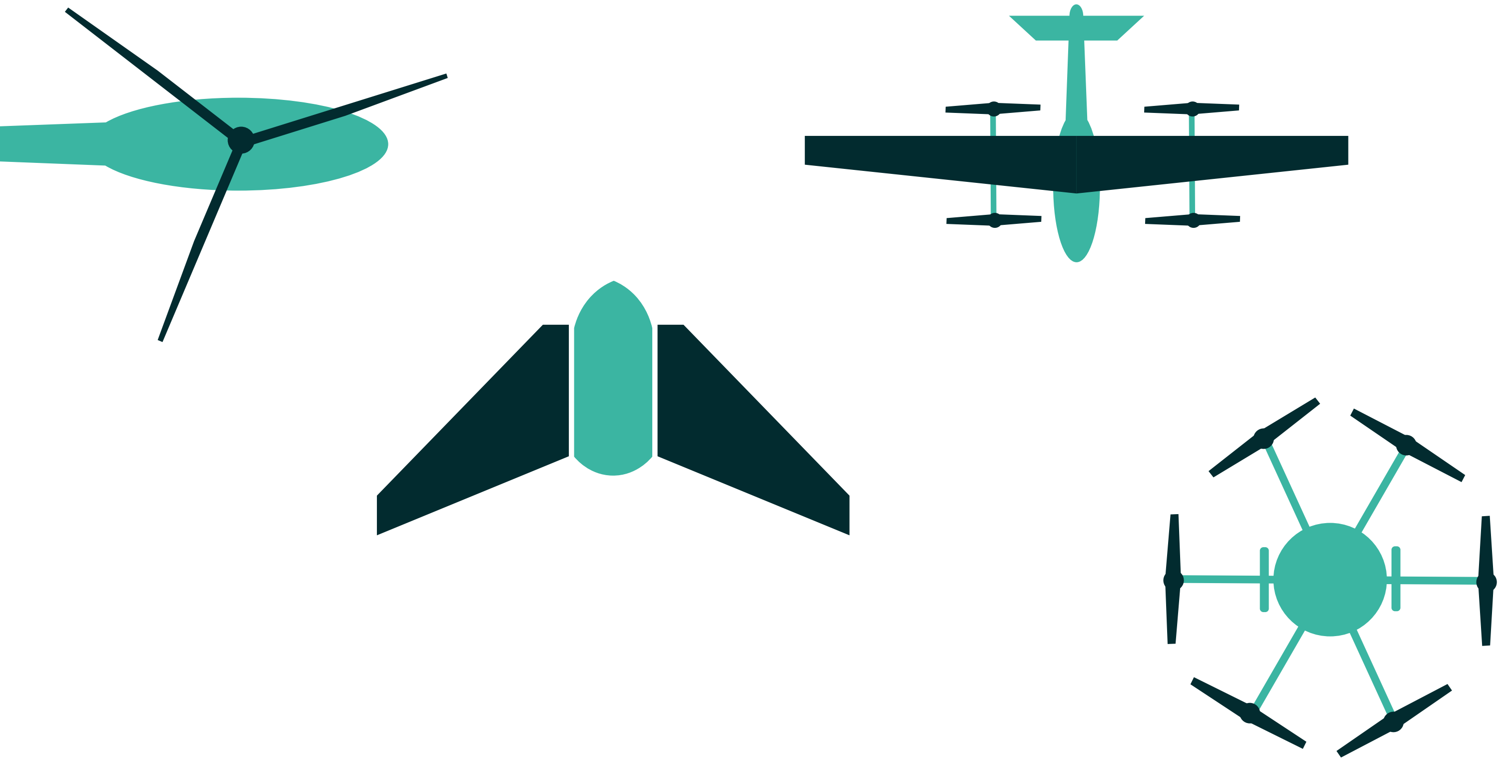
flyinghigh



Use cases for drones in your city

Introductory pack

VERSION 1.0.1 6 DECEMBER 2017

nesta

Innovate UK

This **Introductory pack** is aimed at cities interested in taking part in the **Flying High Challenge**.

Its aim is to map out potential applications for drones in urban contexts and provide a range of use cases and examples as inspiration. For each application, we have also tried to outline key considerations and implications for developing such a drone system in an urban environment.

We're keen to explore together the potential opportunities, benefits, challenges and risks that drone systems may bring to cities. But we're also aware that implementing these systems in a valuable, safe and sustainable way will require work and collaborations. That's why the Flying High Challenge will convene city leaders, regulators, public services, businesses and industry around the future of drones in cities.

Use this Introductory Pack as a guide to help you identify exciting use cases or as a way to think through some of the challenges of implementing drone systems in your city.

Contents

Definitions

Drone, UAV, UAS? What are they, how do we categorise them and which ones are we talking about?

What is a drone?

A drone, technically known as an **unmanned aerial vehicle** (UAV), is an aircraft without a human pilot on board. Drones are a component of an **unmanned aircraft system** (UAS); these include a drone, a ground-based operator and a system of communications between the two. Drones can operate with different degrees of autonomy. Some are remote controlled by a human operator, while others can operate autonomously.

Drones can have many different applications. A distinction is made by the Civil Aviation Authority (CAA) between **recreational** drones and **commercial** drones. While the first category refers to individuals using drones for entertainment or as a hobby, the latter refers to cases where the use of a drone can either generate a public service or good, or an economic benefit or other valuable consideration for the operator.

For recreational drones, UK regulation states that drones have to always be kept within line of sight while flying. They can't be flown above 400ft, and they have to be at least 150ft away from people and properties, and 500ft away from crowds and built up areas (see more at Drone Safe UK).

Most of the same rules apply for commercial drones, but exemptions can be made depending on the intended use of the drone. To operate a drone commercially, operators need a Permission for Commercial Operation from the CAA (more here).

Acronyms

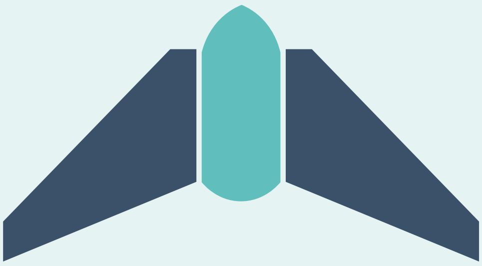
ADS–B	Automatic Dependent Surveillance – Broadcast
ATC	Air Traffic Control
BVLOS	Beyond Visual Line of Sight
CAA	Civil Aviation Authority (UK)
D-NAS	Digital Notice and Awareness System
FAA	Federal Aviation Administration (US)
NATS	National Air Traffic Services
SAA	Sense And Avoid technologies
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UTM	Unmanned Aircraft System Traffic Management
VTOL	Vertical Take-off and Landing

Types of drones

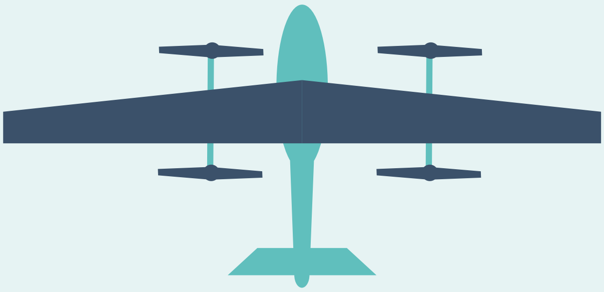
Drones can be categorised in multiple ways. We present here a taxonomy according to lift method and size.

Drones by lift method

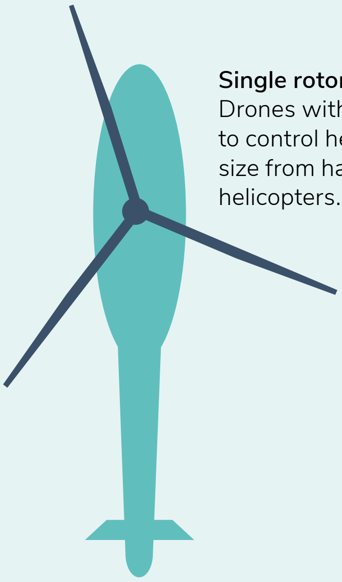
The lift method of a drone will have an impact on the types of use cases it is well suited to carry out. For example, fixed wing drones can cover longer distances than multi-rotors because they only need to use energy to move forward, not hold themselves up in the air. Multi-rotors, on the other hand, offer a much greater control over position and can operate in confined areas. Some hybrid models also exist.



