smaller and are expected to be more cost effective. The future might see airlines incorporating drone services into their networks. Airlines already have experience and know-how in aircraft operations, safety management and logistics, which gives them a natural competitive advantage in adopting drones into their service portfolio and diversifying their businesses (PwC, 2016).

Data-driven planning methods for integrating drones into the transport system

Since it is expected that most drones will not be individually owned (Grandl et al., 2018), the strategic decisions for data collection, analysis and exchange should build on and align with regulation and standardisation developments of MaaS in general, as well as with automated driving. Digitalisation and data integration should be in the focus as they are the basis for efficient and safe interaction between modes and contribute towards seamless multimodal trips. U-space (SESAR, 2019) has also highlighted the importance of cooperation and exchange of data between the various service providers for multiple simultaneous drone operations in all classes of airspace. A digital infrastructure capable of exchanging data between drones and a UTM will be an important element of drones' safe integration into the air space.

Transportation planners should leverage data analytics and predictive models to better understand, for instance, which routes or mobility services can be more effectively covered or replaced by drones and where to invest in transport infrastructure. A recent example is presented by Rothfeld, Fu and Antoniou (2019) using the open-source multi-agent transport simulation tool MATSim (Horni, Nagel and Axhausen, 2016) to investigate future drone-usage scenarios in the Munich metropolitan region. The applicability of drones should be assessed within the larger mobility network to ensure interoperability and scalability, and should include the time required for drone-related passenger or parcel processing. Effective demand management can ensure that drones are restricted to a supporting role for more sustainable transport modes, and that coordination with air traffic management is feasible.

An early integration of drone transport into the design of MaaS services and platforms should be considered, as the development of drone-related services can benefit from the ability first to easily link to various modes of transport, and then to select the mode that is most optimal for the given situation. Embedding drone services into MaaS in advance of their wider introduction to the market could facilitate a more successful adoption. MaaS integration would allow drones to become part of a single-use platform providing universal access to modal options, payment, and relevant on-board trip information. Policy makers could also consider establishing a regulatory framework that requires passenger drone operators to disclose relevant mobility data (e.g. timetables and real-time location data) in order to share it with MaaS platforms. The regulatory framework should also address the payment channel and respective interfaces. The overarching goal of MaaS is the creation of a single window as a one-stop shop for riders.

Intermodal transport for seamless connectivity

Equitable access to drone mobility services should be provided for all users. This requires a reimagining of physical connections in the transport system to support seamless trips and transfers and standards for key last-mile delivery infrastructure (NASA, 2018). This may include adaptations to existing infrastructure, such as droneports on buildings and transport hubs (Airbus UAM, 2018; Airbus, 2020; Volocopter, 2018; Fairs, 2018) as well as the construction of new edifices such as drone hubs (Matternet, 2020; H^{3}Dynamics, 2020). Due to their small size and limited weight, drones could potentially be integrated into an existing mobility network and the broader built environment without causing a significant disruption (Thipphavong et al., 2018). Building on the concept of integrated, multi-modal networks, Choudhury et al. (2020) present a scalable framework for multi-drone delivery linked to a ground-based public transit network as temporary modes of transport to conserve energy and increase effective travel range.

Drones have the potential to improve connectivity between major transport hubs such as airports or train stations. For instance, Volocopter and Fraport are working towards linking existing urban transport junctions with one another to provide connections to and from Frankfurt Airport (Fraport, 2019). Careful consideration is required of air space integration and the location of strategic droneports at airports and at areas of interest such that they are easily accessible for travellers (Roland Berger, 2018). An initial focus on incorporating drone services into existing infrastructure could lower obstacles to implementation, allowing for pilot programmes that can be studied for impacts. In particular, integrating drones into existing transfer hubs could facilitate their inclusion into the broader mobility network, expanding travel options and providing passengers with seamless connections (Roland Berger, 2018). Adding drones to the suite of mobility options offered at existing transport hubs may also reduce environmental impacts, reducing the need to build new, separate drone facilities. At-grade, or ground-level, drone infrastructure will ideally require limited modifications to the transport stations and stops in already existing in networks. However, this depends to a high amount on the future requirements for drone landing areas as well as the amount of drone operations. The addition of droneports to existing infrastructure not related to transport could reorient foot traffic and increase pressure on nearby mobility options. Properly co-ordinated in a user-centred planning process (Nisenson, 2017), these ports could be strategically placed to encourage the distribution of mobility activity more evenly around a city.

