Flying High: shaping the future of drones in UK cities

Appendix: technical and economic feasibility studies

Technical and economic feasibility study: medical delivery in London 2
Technical and economic feasibility study: traffic incident response in the West Midlands........ 26
Technical and economic feasibility study: Southampton-Isle of Wight medical delivery 48
Technical and economic feasibility study: construction and regeneration in Preston........ 69
Technical and economic feasibility study: supporting the fire and rescue service in Bradford........ 91
Key assumptions in the economic feasibility studies 114

Technical and economic feasibility study: medical delivery in London

Using drones to move urgent medical deliveries between London's hospitals

- The study explores rapid transport of light medical deliveries between hospitals
- Increased speed and reliability could cut costs and improve patient care
- We find this use case technically feasible; economic feasibility could be compelling if implemented at a larger scale

Introduction

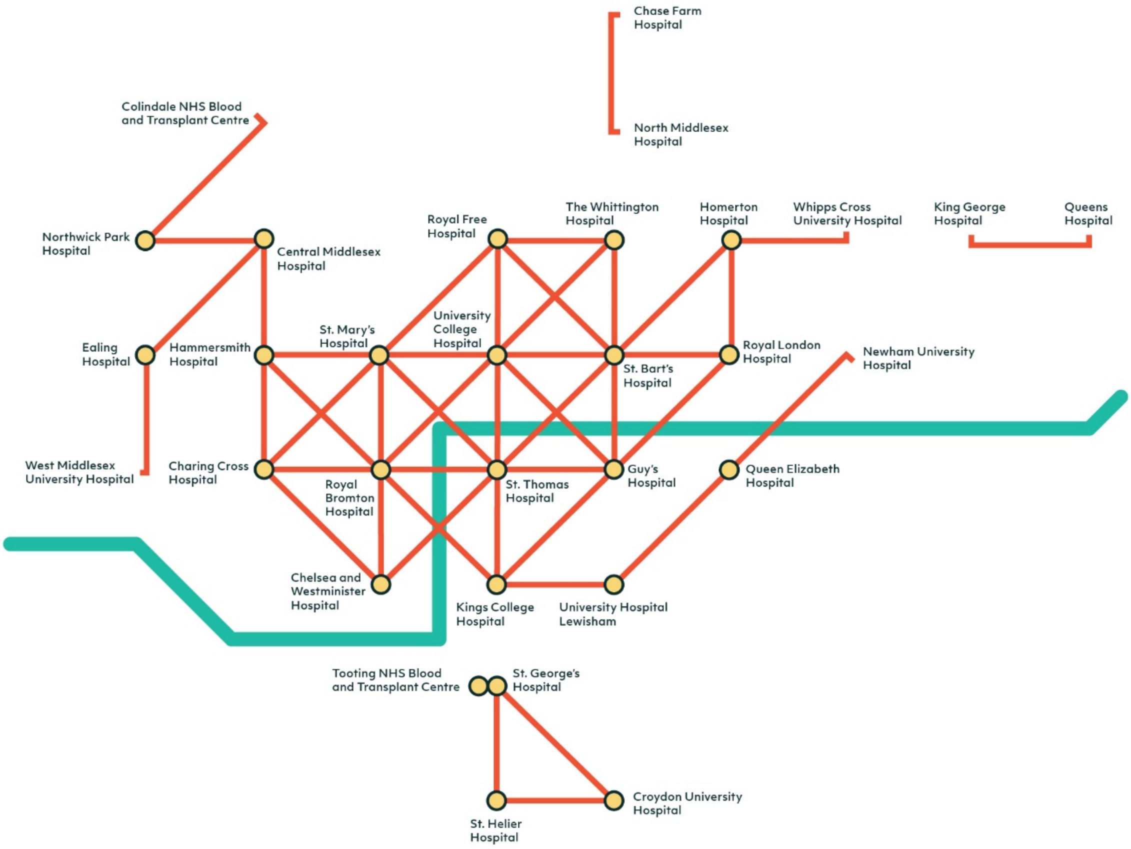
This section outlines a drone delivery network for carrying urgent medical deliveries between NHS facilities in London. This would routinely carry products such as pathology samples, blood products and equipment over relatively short distances between hospitals in a network, reducing journey times and speeding up patient care.

We consider the opportunity for drone-based medical logistics in London, in general and focus specifically on the technical and economic factors relating to the movement of pathology samples between Guy's and St Thomas' hospitals in central London.

General discussion

The case for medical delivery in London

London has a significant number of hospitals within a relatively small area. There are 34 hospitals within Greater London, including 28 A&E departments, four major trauma centres and three hospitals with London's Air Ambulance helipads. This does not include smaller community hospitals and psychiatric hospitals. Deliveries between hospitals are frequent, in many cases, time sensitive.



Caption: Opportunities for drone flights between London hospitals.

Medical deliveries are a unique and appropriate drone use case in London, because:

- Hospitals form a dense and relatively large network within a small area, which lends itself to many short point-to-point journeys, but one that is relatively predictable: the service follows a finite number of fixed routes (unlike a completely open network that can deliver anywhere).
- Medical deliveries are often time-critical, but the average traffic speed across London is 17.6mph and in central London this reduces to 8mph.[1] The variability of road speed leads to unreliable and unpredictable journey times.
- the use of drones for medical deliveries aligns with and potentially drives two strategic priorities of the NHS in London: pathology consolidation networks[2] and a shift towards delivering care closer to the home[3], as well as an initiative to provide one stop shops[4] to speed up diagnosis.