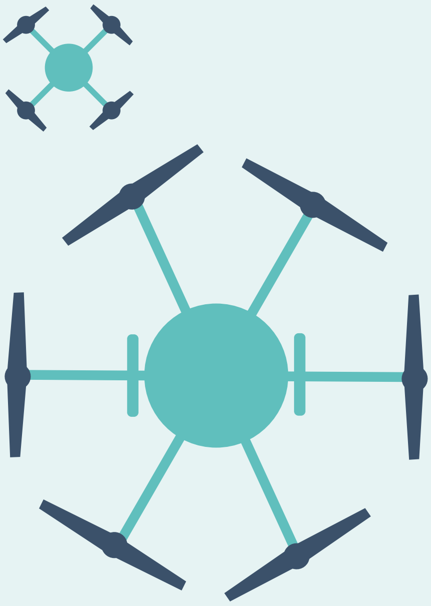
Fixed wing
Drones that use aeroplane-like wings to provide lift rather than vertical lift rotors.



Fixed-wing hybrid VTOL
Drones that mix fixed-wing capabilities with the ability to vertically take off and land.



Single rotor
Drones with a single rotor, plus a tail rotor to control heading. These can range in size from hand-held drones to unmanned helicopters.

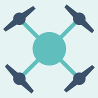


Multi-rotor or multi-copter
Drones with multiple rotors. **Quadcopters** (drones with 4 rotors) are the most popular.

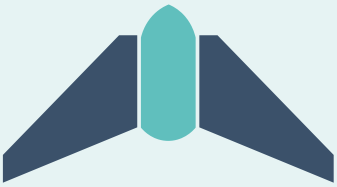
Drones by size

Drones come in a wide variety of shapes and sizes. There is no agreed convention for categorising drones according to their size, but their dimensions will have an impact on regulation (e.g. whether you have to register it or not) and their possible applications.

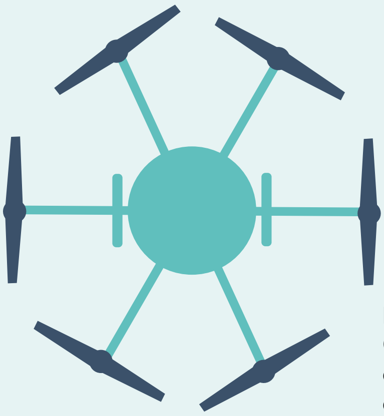
Micro
Drones that can fit in the palm of your hand. Used mostly indoors for recreational purposes.



Small
Drones between 50 and 100 cm. Mostly used for photography or filming.



Medium
Drones usually double the size of small drones. Commercial drones able to carry professional sensors and cameras, as well as small parcels.



Large
Commercial drones able to carry larger and heavier cargo & complex equipment.

Supersize
Drones able to carry people or heavy cargo.

Systems approach

Drones as part of an urban setting

Multiple drones, simultaneous operation

The ambition of the Flying High Challenge is to encourage thinking around future **drone systems** where multiple drones carrying out tasks would be operating at the same time. To this aim, the **applications** and **use cases** presented in this document represent a starting point. As part of the Flying High Challenge, you will be invited to embark on a strategic visioning and public engagement exercise to explore if and how drones can operate in your city.

We would like you to start thinking about potential use cases that would be suitable for your cities. What problems would drones be solving in these cases? What priorities can drones help you meet in your city?

In addition to the use cases, it is important to think about what kind of drone system you would like to establish in your city. The envisioned drone system will have implications, and likely constraints, on which use cases are viable, how they might operate, and under what conditions.

You might find it helpful to think about what contextual constraints may impact on the type of system you would like to develop, and what that might mean for your identified use cases.

System constraints

—

Which contextual constraints may impact on the type of system you would like to develop? What that might mean for your identified use cases?

Place
Are there existing transport corridors that drones could fly along? Is the city densely built up or are there open areas (such as parks or rivers) that drones could preferentially fly over? Is there an airport within the city limits that would impact on drone operation?

People and attitudes
Are there major local employers or public services that are enthusiastic about drones? What are the attitudes of local people? What will local attitudes to noise pollution be? What are local attitudes about drones flying over residential areas?

Technological
Does the city have extensive communications infrastructure? Does it have a plan for rollout of next generation mobile or data networks?

Legal and economic enablers
Is the city council or local economic policy supportive of relevant businesses? Will fast-track planning regulations be put in place for drone infrastructure? Are there any bylaws that affect the rollout of drones?

Identifying conflicts

—

Understanding these contextual constraints can help you identify whether there is a conflict between a desired use case and a desired overall drone system.

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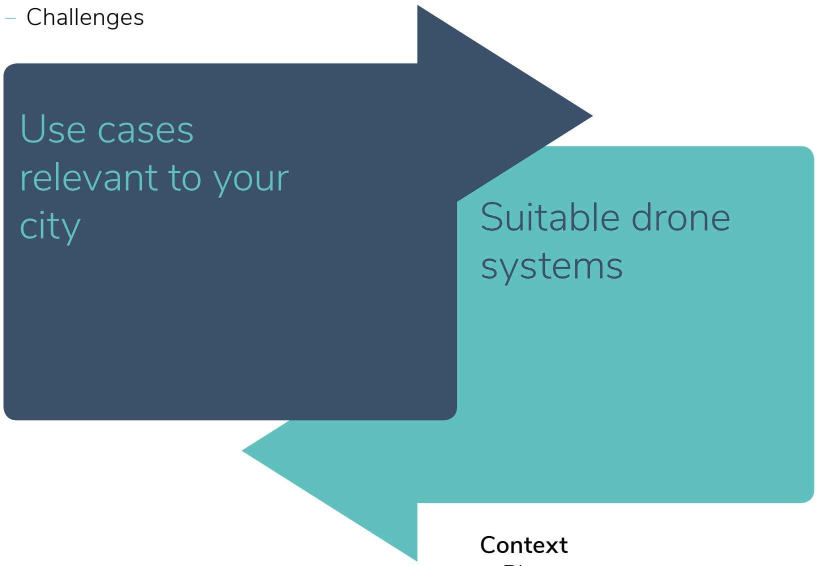
City
- Vision
- Priorities
- Challenges



Context
- Place
- People & attitudes
- Technology
- Legal & economic enablers

Use cases and the overall drone system need to be considered together. Relevance of use cases will depend on city vision, priorities and unique challenges. Drone system suitability will depend on place, people and attitudes, available technologies, and legal as well as economic enablers. The two areas of exploration are mutually informing.

Applications

What can drones do?

Commercial drones can carry out a number of different tasks in urban settings. We propose here a breakdown of these into five high-level applications: **monitor**, **inspect**, **deliver goods**, **transport peopl**e, and **intervene**.

Each of these applications will have different implications on the technical capabilities of the drone, privacy and safety, regulation around its operation, and on the overall drone system.

Because of the diversity of tasks even within these high-level applications, we have further broken these down into specific ones.

Each specific application page includes a list of potential use cases and a couple of examples of drones being used around the world. At the bottom of each page we have also tried to highlight three priority areas for consideration.

Applications

Applications of commercial drones have been grouped into five categories. An overview of these categories is provided here. More detailed information is provided in the page-long profiles of each category and each application that follow this overview.

1. MONITOR

–

Continuous scanning or assessment of a defined area looking for live changes.

This includes tracking environmental changes such as air pollution or weather patterns, monitoring flowing crowds at an event or cars in traffic, all the way to looking for individual missing people.

Drones carrying out such tasks will have to hover for long periods of time, use a variety of complex sensors to collect data and be safe to operate over crowded or residential areas.

Advantages of using drones to monitor include the ability to collect higher quality data from otherwise inaccessible locations, reduced cost relative to other methods such as helicopters, and faster response times in emergency situations.

2. INSPECT

–

Assess a discrete physical object, area, or system to evaluate its current state.

This includes inspecting discrete objects such as bridges, tall buildings or confined and compromised structures, as well as linear systems such as railway tracks, roads or sewers.

Drones carrying out such tasks will have to accurately scan large surfaces, avoid accidents while flying very close to critical infrastructure, and ideally fly and detect faults in structures without human input.

Advantages of using drones to inspect include reduced risk for personnel working in hazardous environments, earlier detection of potentially dangerous faults, and the ability to inspect confined and otherwise inaccessible areas.

3. DELIVER GOODS

–

Collect, transport, and deliver goods from origin to destination.