With any addition of drone access to existing infrastructure, changes must be made to enable passengers to enter and exit the building in a timely manner. A tight transfer link between metro and drone is not beneficial to mobility users if they cannot afford the latter. Both physical and financial accessibility must be addressed in order to reap the benefits of drone integration, including a higher dispersal of ridership across modes that reduces congestion. Without this stipulation, drone fleets may be benefiting from public transport infrastructure without serving public transport users.

Wait times for passenger journeys and in logistics supply chains are another concern (Deutsche Bahn, 2019). Times between trips may be longer for drones than for other modes of transport, especially at first when fleet sizes are small and on/off-boarding processes are in flux. But with time to learn from pilot programmes and with sufficient competition, urban air mobility via drone may become more viable and accessible. Accurate time synchronisation of drone departures and arrivals by fleet managers or artificial intelligence (AI) based systems will be critical in order to meet demand and establish dependability (UNECE, 2009).

The potential impacts of drones on existing mobility ecosystems

The impact of drones on mobility will be largely determined by the nature of public sector involvement in their development and deployment. Given the investments already made in drones by the private sector, regulators have an opportunity to harness that excitement by encouraging drones to be deployed in use cases that address shortcomings in current mobility networks and serve broader policy goals. Policymakers can also use their regulatory tools to promote interoperability between existing mobility options and drones, as discussed in the context of Mobility as a Service (MaaS) platforms.

Alternatively, a laissez-faire regulatory approach to drone integration could lead to chaotic and inequitable results that are bad for both the drone industry and mobility sector at large.

Without efforts at integration shepherded by the public sector, the drone industry might develop isolated from other mobility modes. This could result in a failure to plug gaps in the transport ecosystem that would contribute to broader sustainable transport goals, instead providing a service that caters exclusively to the affluent. This type of issue has already emerged for the urban helicopter industry in New York. Mobility firms Uber and Blade charge around USD 195 for direct helicopter flights between Manhattan and John F. Kennedy Airport, and up to USD 1 400 for flights to the remote wealthy enclave of Southampton (Barron, 2019). City authorities have been inundated with official helicopter noise complaints, which rose from 1 309 in all of 2018 to 2 602 from January to November 2019. The scrutiny has prompted several US Congress members representing New York City to propose a ban on non-essential helicopter use in the city, which is supported by the mayor and several local officials (Dorn, 2019). While some externalities from increased air traffic are to be expected no matter what, drones may be more tolerable for average citizens if they also provide improved mobility services for all. Regulators can enforce certain routes on drones in order to minimise quality-of-life disturbances, but indirect routes may lengthen travel time and raise costs, which may undermine the potential benefits of drone service from the outset.

By engaging with the quickly growing drone industry and setting certain legal parameters, policy makers can encourage drone developers to bring novel solutions to mobility problems that cannot be found in other modes of transport. Instead of overregulating drone use based on technological specifications that restrict innovation, officials can adopt performance-based standards that restrict noise levels, flight patterns, operation times and fuel sources. A version of this type of performance-based regulatory framework for drones has been implemented in Rwanda (WEF, 2019).

There is also the risk of “induced demand”, where the option of using drones for delivery or short-range travel leads to more drone trips but not less ground transport trips. For example, if a commuter who would normally take a ride-share service to the airport instead opts for a passenger drone, the other ride-share user who cannot afford a drone ride may still take the car trip. This change leads to an additional drone trip, but does not decrease the number of cars on the road. Similarly, more-efficient drone technology leading to savings in energy, cost or traffic space bears the risk of rebound effects, i.e. inducing additional parcel and passenger transport (Kellermann, Biehle, and Fischer., 2020), which has to be accounted for during policy making.

Mobility sector research should therefore conduct detailed quantitative analyses of existing mobility networks before developing data-driven approaches to drone deployment and integration. Likewise, transport authorities should approach drone regulation by first establishing the mobility sector’s needs and priorities from the public sector perspective, then exploring how drones can support them. Collectively, this research may produce detailed insights into the cause-and-effect relationships between investments and impact, in order to inform how a city should invest in improving its transport system. Decision-making must be able to rely on defined key performance indicators (KPIs) that directly reflect transport sector concerns such as congestion, externalities, modal share and energy consumption. These impact assessments should also take into account local contexts pertaining to geography, culture, existing infrastructure, and political climate.

Regulations and exchange

Successful drone regulation will likely require some basic universal guidelines at an international level, which can be expanded on as seen fit by governments at the national, regional, and local levels. More-specific regulation will be most effective when grounded in research that explores the local context in order to identify mobility and broader societal needs where drones can best contribute. Basic international drone standards, including technical standardisation mutually beneficial to all governments, might include a taxonomy of drones by weight, size and use; universal design for chargers, batteries and docks; and data systems that ensure interoperability between different fleets and networks (especially across borders) and avoid monopolies.