1 http://content.tfl.gov.uk/street-performance-report-quarter2-2017-2018.pdf

2 https://improvement.nhs.uk/resources/pathology-networks/

3 https://improvement.nhs.uk/resources/moving-healthcare-closer-home/

4 https://www.england.nhs.uk/2018/04/new-one-stop-shops-for-cancer-to-speed-up-diagnosis-and-save-lives/

The NHS could eventually build a London-wide medical delivery network handling all types of urgent deliveries. This would be particularly useful in the case of pathology. The NHS is planning to join together the 105 individual pathology services within English NHS hospitals into 29 pathology networks. Drones could be used in these networks to increase the speed and lower the cost of transporting samples between hospitals. The NHS will then be able to build on this system and test out other ways of using the drones to improve efficiency.

There is another reason to specifically explore this use case in London. Airspace over London is limited and a proof of concept can be one way of ensuring that the available airspace is prioritised for the most important types of deliveries.

Future implications of drone delivery in London

There is a longer term prize if we prove this concept

If we prove the concept of drone delivery between London hospitals, it could be rolled out to other urban areas and cover a wider variety of medical items such as equipment and pharmaceuticals. It could become a transportation system on its own, with distinct emergency flight corridors or connect to other systems such as hospital pneumatic tubes.

Drone medical delivery could also be used in emergency situations; becoming as integrated into emergency procedures as ambulances and defibrillators are now. For example, paramedics could take a blood sample at the scene of an emergency and have a drone fly it direct to the lab. Similarly, medical first responders could request additional equipment to be brought by drone once at the scene.

Drone medical delivery could be extended to residential areas. Patients could consult with a doctor using video conferencing software and then take urgent diagnostic tests at home, at a chemist or a doctor's surgery. A drone could collect samples at a centralised neighbourhood hub location to transport to the lab. Prescriptions and personal medical devices could also be delivered by drone to a neighbourhood hub location which could be particularly useful for individuals with limited mobility.

Benefits of drone delivery in London

Economic benefits

Faster and more frequent deliveries could save money

A fundamental advantage of drone delivery is the ability to deliver goods in a fraction of the time taken by conventional courier services. In Switzerland, where drones are being used to connect hospitals in Lugano and Bern, the drone is 2.5 times as fast as bike or van couriers over a distance of approximately 5km.[5] In addition, the flight times of drones are

5 http://www.20min.ch/schweiz/bern/story/Post-Drohne-verschickt-Blutproben-in-5-Minuten-24142778

significantly easier to predict, making services more reliable. Live monitoring of the drone during its flight provides even more planning security.

Cost savings are the second key economic benefit of deploying drones for medical deliveries. Whilst upfront investment can be significant and is highly dependent on each site's unique infrastructure requirements, the marginal cost of additional flights is negligible. A bike courier, as the least expensive means of transport between hospitals, usually costs at least £15 for each delivery of a distance comparable to that between Guy's and St. Thomas' hospitals in London; and even more outside of normal working hours. A drone, on the other, hand can fly at demand at the marginal cost of recharging the batteries, which is estimated to be less than five pence. This lower marginal cost enables more frequent deliveries and reduces the pressure to send samples in batches.

The main benefit of drones is that they allow hospitals to carry out additional deliveries, at any time of the day, which cannot currently occur because of resource constraints. These savings are likely to materialise, in the long term, when new contracts with couriers are sought. Drones should thus be seen as being complementary to existing delivery services in the short term.

Drones also have the potential to reconfigure medical logistics by allowing types and frequencies of delivery which are not currently feasible. Medical logistics are currently largely on a hub-to-hub model with regular deliveries of multiple packages between logistics hubs in each hospital. Drones would allow more flexibility of deliveries of small packages at irregular times. They would also allow delivery much closer to the ultimate destination of a package - for instance in Switzerland, a landing pad has been installed within ten metres of a hospital's pathology laboratory, bypassing the hospital's internal logistics network and improving the efficiency of laboratory processes.

Social benefits

Improved patient outcomes

More reliable and timely delivery of certain test results is likely to have a significant impact on patients' physical health. This applies to patients in hospitals, as well as those who require testing outside of hospitals . Additionally, being able to leave the hospital earlier will decrease the negative effects on health due to longer-term hospitalisation. It is difficult to provide a quantitative estimate of this benefit given the wide range of different pathology tests and related diseases.

If samples are processed too late, it is possible that a patient, due to be discharged, is required to stay at the hospital or return the next day in order to adjust medication based on the results of their delayed blood test. In addition to the cost associated with bed blockage, extended and unnecessary hospital stays can often put considerable strain on a patient. Faster execution of blood testing via drones can substantially improve the patient experience, thus improving the mental well-being of patients.

Environmental benefits

Reducing traffic caused by medical logistics

Using drones for medical deliveries at scale is likely to reduce the number of delivery cars and vans, as well as the number of bike couriers on London streets; more work would be required to quantify this.