This includes deliveries between two hubs, such as organ deliveries between two hospitals, deliveries from a hub such as a warehouse to individual homes, or using drones to deliver packages between two variable locations such as from one home or office to another.

We have made this distinction between fixed hubs and variable locations as this will have a significant impact on the required infrastructure, route planning, frequency of deliveries, and overall number of drones on a route.

Delivery drones will have to autonomously plan flight paths to their destination, dynamically avoid obstacles during flight, take-off and landing, and be capable of safely carrying payloads of different weights and sizes.

Advantages of using drones for the delivery of goods include reduced traffic congestion and pollution in city centres, faster delivery times for consumers, and a reduced cost of the ‘last mile’ for delivery companies.

4. TRANSPORT PEOPLE
–
Transport passengers from one location to another.

This includes transporting people between fixed hubs (e.g. stations), transporting them from a hub to a variable location, or taxi-like deliveries where drones can pick up people at a variable location and drop them off at another. The pick-up and drop off locations will have huge implications on required infrastructure, route planning, security, and regulation.

For passenger-carrying drones the safety of passengers and people on the ground will be paramount. The infrastructure around the drones will have to be carefully designed and integrated within existing urban systems; this will include take-off and landing infrastructure, as well as servicing and maintenance points. To enable their integration in cities, drones will have to keep noise pollution to a minimum.

Advantages of using drones to transport people include reduced congestion on city roads, improved mobility of people around a city, and reduced strain on existing public transport networks.

5. INTERVENE
–
Interact with an object or person in an attempt to improve or support their current state.

This includes drones performing repairs on infrastructure, removing debris that might be causing problems, or supporting existing services to improve speed and capacity.

Drones carrying out such tasks will have to have the flexibility and ability to perform complex tasks, the strength to carry heavy payloads, and will likely require a high battery life.

Advantages of using drones that can intervene include an extension of capabilities and services and a greater flexibility of carrying out tasks in confined or dangerous locations. It can also shorten response times, and lower the risk for staff who would otherwise have to carry out their activities in hazardous environments.

\+ EMERGENCY SITUATIONS

Drones can be incredibly valuable in emergency situations.

Relevant emergency use cases are included in each of the above applications – these are marked with the icon !. However, emergency drones will require extra considerations, in addition to those required by drones in respective applications. These additional considerations are highlighted as a separate section ("Emergency situations" on page 32).

\+ MULTIFUNCTIONAL DRONES

Focusing on discrete applications of drones makes early conversations about their implications more manageable. But, in reality, it's very likely that individual drones will carry out multiple applications. For example, a single drone might inspect a road for potholes or a bridge for cracks, be able to assess levels of risk, and then repair the most critical issues.

This multifunctionality can have a number of advantages, one of the most interesting ones being a cheaper and quicker way to carry out prevention works and thus avoid costly or disruptive interventions when it's too late. This final section ("Multifunctional drones" on page 34) highlights some of the implications of integrating multifunctional drones in a wider system.

Considerations

Each drone application and use case will present different challenges. It's important to understand these from the onset, as well as their implications on an overarching drone system. To offer a starting point for informed conversations around key considerations, we have broken these down in six categories.

Functionality	Are currently available drones capable of performing the chosen application? What advances in technology would be required for a drone to complete it? What would be the implications of additional sensors or being able to deliver a sensitive package? What would that mean for power capabilities or flight duration?
Safety	What are the risks of drones causing injury to people or damage to property? How can that risk be reduced? How to make sure that effective emergency protocols are put in place? Who will be liable for injuries or damage caused by drones?
Security	How to ensure drone security, as well as the security of the data it collects? How to protect drones being used for sensitive or critical tasks? How will citizens be protected from illegal use of drones in city skies? How will unauthorized drone access to restricted areas such as airports be prevented?
Privacy	How will citizens' right to privacy be protected? How will you ensure drone noise doesn't disturb residents? Will your drones have the right to fly above private land? Where will you build the infrastructure you need to introduce drones to your city?
Scalability	What will the drone system look like when a particular use case is scaled up? Will the system need to support 10s of drones, 100s, or 1000s? What are the implications of this on regulation or on the required infrastructure? Are there economic or practical limitations on how many or how few drones can be employed?
System integration	How will drones interact with a wider system of drones operating in your city, all performing different tasks? What are the implications on traffic control and who will enforce the law in crowded skies? Will drones on urgent missions have priority over others? How will a system containing thousands of drones function with minimal human input?

▸ While all of these aspects are important to consider, some will be more relevant for some applications rather than others. That is why, for each specific application, we have highlighted the most important three aspects to consider.

1. Monitor

Continuous scanning or assessment of a defined area looking for live changes

Benefits

- Inform and support decision-making
- Quicker response times
- Lower costs of gathering useful data
- Reduce risk to personnel
- Increase citizen safety
- Improve public services
- Maintain the environment

Considerations

There are six categories of key considerations, including functionality, privacy, safety, scalability, security, and system integration. The most critical considerations for the monitor application are:

Functionality

System integration

Safety

1.1 MONITOR ENVIRONMENTS

Monitor changes to the urban or natural environment in a given area over time

- Kent Fire and Rescue Service lent their drone to the London Fire Brigade to assist them in monitoring the damage of the Grenfell Tower fire.
- Imperial College's 'flying fish' drone can cheaply and quickly collect water samples from rivers, seas and reservoirs.
- In 2016, around 12% of construction firms across the UK used drone technology to monitor their construction sites.

Use cases

—

How can drones help in your city?

Environment management
- Measuring air pollution
- Measuring water pollution (rivers & seas)
- Analysing flue gases from power stations
- Weather monitoring

Parks
- Detecting changes in wildlife populations
- Identifying landscape changes

Industry
- Tracking building progress on construction sites

Fire brigade
- Mapping fires and floods
- Monitor firefighters during hazardous missions

Considerations

Functionality
Drones used for monitoring the environment will likely require long hovering times and carefully chosen sensors to maximise their capacity to collect meaningful data. How will enough power be provided to the drones to make sure they can effectively collect data? Which sensors will be required to monitor your environment? How much data should be collected?

System integration
Longer term monitoring projects would benefit from work to minimise the demands on human operators. Autonomous flight as well as BVLOS are options to increase the capacity for drones to regularly collect environmental data. How could you design systems that allow many drones to work together to collect data for extended periods?

Safety
Whether a drone is monitoring a natural or an urban environment they will likely be operating around people. How to develop failsafe mechanisms to avoid crashes? How can flight paths and flight times be designed to minimise risk?

1.2 MONITOR FLOWS

Analyse the movement of people or objects in a defined space

- West Midlands Police are using drones to watch for disturbances in crowds leaving football games.
- In Mumbai, traffic monitoring drones helped investigate a rise in accidents on particularly dangerous stretches of motorway.
- Busan Port in Korea uses drones to police monitor shipping lanes for illegally anchored vessels.

Use cases

—

How can drones help in your city?

Transport
- Monitoring traffic flows and road usage
- Monitoring shipping lanes in ports

Media & sport
- Monitoring crowds at events including games and music festivals

Industry
- Ensuring health & safety on construction sites

Police
- Monitoring crowds following attacks/disasters
- Aiding emergency evacuations

Considerations

Safety
Drones that are monitoring the movement of people will require safety features that monitor their own system health and power levels and respond appropriately if there are any issues. In the event of emergencies, safeguards should be designed that allow for a controlled emergency landing, away from people.

Functionality
Monitoring crowds will require long-term stable hover capabilities coupled with suitable cameras. How can technologies be improved to enable sufficient flight time for sustained monitoring? Event monitoring may require drones to fly in challenging weather conditions. How can the tolerance be increased for poor weather? Reducing demand on human pilots to fly drones, freeing them to focus on interpreting video information will improve the ability to monitor flows. How can automation or dual control be employed to assist operators?

Security
The presence of authorized drones above crowds may make it harder to quickly detect rogue or unauthorized drones. How can security systems rapidly detect unauthorised drone flights? Crowd monitoring drones will also require resistance to hacking or disabling. How can software systems be designed so that attempts to hack or disable are not able to put people at risk?

1.3 MONITOR INDIVIDUALS

Search an area for the presence of an individual, or follow single individuals as they move through an area

- Devon and Cornwall police are now using drones regularly to search for missing persons and patrol restricted areas for intruders.
- Merseyside Police have used a drone to monitor a series of drugs raids around Liverpool and track stolen cars.