At the national and subnational levels, regulation might focus on registration, geofencing, punitive measures for rogue drone use, and clear restrictions on authorised use. Registries can be established to ban drone activity in certain areas, including military bases, airports, schools and parks. This registry would ideally include machine-readable GPS data that is interoperable with drone operation, to automatically enforce geofencing. An emergency response plan that also defines the responsibilities, relevant stakeholders, and protocols for drone operators and potential victims can also ensure proper preparedness in case of accidents.

As discussed in the previous section, performance-based drone regulation may be the best way to prevent intrusive uses while permitting innovation. Regulation that specifies the volume, size, flight altitude and parameters, and use of drones can ensure that citizens' concerns are respected while still allowing companies adequate freedom to experiment without restrictions on technology or equipment. However, as the concepts of MaaS and combined mobility modes continue to gain traction in both the public and private sectors, regulators can additionally require emerging modes like drones to provide semi-open data in order to guarantee interoperability. As shown in Box 7. Mobility as a Service: The Helsinki example

7 earlier in this chapter, Finland has implemented such a regulation to ensure basic interoperability between all transport modes in the country. Decisions for data collection, analysis, exchange should build on and align with regulation and standardisation developments such as MaaS.

Another new mobility technology to emerge in the MaaS era, the electric scooter, has provoked a similar regulatory requirement for data-sharing and fleet monitoring. Initiated by the Los Angeles Department of Transportation (LADOT) in 2018 in response to the influx of shared e-scooters on their streets, Mobility Data Specification (MDS) has now been adopted by over 80 cities around the world. MDS establishes a data standard that legally requires data interoperability between mobility operators and regulators via open application programming interfaces (APIs) (GitHub, 2020; Zipper, 2019; LADOT, 2018). This not only grants regulators access to information on mobility fleet location and performance, but empowers them to adjust and update mobility policy based on concrete data. By increasing their visibility into mobility trends, policy makers can identify dangerous traffic zones, target certain areas for protected lanes and parking, implement geofencing, and more. Establishing an MDS-type requirement is foundational for regulators who want to ensure that innovative mobility solutions serve the needs of the city as a whole. Though the impetus for MDS was the e-scooter, it has been designed in anticipation of the need to incorporate other modes, including drones (Pyzyk, 2019).

The sudden proliferation of dockless shared e-scooters around the world in 2018 can help inform regulators on how to approach drones for another reason. Authorities were caught off guard by the overnight emergence of e-scooters on their streets and sidewalks, and were forced to scramble to understand their benefits and risks. Some cities have sought to understand them as supportive of MaaS-style alternatives to private car use, allowing them to operate within minimal regulatory parameters, while other cities like New York have banned them completely (O'Kane, 2019).

What can policy makers do?

Instead of waiting for the drone industry to go into overdrive and inundate some regions overnight, policy makers at all levels should be proactive about integrating drones into the wider transport system and shaping respective regulation. More specifically, policy makers should:

- **Establish the mobility sector's needs and priorities** from the public sector perspective, and then explore how drones can support them. This could be done **by leveraging data analytics and predictive models** to assess, for instance, which mobility service gaps may be covered by drones, or which services can be more effectively carried out by drones. Such assessments will also help identify where investments in transport infrastructure are required.
- **Ensure the interoperability and scalability of drones within the larger mobility network**. This may include
    - Establishing a **concept for droneports** on/at intermodal hubs, on relevant buildings within the city environment and in suburban areas, while ensuring interoperability for different operators and suitable access for users;
    - Considering a regulatory framework that requires passenger drone operators to **disclose relevant mobility data** to share it with MaaS platforms;
    - Developing integrated policies that facilitate **coordination and coherent decision making** where multiple agencies are involved.
- **Ensure consumers and non-consumers** (e.g. pedestrians, property owners) **are protected** and have fair access to the market. This may include:
    - Establishing regulations for geofencing, punitive measures for rogue drone use, and restrictions on authorised use to **ensure protection of sensitive areas** and to **hold drone users accountable**; and
    - **Developing procedures and defining responsibilities**, relevant stakeholders, and protocols for drone operators **in case of accidents**.
- Adopt **performance-based standards i**nstead of overregulating drone use based on technological specifications that restrict innovation.
- Conduct small-scale drone **pilot programmes** where both public and private sectors participate.

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Ready for Take-Off? Integrating Drones into the Transport System

This report presents policy options for the successful integration of drones into the transport system. How can countries reap the benefits of drone transport while limiting risks? The report examines concerns about the acceptability, efficiency and sustainability of drone transport. The analysis covers passenger and freight drones with different payloads and ranges, and also addresses other drone uses that support the transport sector.

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