Example: transporting pathology samples between Guy's and St Thomas' hospitals

We explore a specific connection between two hospitals to better understand the challenges of this use case

Definition

As a test case to explore the technical and economic feasibility of medical logistics in London, we chose to focus on delivery of pathology samples between Guy's hospital and St Thomas' Hospital. These locations were selected because of their proximity to each other, their close institutional links (they are part of the same NHS Trust), the high volume of daily traffic between the two sites (in particular thanks to the Viapath pathology laboratories that operate at both sites) and because they present interesting and complex technical and regulatory challenges, including:

- Areas of restricted airspace, including heli route 4 that follows the River Thames near Guy's and St Thomas' hospitals.
- Tall buildings that extend high into the airspace in which drones would operate, including the Shard - Western Europe's tallest building - and the Tower Wing of Guy's hospital.
- Proximity to nationally important, high-security sites including the Palace of Westminster, which is located directly across the River Thames from St Thomas' Hospital.
- Heavily built-up areas including residential areas (over 11,000 people per sq km[6] in the two boroughs covered by the proposed link) and facilities such as schools.
- Key transport infrastructure hubs, such as Waterloo Station and London Bridge Railway Station, as well as central roads, such as the inner ring road and the River Thames.

Post kidney transplant monitoring was identified as a suitable test case for drone transport between these two hospitals: there are approximately 250 blood samples delivered from the renal clinic at Guy's hospital to the laboratory at St Thomas' hospital per

6 https://data.london.gov.uk/dataset/land-area-and-population-density-ward-and-borough

week. These are used to control the dose of immunosuppressant drugs applied, with variable frequency depending on patient response.

Our research found that this is currently provided by a bicycle courier, with deliveries conducted twice a day (10am and 12noon), with delivery times ranging from 35 minutes to 1 hour 35 minutes.

The drone we propose to carry out this service has the capacity to transport between 1 and 10 samples per journey, with a total payload of no more than 2 kilograms.

A drone delivery connection would transport samples directly from docking stations in the relevant departments at Guy's hospital to a docking station near to the lab at St Thomas'. It is envisioned that flights would operate routinely or on demand, multiple times a day, autonomously and beyond visual line of sight of an operator. Flights should be able to occur at any time of day and on weekends.

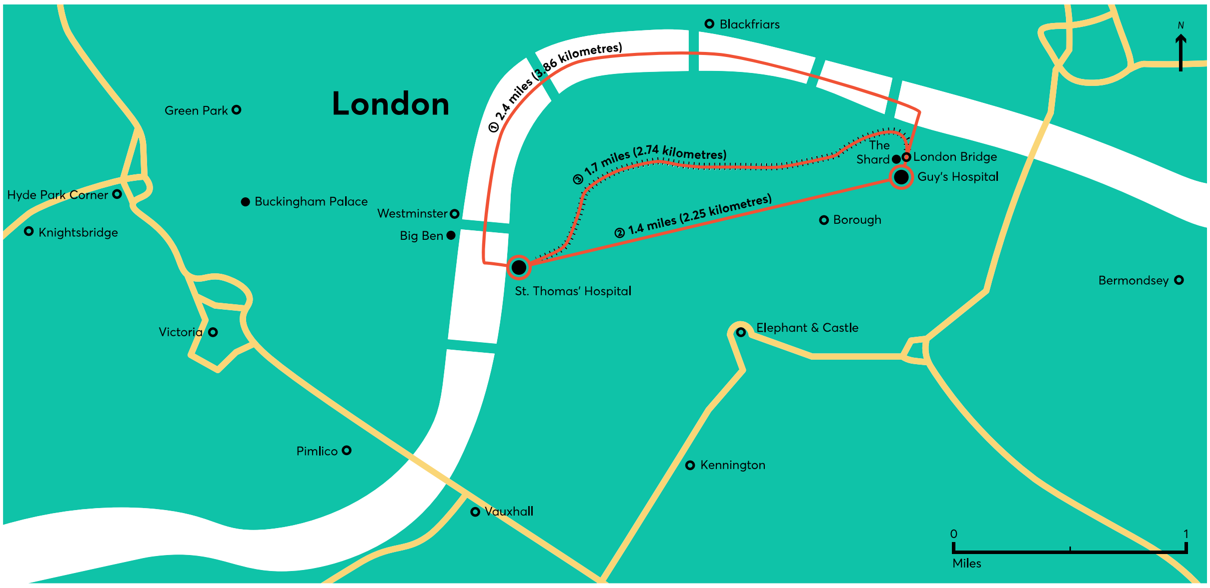
The ability to have a low-cost, fast delivery connection on demand could allow a more even flow of samples to the laboratory and avoid the risk of turnaround delays that can be associated with batch processing. As well as speeding up turnaround time, a drone delivery connection could enable a seven-day service where there are currently restrictions due to logistics timetables. The ability to deliver directly from clinic to lab would avoid the risk of a handoff delay onsite by directly connecting the relevant sites at the two hospitals.

Technical attributes

This section outlines the key technical attributes that would be required of a drone to operate a medical delivery service between Guy's and St Thomas' hospitals.

Flight plan

Three possible drone flight paths have been identified between Guy's and St Thomas' hospitals.



Flight Path 1: along the Thames

2.4 miles, cruise time 4 minutes at 30 knots

Pros:

- Flying along the River Thames would minimise the need to fly over people, buildings and roads, therefore reducing the risk of damage in case of an engine failure as drones would be able to emergency land onto the river.
- Journey time not significantly longer than a direct route.

Cons:

- The Thames is a relatively congested airspace, as it is beneath the path of London heli route 4 - the sole permitted path through Central London for single-engined helicopters.
- The Port of London Authority currently opposes drone flights without special permission.[7]
- Entails flying past the Palace of Westminster (directly across the Thames from St Thomas' hospital).