Use cases

—

How can drones help in your city?

Fire Brigade
- Search & rescue of missing persons either in open spaces (e.g. at sea) or in compromised structures (e.g. in a collapsed building)

Ambulance
- Remote sensing of vital signs to support paramedics prioritise casualties

Police
- Finding and following suspects
- Monitoring active operations

Security
- Detecting trespassers

Considerations

Privacy
There are major public concerns around monitoring the public by air, particularly if people's faces can be recognised or if drones are not visible to those being observed. How can the public be consulted to understand opinion on how and where individual monitoring can be applied? What restrictions will be necessary on the criteria for who can be monitored? What data protection systems should be developed or repurposed to ensure appropriate use and storage of data?

System integration
Following individuals will require drones that are able to move in unpredictable flight paths, likely using priority paths. Individual monitoring drones will also require increased awareness of the flight paths of other drones to avoid collisions. In the case of sensitive operations, flying BVLOS to avoid detection might be required.

Security
In some cases individual monitoring may be conducted by the police on vulnerable people and in sensitive circumstances. How can data be secured to protect live operations, as well as those people being monitored? Additionally the circumstances in which individual monitoring is permissible will require careful legal consideration. Who should be authorised to conduct this type of monitoring?

2. Inspect

Assess a discrete physical object, area, or system to evaluate its current state

Benefits

- Reduce risk to personnel in hazardous environments (e.g. at height, inside damaged buildings, inside pipelines, sewers, or over water)
- Reduce inspection costs
- Speed up inspection times
- Inspect more regularly to find faults before they develop
- Inspect more closely/in hard-to-reach areas that might otherwise be neglected

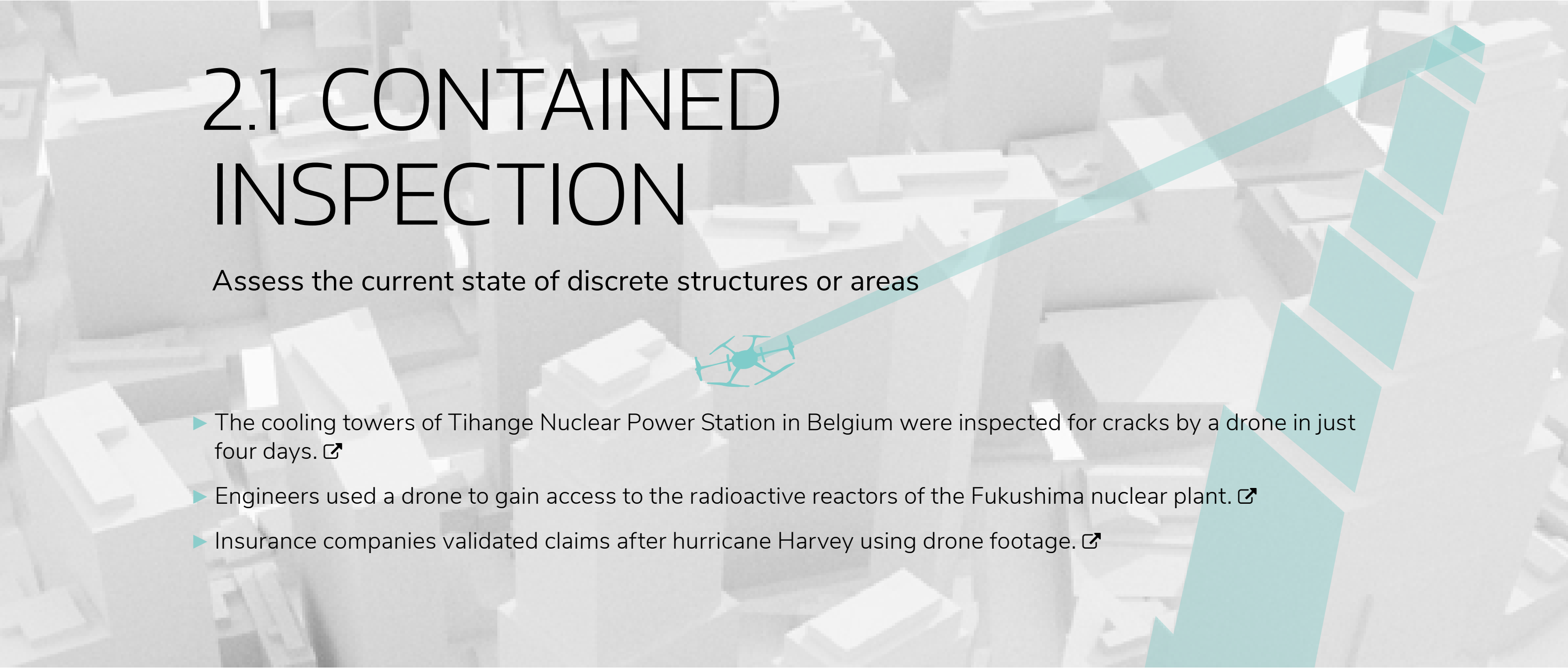
Considerations

There are six categories of key considerations, including functionality, privacy, safety, scalability, security, and system integration. The most critical considerations for the inspect application are:

System integration

Functionality

Safety



2.1 CONTAINED INSPECTION

Assess the current state of discrete structures or areas

- The cooling towers of Tihange Nuclear Power Station in Belgium were inspected for cracks by a drone in just four days.
- Engineers used a drone to gain access to the radioactive reactors of the Fukushima nuclear plant.
- Insurance companies validated claims after hurricane Harvey using drone footage.

Use cases

—

How can drones help in your city?

Transport
- Inspecting bridges for cracks or corrosion
- Inspecting planes in airports

Energy
- Inspecting wind turbines
- Inspecting in hazardous environments (e.g. inside nuclear power plants, electrical substations)

Construction
- Inspecting cranes
- Inspecting tall buildings
- Urban planning

Fraud detection
- Validating insurance claims for property after a disaster
- Checking planning applications

Fire brigade
- Mapping inside compromised structures
- Mapping inside burning/ smoke filled buildings

Police
- Photographing crime scenes
- Inspecting traffic accidents

Considerations

Functionality

Inspecting structures involves precise, controlled flight, in particular for internal, confined spaces. How can the pressure on highly skilled pilots be lessened? Could autonomous flight or increased camera and sensor capability help alleviate this? How can drones be optimised to be capable of flying in adverse conditions or in hazardous environments?

System integration

Current regulation make it difficult to carry out inner-city inspection activities due to the proximity to other buildings. How can regulation enable effective and safe infrastructure inspections in cities?.

Safety

Inspecting drones are required to fly in close proximity to gather meaningful data on structures. Therefore the risk of collision is comparatively high. How can safeguards and emergency protocols be developed that minimise the consequence of any impact? Self-monitoring health and safe emergency landings, will be necessary steps towards this goal.

2.2 LINEAR INSPECTION

Assess a system or network of objects to evaluate its current state and identify changes

- Network Rail is using drones to survey railway tracks for regular maintenance or following incidents.
- The national grid has begun monitoring the UK's electricity network and gas pipelines using drones.
- Water providers in Barcelona are to begin using drones to inspect and maintain sewers.

Use cases

—

How can drones help in your city?

Transport
- Inspecting railway tracks
- Finding and reviewing potholes in roads
- Inspecting progress on roadworks

Water
- Inspecting inside sewers

Energy
- Inspecting power lines for debris or damage
- Inspecting interior or exterior of oil/gas pipelines

Fire brigade
- Inspecting flood control waterways

Considerations

System integration
Linear networks such as power lines and railways are spread over large geographical areas. How can BVLOS flight be regulated and integrated to allow for inspecting full networks? The flight path of these drones can be anticipated beforehand. How can this knowledge be used to ensure that these drones run efficiently?

Scalability
Scanning large networks will likely require a large number of drones. What considerations may be needed to allow for high quality information capture? How should trade offs between flight speed, drone range and image quality be managed? Flights may need to be slow to enable high quality image capture, so covering extended distances may require a 'tag-team' approach. What kind of charging and take off/landing infrastructure will be needed?

Safety
Infrastructure is an essential component of public and private services. How can safety procedures be designed to ensure that infrastructure is not at risk during inspection? Drone safety measures such as self-monitored health during flight and safe emergency landing protocols are critical.

3. Deliver goods

Collect, transport, and deliver goods from origin to destination

Benefits

- Reduced cost of ‘last mile’
- Reduced traffic on city roads, reduced pollution
- Faster delivery times for consumers/in emergency situations
- More consistent delivery times in busy periods

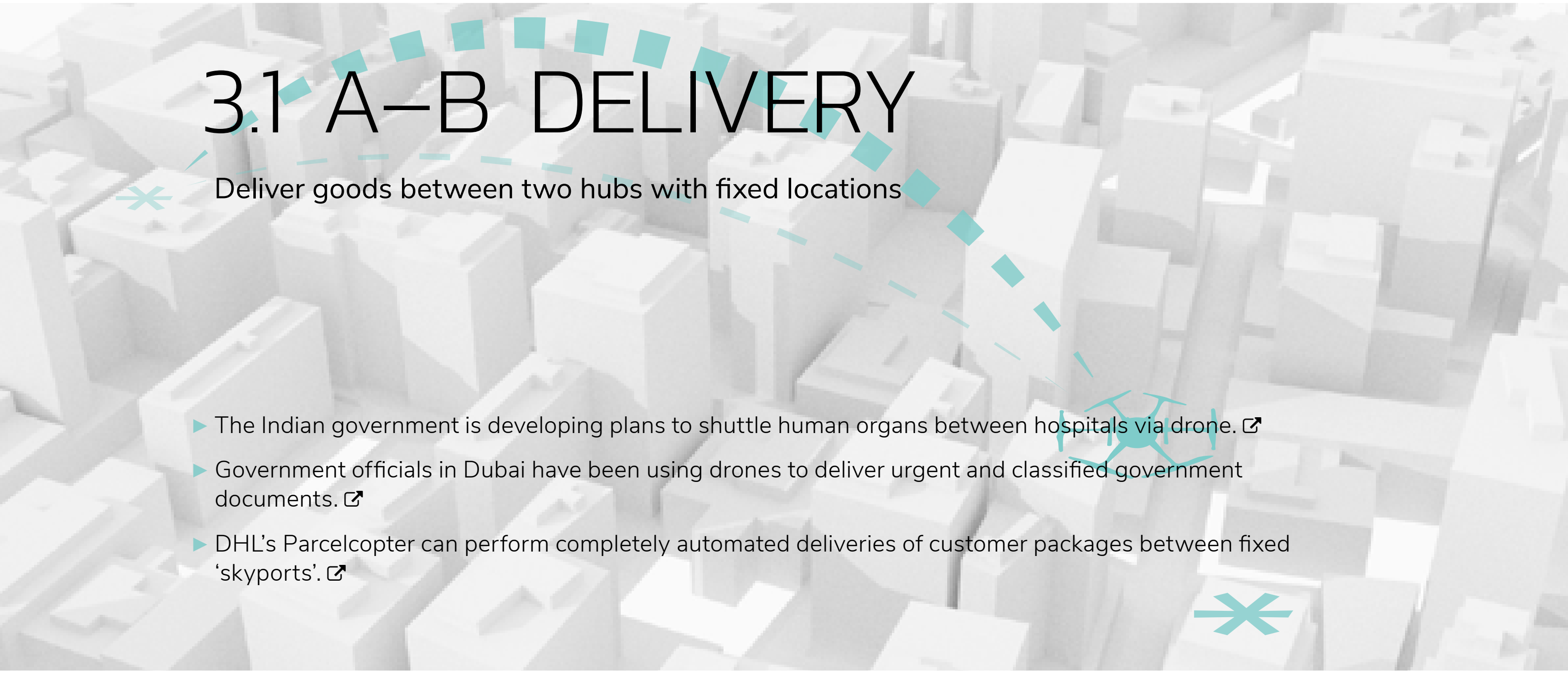
Considerations

There are six categories of key considerations, including functionality, privacy, safety, scalability, security, and system integration. The most critical considerations for the deliver goods application are:

System integration

Safety

Security



3.1 A–B DELIVERY

Deliver goods between two hubs with fixed locations

- The Indian government is developing plans to shuttle human organs between hospitals via drone.
- Government officials in Dubai have been using drones to deliver urgent and classified government documents.
- DHL's Parcelcopter can perform completely automated deliveries of customer packages between fixed 'skyports'.

Use cases

—

How can drones help in your city?

Ambulance
- Organ delivery
- Blood sample or blood transfusions delivery

Consumer delivery
- Delivery of goods from a warehouse to an established delivery centre

Administrative
- Secure delivery of contracts or important documents between two headquarters

Considerations

System integration

What will delivery hubs look like and how will they integrate into a wider city infrastructure? To make hub to hub deliveries viable, it's likely that drones will require a high level of autonomy and should be allowed to fly BVLOS. Defining fixed flight paths or corridors for hub to hub deliveries might make it easier support the development of a secure system.

Safety

How to make sure that deliveries and their associated flight paths present no risks to citizens, below traffic and infrastructure? What regulation or permissions need to be granted with regards to payload content, weight, or size? Robust emergency protocols need to be in place to minimise any risk in case of drone malfunction or interference from the outside.

Security

Having fixed takeoff and delivery locations means that these drones are in a good position to transport sensitive payloads. These can range from blood donations for hospitals to sensitive contracts. How to make sure that these deliveries occur securely, without any tampering? Any deviations from the set route should be recorded and flagged up to an operator. How to ensure that packages are secure and that they are only accessed by the intended recipient?

3.2 A–X & X–A DELIVERY

Deliver goods between a hub with a fixed location and a variable location and/or vice-versa

- Amazon has begun delivering packages to consumer's homes through its Prime Air project based in Cambridge.
- Google has been delivering burritos by drone in Southern Australia as part of Project Wing.
- Postal services in France, Finland and Finland have all begun using drones to deliver parcels to customers.

Use cases

—

How can drones help in your city?

Postal delivery
- Delivery of letters and post

Consumer delivery
- Delivery of goods from warehouse to home
- Product returns

Ambulance
- Deliver emergency supplies (e.g. first aid kits, medicine) from medical centre to emergency location

Considerations

Privacy
In the case of postal or consumer deliveries, drones will need access to people's homes to deliver goods – what will be the privacy implications of granting them this access? What will happen in residential areas – will drones be restricted to flight corridors above public spaces (e.g. roads) or will they be allowed to fly over private land? How will the drone know if it is landing on land owned by the resident or someone else? Will the drone's cameras be capturing video and if so, who owns this data and how will it be handled? Will additional noise regulations need to be put in place?

System Integration
A hub to home package-delivery system will likely scale up to hundreds or thousands of drones in order to become viable. How to regulate air traffic and prevent collisions? As with most applications suggested, to become viable, delivery drones will most likely need to fly BVLOS and autonomously plan and fly routes. Take-off and landing infrastructure also needs consideration. While hubs will be recognisable, what will these points look like in people's homes?

Functionality
Drones must have a safe and secure delivery mechanism. This could involve scanning and landing in any location to deliver packages to consumers or dropping packages without landing. How will they do so in crowded city centres/tower blocks where open spaces are not available? Payload weight is also a serious limitation as heavier packages will require greater battery power to lift and can be carried over shorter distances.

3.3 X–X DELIVERY

Deliver goods between two variable locations

Auburn fire department in Maine, USA retrofitted a monitoring drone to deliver life jackets to victims stranded in a river.

Use cases

—

How can drones help in your city?

Consumer delivery

- Person-to-person package deliveries via drones
- Multiple deliveries in one flight

Fire brigade

- Deliver supplies or equipment to stranded victims

Considerations

Scalability
To become viable, this use case will likely require a large number of drones in the skies (>1000s) to ensure they are rapidly on hand to deliver cargo. This will have significant implication on the overarching system, as many highly variable and dynamic flight paths will need to be managed simultaneously. Due to the number of drones required, flight planning and execution will most likely have be automated and carried out BVLOS.

Security
The security of individual deliveries and their payloads will be a prime consideration. In the case of multiple deliveries, how do you ensure that recipients access only their package to prevent theft and ensure there is no tampering with cargo for future deliveries? If collecting packages for delivery to other locations, how to ensure that payload is not dangerous or illegal? How to make sure the functionality of the drone is not interfered with? How to prevent the theft of drones carrying out deliveries?

Functionality
For this type of mission to work, drones would have to enable the delivery of a wide range of cargo with different weights, different volumes, different levels of fragility or sensitivity. This will have implication on the size and weight of a drone, and implicitly on its power requirements. How to manage these tradeoffs and give customers variability in terms of what they can receive and deliver?