Flight path 2: direct

1.4 miles, cruise time 2 minutes 30 seconds at 30 knots

Pros:

- The quickest journey time.
- Avoids the congested airspace of heli route 4 and any requirements for permission from Port of London Authority.
- Avoid flying past sensitive sites such as the Palace of Westminster.

Cons:

- Flies over a heavily built up area, including a large number of residential properties, offices and roads.
- No obvious emergency landing sites.

Flight path 3: along the railway line

1.7 miles; cruise time 3 minutes at 30 knots

Pros:

- Avoids the congested airspace of heli route 4 and any requirements for permission from Port of London Authority.

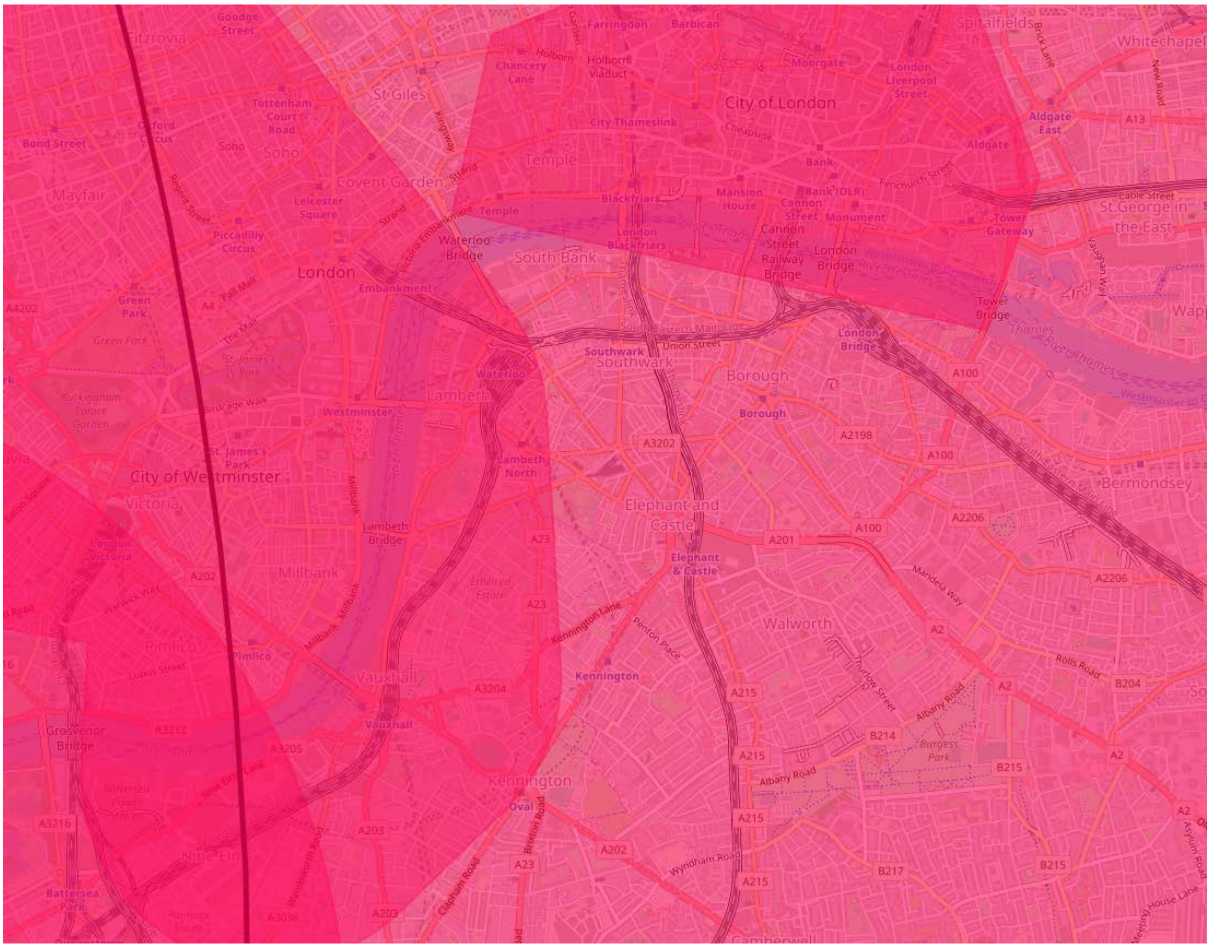
7 http://www.pla.co.uk/Safety/Use-of-drones/unmanned-aerial-vehicles-UAVs

- Avoids flying over buildings people and roads.

Cons:

- Possibility of malfunctions disrupting rail traffic or damaging rail infrastructure with associated costs and delays.
- No obvious emergency landing sites.

Airspace and altitude



London's airspace is highly restricted: the area as a whole is shaded in pink as it is covered by the Class D airspace of London CTR Control Zone; much of West London including the Thames by St Thomas' hospital is covered by restricted area R157 for Hyde Park (dark pink); the north bank of the Thames and the river Thames outside Guy's hospital is covered by restricted area R158 for the City of London (also dark pink). Credit: Altitude Angel

According to the Air Navigation Order 2016, camera-equipped drones are not permitted to fly within 150 metres of a built up area, so exemption from the CAA would be necessary, entailing a safety case for how the drone operation will be safe with respect to people and infrastructure on the ground and other airspace users. In addition, Guy's and St Thomas hospitals lie in the London CTR Control Zone, which covers all of central London. This extends from the surface to 2500 feet and is classified as Class D controlled airspace, which means that clearance from air traffic control is required and so ATC will have to give permission for the flight.