4. Transport people

Transport passengers from one location to another

Benefits

- Decongest road traffic
- Decrease pollution due to road traffic
- Reduce transport time
- Provide quicker services in an emergency (e.g. air ambulance)

Considerations

Safety
Because we are talking about transporting people from one location to another, safety will be paramount. This will have implications on the structural design of the drone, the software that will enable its safe navigation, robust traffic management systems will have to be in place, as well as take-off, landing and servicing infrastructure. Drones will require robust protocols for safe landing in the case of an emergency. How to engage with local and national regulators and authorities to ensure effective traffic management systems are developed and implemented?

Functionality
There are a lot of innovations happening in this space with at least 19 companies working on developing people carrying drones. These include Boeing, Airbus, Uber and startups like Volocopter. To enable people carrying drones to become a viable and safe transport option, technological developments around battery power, noise, VTOL technology and navigation are needed.

4.1 A–B ROUTE

Transport passengers from a fixed hub to another

Use cases

—

How can drones help in your city?

Transport

- Transport between two hubs (e.g. commuters going from local hubs to a central one)

Ambulance

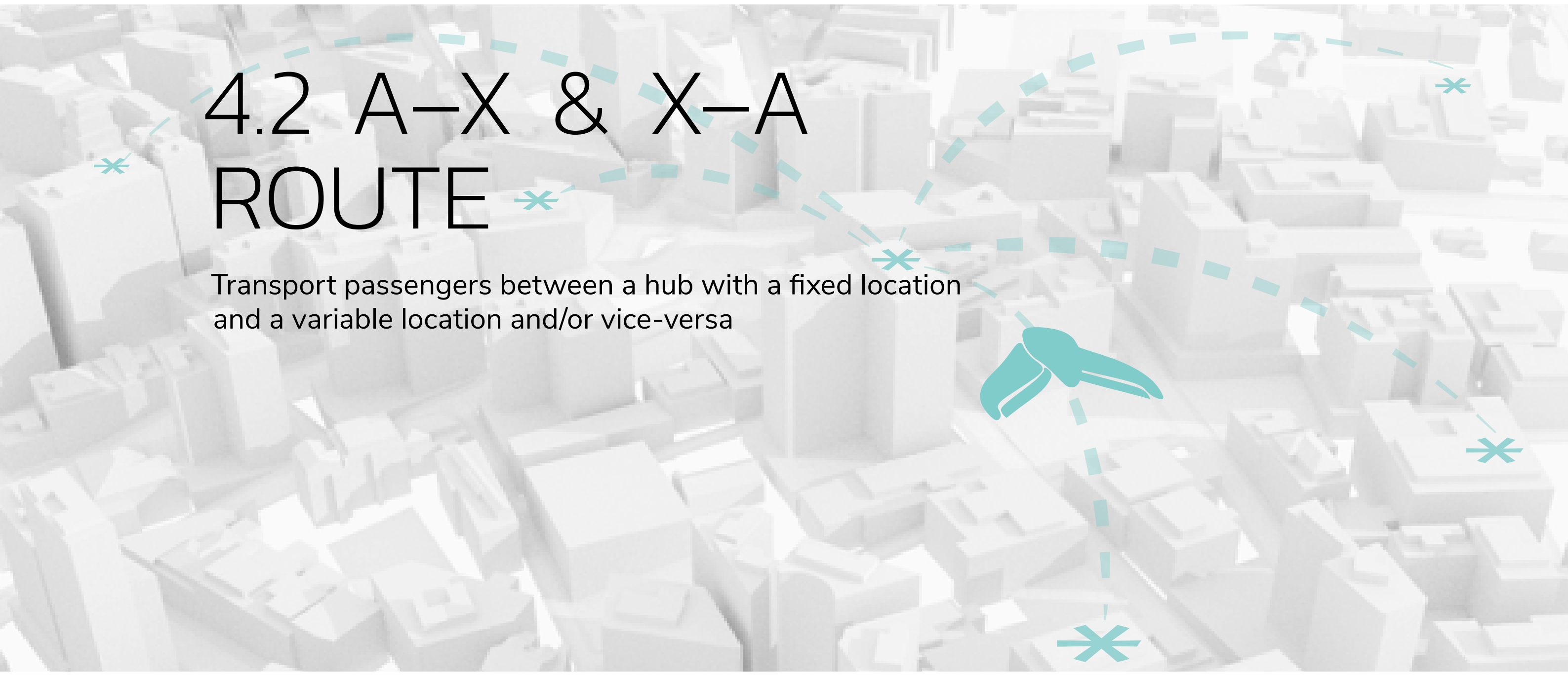
- Air ambulance transporting patients from hospital to hospital

Considerations

In addition to **safety** and **functionality**, which are the most critical considerations when transporting people, the following considerations are also important for the A–B route application:

System integration
A hub-to-hub route implies supporting infrastructure at both take-off and landing. What will this infrastructure look like? Where will this be implemented in your city? Will people carrying drones have priority lanes? How will they interact with drones carrying out other activities in the airspace?

Privacy
A hub-to-hub route implies frequent trips along the same path. How to establish a hub-to-hub route with a minimal negative impact on residents? Think about any potential implications in terms of noise pollution for local residents, or the impact of having drones flying above their homes or gardens. Could noise restrictions or regulations apply? How to involve local citizens in the process of defining flight paths?



4.2 A–X & X–A ROUTE

Transport passengers between a hub with a fixed location and a variable location and/or vice-versa

Use cases

—

How can drones help in your city?

Transport

- Transporting people from a central hub to their individual homes

Ambulance

- Air ambulance transporting patients from emergency location to hospital

Considerations

In addition to **safety** and **functionality**, which are the most critical considerations when transporting people, the following consideration is also important for the A–X route application:

System integration

How will these drones interact with others carrying out tasks in the city? As opposed to a hub-to-hub model, having a variable destination implies that additional considerations need to be given to safe navigation, traffic management and priority in terms of establishing flight paths. What counts as basic take-off or landing infrastructure also needs to be taken into consideration, particularly in the case of the variable location (whether it's at take-off or landing). What will this look like and where will it be allowed?

4.3 X–X ROUTE

Transport passengers between two variable locations

- Dubai has began testing a drone taxi service using passenger carrying drones designed by German firm Volocopter.
- Uber will start testing their electric drone-like flying cabs in LA in 2020.
- The state of Nevada has partnered up with Chinese firm Ehang to test the feasibility of its EHang 184 passenger drone.
- AirMule, an autonomous drone ambulance has been tested in Israel.

Use cases

—

How can drones help in your city?

Transport

– Flying taxi model of carrying people from one variable location to another

Considerations

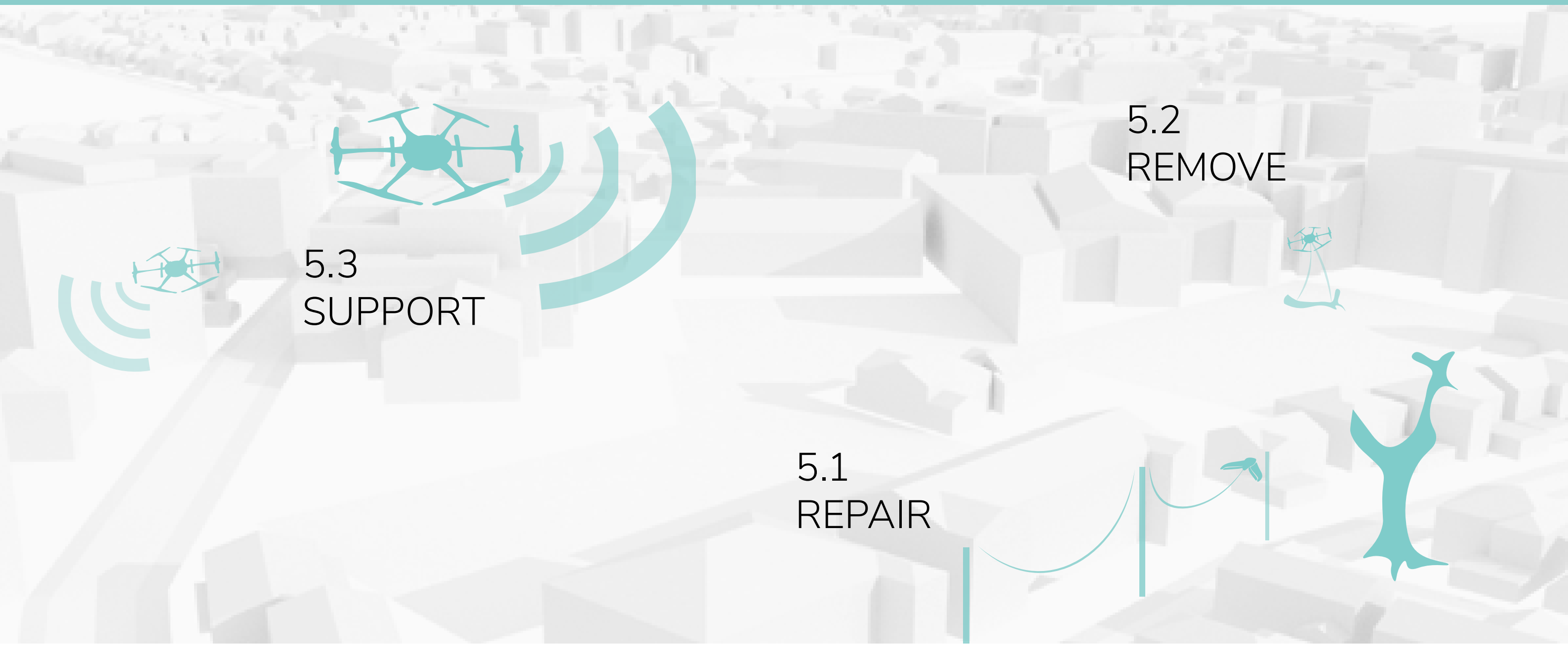
In addition to **safety** and **functionality**, which are the most critical considerations when transporting people, the following consideration is also important for the X–X route application:

Scalability

In this particular case, the scalability of the system will become increasingly important. The implicit high frequency of a taxi model will have significant implications on the security of the system. How to make sure that autonomous drones with dynamic flight routes can safely navigate alongside drones carrying out different actions? How will the system look like if we will have hundreds or thousands of people-carrying drones in the skies?

5. Intervene

Interact with an object or person in an attempt to improve or support their current state



Benefits

- Faster response times
- Increased personnel safety
- Intervention in environments that are too dangerous or inaccessible for humans
- Reduced intervention costs
- Provide better public services to citizens

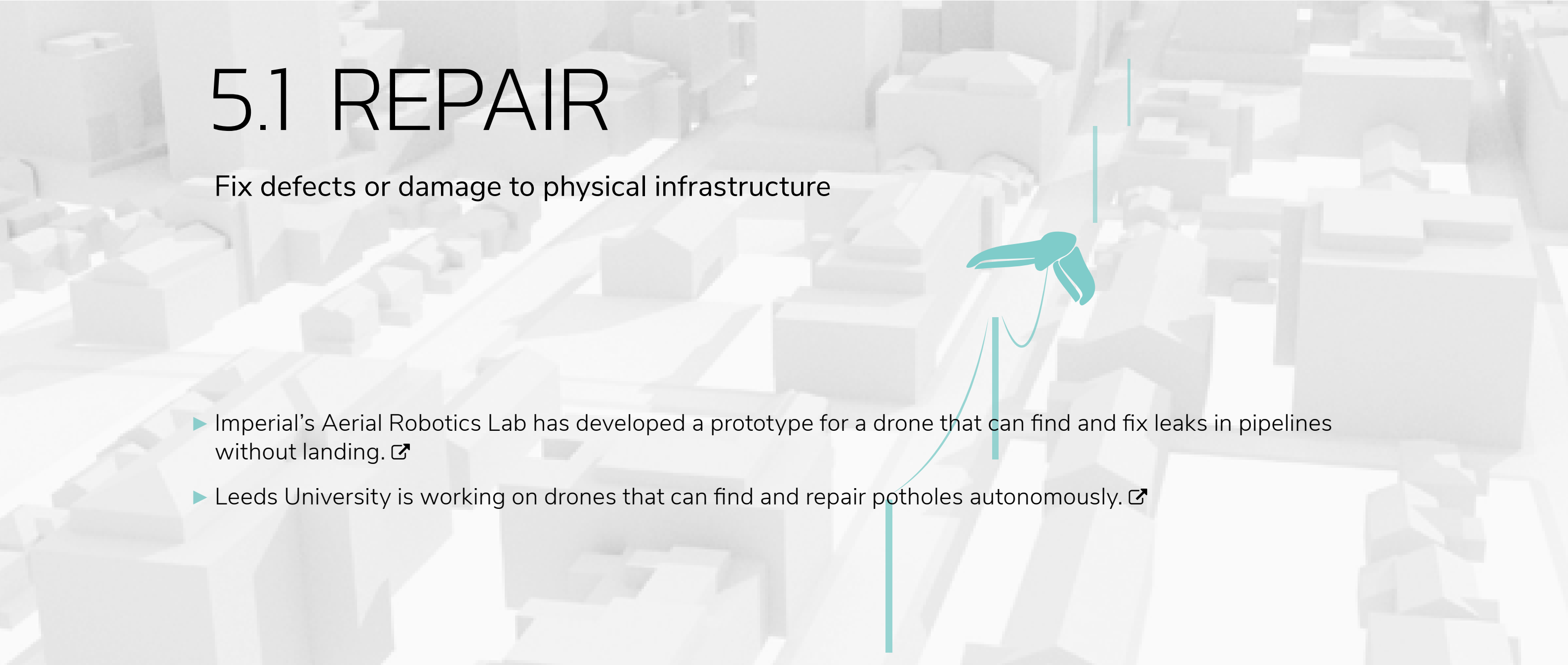
Considerations

There are six categories of key considerations, including functionality, privacy, safety, scalability, security, and system integration. The most critical considerations for the **intervene** application are:

Functionality

Safety

Autonomy



5.1 REPAIR

Fix defects or damage to physical infrastructure

- Imperial's Aerial Robotics Lab has developed a prototype for a drone that can find and fix leaks in pipelines without landing.
- Leeds University is working on drones that can find and repair potholes autonomously.

Use cases

—

How can drones help in your city?

Transport
- Repairing potholes in roads
- Repairing streetlamps

Energy
- Repairing leaks in pipelines

Construction
- Repairing faults in large or inaccessible structures (e.g. cracks in bridges)

Considerations

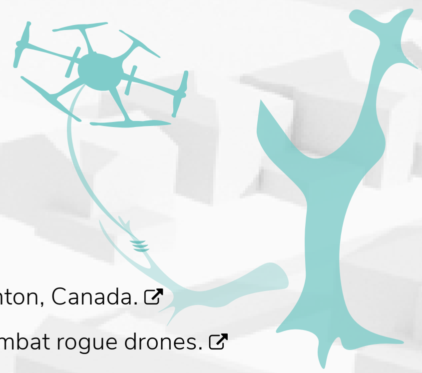
Functionality
What technological developments are required to enable drones to carry out complex activities such as repairing a structural crack or changing a streetlight? While significant developments are happening in robotics, careful consideration is needed when thinking about the trade-offs between activities such as hovering, carrying relevant equipment and performing delicate repair tasks.

Safety
How to make sure that any required reparations are carried out safely and cause no risks to people, surrounding infrastructure and the local environment? How to minimise any disruptions caused by the repair? Consider noise implications, intended flight path, any resulting debris and the safety of the equipment used. Also, what would happen if the drone cannot successfully repair the target?

Scalability
How regularly are repairs going to be required? How localised or geographically spread are the repairs? How long will each repair take and how many drones are needed to carry out the reparation? How many repairs could a single drone do before needing to recharge/refill supplies? Can the repair be automated or will a human pilot be required?

5.2 REMOVE

Remove objects from areas where they may cause disruption



- Robotic ‘falcon’ drones are being tested to scare away birds from the airport in Edmonton, Canada.
- Tokyo police are thinking of setting up a ‘drone squad’ to enforce no-fly-zones and combat rogue drones.
- A graffiti-removing drone won a competition in San Jose that set out to find a solution to remove graffiti from hard-to-access locations such as bridges or sound walls on motorways.

Use cases

—

How can drones help in your city?

Transport
- Clearing debris from railway lines
- Scaring birds away from airports

Energy
- Clearing debris from solar panels
- Clearing rubbish from power lines

Police
- Removing rogue drones

Maintenance
- Clearing leaves from gutters and roofs
- Cleaning windows of high buildings
- Collecting litter from public spaces
- Removing graffiti from access locations (e.g. bridges)

Considerations

Safety
How to ensure the safe removal and disposal of debris? This is of particular importance if drones are used to remove hazardous materials. How to ensure that the removal operation does not affect existing infrastructure?