St Thomas' hospital lies within restricted airspace R157 (vicinity of Hyde Park) and Flight Path 1 enters R158 (vicinity of City of London), which Guy's hospital sits just outside the edge of. The areas extend up to 1400 feet and are no-fly zones without Enhanced Non-Standard Flight (ENSF) clearance from ATC, which operators would have to obtain.

A flight path over the River Thames (Flight Path 1 above) would need to consider London heli route 4. Here helicopters generally fly under VFR over 2000 feet in this area, reducing to 1500 feet near Battersea heliport. Rule 5 of the rules of the air forbids helicopter flights closer than 500 feet from any person, vehicle or structure,[8] though London Air Ambulance have special dispensation over this. In addition to operating at or below 400 feet, drones must not fly higher than 300 feet when operating directly below London Helicopter routes. Any flight directly below the helicopter routes must obtain a non-standard flight (NSF) approval from the CAA prior to flight.

This drone operation in London is envisioned to be operating beyond visual line of sight (BVLOS) and would thus need to be IFR capable. VFR flights are premised on the pilot being able to discharge responsibility by unaided visual processes (they can see and avoid hazards), which is not possible for BVLOS flight, so the drones will have to use IFR. Routine BVLOS flights will need either special exemption from the CAA or updated legislation taking into account capability of the drone and surrounding infrastructure.

Making this case study feasible in the context of large-scale drone operations in Central London would require streamlining of permissions or exemptions processes for flights in restricted and complex airspace and a UTM system that can deconflict the different users of this airspace.

The tallest structure within London is the Shard at 309 metres (1,016 feet). Of the top 10 tallest structures, the majority are towers with heights of 180m (590 feet) to 233m (765 ft).

Operational cruise altitude could vary but could be based on at least 100 feet obstacle clearance (this is scaled down from the principle of 1000 feet manned aviation obstacle clearance, unless under radar control), in which case the drone would operate above 865 feet, providing sufficient margin from most obstacles below (not including the Shard, which the drone would have to avoid). A suggested altitude of 900 feet or 1000 feet (above ground level) is recommended depending on the direction of travel. (We propose 900 feet if travelling east or 1000 feet travelling west, following on from manned aviation rules of the air in which aircraft fly at an odd altitude flying east or even when flying west).

As altitude separation in this scenario is significantly less than manned aviation, altitude systems need to be designed to a high accuracy especially as the operation could take place within class D airspace London CTR and London heli route 4. A dedicated UTM will need to be designed, able to deconflict both drone and manned aviation traffic - drone corridors could be a solution to deconflict traffic.

---

8 http://publicapps.caa.co.uk/docs/33/ORS4No1063.pdf

Take-off and landing points

At St Thomas hospital there are potentially three areas which could be considered for take-off and landing.

- The current loading bay, which would link into the current logistics chain inside the hospital.
- The hospital's flat roof.
- Dedicated docking platform: for the purpose of modelling the optimum solution minimising the movement of the samples around the hospital, it is conceivable that the samples be directly delivered into the lab, by a means of a dedicated platform or docking interface (in the case of immunosuppressant services and regional newborn screening this would be on the fourth floor of the north wing).

At Guy's hospital take-off and landing is more suited to the roof due to the site's very close proximity to other buildings including the Shard, which could create wind corridors and downwash providing difficult conditions for the drone to safely take off and land.

Drone platform requirements

Based on the requirements of the use case and of the flight plan outlined above, our technical analysis indicates that the drone would require the following features.

Platform type

- The platform must be a vertical take-off and landing (VTOL) drone as it needs to be able to take off without a runway. As it will operate over a built-up area, it needs to be able to survive loss of power either through gliding or through having redundancy in rotors. This redundancy could be achieved by multi-rotor drone or a hybrid fixed-wing VTOL drone. Over the relatively short distances between these three hospitals, a fixed-wing drone is not necessary but these drones have longer range which could be useful if the service was extended.
- Speed is not a critical factor.When selecting the longest route and flying at very modest speeds of 30 knots, the drone would complete the journey in approximately four minutes. We estimate that take-off and landing combined would add less than a minute.
- Due care and consideration needs to be made towards the payload as the pathology samples need to be handled with care, with smooth manoeuvres and avoiding harsh acceleration and deceleration.

Propulsion

- Zero-emissions power system: as a heavily populated area with significant air quality problems, we are assuming a zero-emission power system, likely to be battery-powered electric motors. Consideration for wind gusts will need to be considered in terms of the stability of the drone to dock and release the payload.

- Endurance: The drone will need to be able to make a return trip from Guy's to St Thomas' hospital, which is a short distance. It is expected that the drone can make multiple trips without being recharged. It could be recharged between flights or have the ability change battery once the battery falls below a certain charge threshold. Before flight, weather impacts, head winds, rain and cold temperature conditions should be considered to ensure the drone can land safely at its main base of operation.

Payload, sensors and instrumentation

- Payload: As the drone will be carrying medical samples, the drone should carry its cargo in an impact-resistant, lockable enclosure. This is unlikely to weigh more than two kilograms.
- Temperature control and shock monitoring: The drone payload is required to provide UV protection together with impact/shock resistance. For a short journey, temperature control is unlikely to be necessary providing the payload is insulated. A transport protocol will be available for every drone flight, identifying whether the delivery has been subject to any major shocks. This is a central benefit in comparison to conventional transport mechanisms where the condition of the package is not monitored throughout the delivery.
- Sensors and instrumentation: The drone should carry a high resolution camera for remote piloting, ADS-B electronic conspicuity device, in addition to sensors for navigation and control.

Communications, navigation and control

- The drones will be flown BVLOS autonomously, from a control station with a pilot present, able to monitor the flight and take control in case of an emergency or anomaly.
- Communications
    - A robust communication system will be needed for the following purposes:
        - Control of the drone with a high level of automation, with telemetry data (position, speed, battery status) relayed to pilot/mission controller for tracking and safety monitoring.
        - In case of a systems failure the drone pilot should be able to control the drone and land it safely, which would require a first person video as the drone will be flying BVLOS.
        - Transmit location to other airspace users and air traffic service providers (e.g. a UTM system or air traffic control) - via an electronic conspicuity device.
    - Redundancy will need to be built into the communications channels to allow for failure or loss of communications, thus a primary, secondary and possible tertiary communications channel will be necessary.
    - The primary communications channel needs secure coverage over the entire journey, as the drone is operating in busy airspace and over urban populated

areas, where the risk to people on the ground and air is greater. Bandwidth should be sufficient to transmit telemetry data.

- The cellular mobile network in general meets these criteria, as this has a combination of generally good coverage (especially within city locations), high bandwidth and good security. As infrastructure is generally preexisting, it is readily available and cheap. Additional boosters or infrastructure outside the network area can address any coverage shortfall, with due consideration to any approvals required; however central London has generally excellent mobile network coverage.
- The transmission of real-time HD video may require different technology. 4G LTE networks may have sufficient bandwidth as long as it can be appropriately secured, future 5G networks would provide greater bandwidth still.
- Using the mobile cellular network requires drones to support a SIM and connectivity module, so hardware and software can be updated when specifications change. Using drones equipped with a SIM card, existing mobile infrastructure can be used which will facilitate fast growth and reduce costs.
- There are limitations to the use of the mobile spectrum, the network is aimed at optimising signal on the ground, rather than in the air.
- Should the drone experience a systems failure, it is recommended to have a different method for backup control in addition to the mobile network, such as data link control via satellites. Note this will be used for control of the drone and not video feed.

- Navigation and control
    - Accurate knowledge of the drone position (latitude, longitude and altitude) is required.
    - In manned aviation barometric pressure is the primary means of altitude determination, however this requires all aircraft in the vicinity to be on the same pressure setting which varies. In this case a ground controller would be required to monitor this area. However this system alone would not provide the level of accuracy required at lower altitudes in an urban setting.
    - Drone position can be obtained from a global navigation satellite system (GNSS) network. However, this too is not accurate enough alone to determine drone altitude to the accuracy required at lower altitudes. The GPS network alone is also not suitable for drone navigation as it is prone to data degradation or complete loss of signal due to multipath effects, interference or antenna obscuration,so it will be necessary to have other systems present.
    - An inertial navigation system (INS) (also known as as inertial reference system or more generally an inertial measurement unit), is a self-contained system that does not require input radio signals from a ground navigation facility or transmitter. This system derives attitude, velocity and direction

information from measurement of the drone's accelerations given a known starting point, however over time the accuracy of this will also decrease and will require resetting. We recommend that the drone used in this situation use both systems together to improve navigational accuracy and for redundancy.

- o A further navigation technology that may be used is the use of vision sensors (e.g. optical cameras, hyperspectral sensors, Lidar), which sense the surrounding area directly and could be used in conjunction with a pre-loaded terrain database to complement existing navigation techniques.These vision sensors would primarily improve take-off and landing ability, with secondary function as a backup navigation source. Currently this is not commonly used for external navigation but could be a way of increasing accuracy of positioning and navigation.
- o To ensure safety and minimise risk of collision, the drones should broadcast their location and an ID signal to other airspace users and to any air/unmanned traffic management system. This capability is referred to as electronic conspicuity (EC). The current standard on aircraft is ADS-B, which has been allocated a specific frequency band in the UK (960-1215 megahertz). This has low transmit power levels, low cost and the potential to be interoperable with other ground and air users and would be the default choice at present, though other technologies for broadcasting position may be developed.
- o If drones are to operate in any mode they are required to 'be seen and avoided'. Detect and avoid systems currently alert pilot to other traffic and suggest resolving vectors. We recommend developing DAA systems to autonomously react to any aircraft installed with an EC device. This is a challenge together with the ability to detect traffic not fitted with EC devices (such birds).

Safety

- We have performed a qualitative risk analysis (SORA – Specific operation risk assessment)[9], to help identify the level of robustness required for all threat barriers based on the three categories of harm: injury to third parties on the ground, fatalities to third parties in the air (mid-air collision with a manned aircraft) and damage to critical infrastructure. Specific threats have been examined and graded on their perceived risk suggesting a required level of robustness against each threat. Threats include: human error, technical issue with drone, aircraft on collision course, deterioration of external systems supporting drone and an adverse operation condition. This analysis has been performed to help identify areas for further consideration and is not intended to be a safety case.
- The SORA assessment shows the risk of injury to people on the ground is high as the drone (max characteristic dimension less than one metre) is likely flying more than 500 feet over a populated environment. It is assumed that a harm barrier

9 http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v1.0.pdf

adaptation will be in place, with a high level emergency response plan, should the drone encounter any technical difficulties. When examining the risk of mid-air collision, based on altitude and airspace class, the airspace encounter rate is high, so is the risk. Based on this information it is recommended that the highest level of robustness is required for all systems to combat these threats.