Privacy
Some removal drones will likely be required to fly at a low altitude and in close proximity to people. How will this impact on noise pollution? How to clarify their role to the public? What kind of data will these drones be collecting and how to make sure it will be securely handled?

System integration
What regulation needs to be in place to enable these drones to operate in cities, and therefore in close proximity to buildings and people? What degree of automation is required from these drones? If drones performing local maintenance tasks become commonplace, how will citizens distinguish between public service drones and rogue drones performing illegal operations?

5.3 SUPPORT

Improve the capacity, speed, or quality of existing services

- EE has begun using drones to boost 4G signal at large events in the UK.
- Startup company AmpyxPower has developed a tethered drone that can harness wind power to generate renewable electricity.
- Researchers at Delft University of Technology have developed a rapid-response ambulance drone that can act as a defibrillator.
- Latvian company Aerones have demonstrated a fire-fighting drone that can tackle blazes at the top of tall buildings.

Use cases

—

How can drones help in your city?

Communications
- Boosting mobile networks

Energy
- Generating renewable energy from wind

Ambulance
- Rapid response ambulance drones

Fire brigade
- Tackling blazes at the top of tall buildings
- Dragging flood victims to safety
- Building bridges to access difficult locations

Considerations

Functionality
The technology for many of these supporting functions is at a very early stage – how will these technologies perform outside of lab conditions? What level of autonomy will these drones require?

Scalability
How many drones will be required to provide support to city services? When services are overwhelmed by demand, will one drone make a meaningful difference? In some cases, a larger number of drones or a swarm of drones might be more effective. How to make sure that these operate safely and are well integrated in the overall system?

System integration
The tasks carried out by drones in this category are very distinct. How will regulation be able to cover the safe functioning of such different drone applications, while at the same time remaining flexible and enabling new developments of service-specific drones?

Emergency situations

Additional considerations for emergency use cases

Using drones in emergency situations can have many benefits

- They can enable faster response times and a quicker evaluation of necessary materials and equipment.
- They can offer live information to support decision-making on the ground and extend or complement the capabilities of emergency services.
- They can also intervene in hazardous environments and thus reduce the risk for intervention teams.

For each specific application discussed in this document, where relevant, we have highlighted useful emergency use cases. These are marked with a ! icon.

Additional considerations

—

Using drones in emergency situations will require them to complete tasks in complex, time-pressured settings. Because of this, we wanted to flag up some extra considerations that will apply to these use cases, in addition to their application-specific considerations.

Functionality

Emergency situations will require drones to be called out at short notice and in time-sensitive situations. Therefore, they must be ready to fly at all times, which presents challenges from a maintenance and power point of view. They may also be required to fly in poor weather (e.g. wind, rain), poor visibility (e.g. fog, smoke) or at night, and still capture useful data (e.g night vision video). Flying under such conditions will require increased functionality, such as increased battery capacity for remaining stable in high winds or more advanced sensors for seeing through smoke. If deployed in hazardous environments, they will also need to be resistant to damage from those environments (e.g. water resistant & buoyant if being deployed in floods, heat resistant and flame retardant if being used near fires). Depending on the applications of the drone, different features may be crucial. For example, communicating with those affected by an emergency may be crucial in some contexts, while in others it might be the rapid and safe delivery of medical equipment. How to manage the trade-offs between key features and power requirements?

System integration

Emergency drones will need to rapidly reach the site of an emergency. Therefore they will most likely be required to fly BVLOS to avoid being tethered to the speed of a ground pilot. Regulations are already changing to recognise the need for emergency drones to fly BVLOS. However, with

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many other drones in the sky performing different missions, there will be a need for robust emergency procedures to prevent collisions; these might include priority lanes for emergency responder drones which would likely need to be managed by ATC. They may also need permission to fly through and in restricted airspace. Permission would need to be granted with little-to-no notice and emergency drones must avoid being marked as 'rogue drones' and immobilized. Similarly, emergency areas may need to be declared no-fly zones as to exclude commercial and private drones from interfering with emergency operations. What protocols need to be in place to make this process safe and secure? In some emergencies, communication networks may be down, so drones should be able to be to function without internet coverage.

Scalability

As the use cases for drones to aid emergency services increase and become more widely used, there will be greater demand on drones in emergency situations. This presents a challenge in funding-strapped departments securing enough hardware to attend calls, and having enough pilots on hand to fly them. A system for prioritising which calls the drone attends may need to be implemented. Increased automation of drone tasks would decrease the demand on pilots and allow faster and cheaper scale-up, and more effective drone use in disasters when emergency services are likely to be stretched. Finally, emergency services must not become dependent on drones to provide services: there must be provision to ensure they can function in the absence of drone availability and fail-safes in the technology to minimise the chance of failures (accidental or deliberate e.g. criminals grounding police drones to cripple observation capacity). Drones are highly likely to be damaged on missions, so effective repair and maintenance procedures are critical to keep them in the air.

Security

Feeds from police drones will be carrying live, highly sensitive data on active operations, so ensuring data security of this footage will be critical to prevent hacking or misuse. Drones must also be highly resistant to being hacked - emergency drones providing information to citizens will be highly credible, and if hacked they could be used to spread misinformation.

Safety

Given these drones will be used to actively improve public safety, the safety risks are outweighed by the danger of not acting. However, rescue operations in particular are likely to involve close contact with those affected and so personal safety (of untrained individuals) around the drone becomes paramount.

Privacy

Emergency operations will require strong regulation around circumstances in which people can be monitored and how data will be handled. Citizens should also be able to clearly identify emergency drones in the sky through visual markings/lights so they are not misidentified.

Multifunctional drones

Complex tasks

—

Drones may carry out multiple tasks as part of an end-to-end service.

For the purpose of this Introductory Pack we have broken down drone functionality into specific applications – from monitoring flows to delivering goods or repairing infrastructure. As we have tried to show, each specific application will have an impact on the type of drone required, regulation, and infrastructure. What's likely to happen in practice is that drones will carry out multiple tasks as part of an end-to-end service. This means that rather than focusing on just one of the use cases we've explored, a single drone would likely carry out a combination of these to complete a more complex task. In other cases, drones carrying out different tasks could collaborate by exchanging meaningful information to complete a shared activity. Here, we present a couple of potential use cases.

Cities that repair and maintain themselves

Drones would inspect urban infrastructure such as roads or streetlamps, identify problems and repair them, all without any human input. Drones could recharge by landing on streetlamps while rooftop depots would provide them with the supplies and equipment they need to perform simple repairs. This would allow them to operate continuously throughout a city.

Other similar drones could scan parks or other open spaces for litter, collect and dispose of it in a safe manner. Using drones to carry out such routine operations could save time and resources for city councils.

Extended capabilities for emergency operations

Rescue drones would scan flooded areas looking for trapped citizens, deliver them with food, medicine, blankets and flotation devices to keep them safe and offer them reassurance and advice. Firefighting drones would help tackle blazes at the top of tower blocks, while rescue drones would map the compromised building from the inside and search for survivors, saving firefighters from entering the building.

Police drones would watch operations from above and provide advice to citizens on how to remove themselves from harm's way. These drones could communicate with first-response drones and share the location of people in greatest need of emergency medical support.

Cleaner air in cities

Drones would circle traffic intersections collecting air samples and studying traffic flows below, looking for ways to reduce emissions and using air scrubbers to remove the most harmful pollutants.

Others drones would scan industrial areas, identifying factories that breach air quality rules and repairing any leaks in pipelines and chimneys that are leaching harmful gases.

Additional considerations

—

For multifunctional drones

Functionality
Carrying out end-to-end services will likely require much more technically complex drones. How can cities start engaging with drone manufacturers to support the development of drones that perform services that are best suited to the needs of a specific city?

System integration
Multifunctional drones will likely need extensive charging and maintenance infrastructure to enable them to function for longer periods of time. How to develop such an infrastructure in an urban context? Drones that collaborate to perform more complex tasks will add pressure to existing communication networks and infrastructure. How to make sure that drones can safely carry out shared tasks?

Privacy
As drones start carrying out multiple tasks across a city, how will citizens be informed about the applications or tasks being carried out by a specific drone?