- Safe operation: To mitigate these threats, the drone should be designed to interact with UTM systems to dynamically allocate airspace and thereby minimise the risk of collision. Use of ADS-B and detect and avoid devices would further reduce risks of collision. The development of drones rules of the air would aid in traffic deconfliction should differing levels of EC be used. Drone corridors would be an example of this.
- Redundancy: As the drone will be operating in a heavily built up area, we recommend that the rotors be individually powered by separate power management systems to allow for redundancy in the case of a rotor, motor or power failure.
- Failsafe: The drone should be designed in a way to minimise risk of catastrophic failure affecting people or buildings on the ground. This should involve building in redundancy (in the case of multicopter designs this is likely to mean six or more rotors) and is likely to mean the use of a parachute device in the case of total loss of power.

Environment

- Noise: Noise can annoy people, disturb sleep, impair cognitive performance and increase the risk of cardiovascular disease.[10] The impact of noise depends on many factors including what the drone sounds like, what kinds of manoeuvres it makes and the context in which it is operating.[11] The noise generated by this use case could affect many people in this densely populated part of London and may especially affect patients and staff in the hospitals. Because there will be regular deliveries, the noise could be particularly annoying for people who live or work under the flight paths. However, since the will already be quite a lot of background noise from the city, the drones may not cause much additional annoyance; different noise levels could be regulated for at different times. As a relatively small multi-rotor drone, noise levels produced by the drone would, in any case, not be particularly high.
- The impact of the noise could be reduced through the choice of route (including potentially varying the route), for example, having the drone fly via the river rather than overland (see above) and making sure the take-off and landing points are as far from patient accommodation as possible. The level of noise reduction needed may vary depending on the time of day, so the drone could operate differently during any night time operations.
- Weather/climate: Current multi rotor drones generally have recommended operating restrictions of 0-40°C and wind limitations of 19 knots[12], these can be more

10https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3971384/

11https://wrightacoustics.com/white-paper

12 https://dl.djicdn.com/downloads/phantom_4/en/Phantom_4_Disclaimer_and_Safety_Guidelines_v1.2_en_160317.pdf

restrictive during take-off and landing. The drone service must be able to operate year round and therefore needs to be able to operate efficiently in these conditions, as well as in moderate rain, poor visibility and cold temperatures sub zero degrees (where icing may be an issue). London can have unpredictable airflow in certain areas especially in the immediate vicinity of tall buildings thus drone design should incorporate tolerances in excess of the limitations above to maximise operational time.

- The design considerations should examine historic maximum wind speeds in London, potentially factored against statistical frequency to reduce extremes and balance cost. There are some extreme weather conditions that may prevent operations. We assume that for 3 per cent of the year (c. 11 days) they are unable to fly, a figure that roughly mirrors restrictions on aircraft.[13]

Regulatory requirements

- The drone operation will need to take place in Class D airspace and in the restricted areas London City. As well as permission required to operate in these areas, there is a requirement to define the rules and regulations for drones within this airspace, addressing the interoperability of cooperative and non-cooperative traffic, both manned and unmanned. Drone capability level together with UTM systems should be integrated into these rules.
- Operation will potentially need to take place over the Thames where London heli route 4 exists. Here drone operation is restricted to below 300 feet. The regulation will need to be amended to support this operation as it is currently set out.
- The London medical drone will be required to operate with a high level of autonomy BVLOS and fly over an urban setting within 50 metres of any person, vessel vehicle or structure. Regulation currently requires any commercial operation to prepare a safety case for submission to the CAA that addresses each of the limitations covered by the Air Navigation Order (ANO) above, however this is currently only for VLOS operation for drones weighing <20 kilograms. Regulation will need to address this for BVLOS operations.
- Overflight permission may be required from the Port of London Authority (PLA) and Network Rail to operate over their facilities and for the allocation of emergency landing sites. Relevant riparian (riverside) local authority, landowner consent where the drone flight and exclusion area will impact on adjacent land and Metropolitan Police filming unit (in the central London area) permissions will all potentially be required. If appropriate, a PLA Notice to Mariners will need to be issued for river traffic controlled by the PLA.
- Mobile phone networks are governed by the Wireless Telegraphy Act 2006. For mobile phones, the use of the spectrum by the network operators is licensed to cover the use of transmitters and repeaters which are under their control, while user

13 In practice drones are likely to have higher vulnerability to adverse weather due to their size and battery life. However, they would have more flexibility to deploy earlier or later compared to scheduled flights and the limits placed on them are unclear until the drone has been created and tested. As such we assume 3 per cent is a reasonable benchmark to apply in this case.

devices are covered by a general exemption. Cellular repeaters, boosters and enhancers are not accepted devices. In exploring our use case if cellular connectivity is to be used, collaboration with the network provider to increase the infrastructure required to realise the task is imperative. Additional boosters or infrastructure outside will require additional specific exemption.

- As the drone will be using specific radio equipment, it must comply with Ofcom regulations[14]. Within the UK the use of radio apparatus, including drones, is regulated by law. This ensures only equipment which is safe and does not cause harmful interference is placed on the market. The Ofcom licence and licence exemption state the terms and conditions on the use of radio apparatus.
- This use case will likely have to comply with the Network and Information Systems Regulation 2018[15]. It applies to 'operators of essential services', which includes healthcare organisations. It requires [16]them to take technical and organisational measures to manage security risks, such as having processes for incident handling.
- This use case will need to comply with the EU General Data Protection Regulation (GDPR)[17], which regulates how organisations can store and process personal data. The GDPR requires organisations to follow principles such as collecting the minimum amount of data needed for the organisation's purpose, keeping the data secure and informing people that their data is being collected. In this use case, data protection will need to be considered when dealing with patient data and any video footage collected.

Operations and traffic management

A traffic management system is required to:

- Track drone position so it is visible to both controllers on the ground and operators in the air, both manned and unmanned. Airspace violations can be monitored and dealt with accordingly by managing authority in this way.
- Identify when traffic will conflict and alert user or autonomously deconflict this trafic should no action be taken.
- Be interoperable with all traffic, other UTM systems and air traffic control.

Should drone deployment increase it is recommended to further develop electronic conspicuity devices together with detect and avoid systems, which securely integrate into the flight control system to autonomously react to any potential conflict. Traffic lanes should be developed with specified rules and regulations defined.

---

14 https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/drones-advice

15 http://www.legislation.gov.uk/uksi/2018/506/contents/made

16 https://ico.org.uk/for-organisations/the-guide-to-nis/

17 https://ico.org.uk/for-organisations/guide-to-the-general-data-protection-regulation-gdpr/

Security

The security of the drone is critical for all operations however there are particular sensitivities within London that need to be seriously considered. A security breach could allow attackers to steal data, control or influence the drone, or prevent it from operating. This could have several implications of varying impact. For example, if an attacker disrupted the drone then its payload could be delayed or lost, meaning that new tests would have to be done and transported.

There is also the risk that the drone could be used for malicious purposes. Central London includes a range of nationally sensitive sites such as the Palace of Westminster, tourist hotspots such as the London Eye and Tower Bridge and iconic buildings such as the Shard. The density of London and the presence of tall buildings and other aircraft such as emergency helicopters or airplanes given the proximity of London City airport, also means that there is little room for error.

There should be consideration not just for the malicious attacks but also to natural interference to signals, signal integrity and the potential for RF saturation which could all cause issues. This would require the use of redundant and independent systems such that a threat would need to overcome multiple systems to have a negative impact.

As the drone will be operating BVLOS this will significantly increase the complexity of ensuring the safe and secure operation of the drone, consideration should be built into the system to manage issues while out of line of sight, which may include trade-offs with other aspects of the system such as technology to increase privacy.

It will be important to check for security weaknesses across the whole system including areas such as communications, data storage and control software. For example, it may be possible for attackers to interfere with signals from command so it is important for communications to be encrypted and robust against jamming. It is also important to look at what is connected to the drone system: attackers can sometimes gain access to one system through another, connected system. In this case, the security of systems like navigation software or hospital logistics software should be checked. The physical security of the drone is also important. For example, a drone could be stolen from the takeoff or landing area.

Security is not just about having the right technology in place, it's also important to have good security processes. For example, there should be processes in place to regularly test for security weaknesses as well as monitor for and respond to security breaches. This use case may have to comply with the Network and Information Systems Regulation 2018[18]. It applies to 'operators of essential services', which includes healthcare organisations. It requires[19] them to take technical and organisational measures to manage security risks, such as having processes for incident handling.

18 http://www.legislation.gov.uk/uksi/2018/506/contents/made

19 https://ico.org.uk/for-organisations/the-guide-to-nis/

Privacy

Privacy is an important consideration for drone operation in densely populated urban areas like London. There is information that the drone could collect during a flight over a densely populated urban area. In this use case the drone may fly over private land and be able to see into normally private areas such residences, hotels, schools and businesses.

Navigation video may capture individuals and vehicles and could also capture the inside of buildings through windows; however there is no need to store this information unless there was a need to analyse the flight information in case of an incident. Operation should be consistent with data protection legislation.

The drones should also be operated by a trusted operator and under the jurisdiction of the NHS. This would reduce concerns around drones being used by system operators to violate privacy. Polling carried out as part of the Flying High project[20] shows that state and emergency services are more trusted than private operators of drones.

To support the adoption and to overcome the challenge of unknown drone systems operating in these areas, we recommend a service that makes it easy for the public to identify any drone and operator (this could be enabled by UTM and electronic conspicuity).

Economic and social feasibility

This economic feasibility study outlines the range and scale of potential benefits arising from drone deployment for the delivery of pathology samples in London. It focuses on the deployment of drones for the collection and delivery of post-kidney transplant patients' blood samples from the renal clinic in Guy's hospital to the laboratory in St Thomas's hospital.

There are three key sources of economic impact:

- Savings to the NHS and its partners from more efficient transportation due to lower marginal delivery costs and faster and more reliable deliveries.
- Health benefits that accrue to patients as a consequence of quicker testing.
- Benefits to the wider health network as a result of more efficient treatment including reductions in 'bed blocking' and improved intra-hospital transferring of samples.

In addition, the deployment of drones, at scale, is likely to improve the efficiency of deliveries between hospitals in London, supporting the shift towards a hub and spoke models. Given that NHS vehicles form a substantial amount of traffic in London, making use of drones is also likely to help reduce congestion and pollution, with associated social benefits to the city, as a whole.

20 https://www.nesta.org.uk/news/drones-in-our-cities-by-2020-predict-a-quarter-of-people-rising-to-half-by-2024/

Key assumptions to the use case

Key parameters to model the introduction of drones in this use case are the volume and cost of deliveries, the level of drone deployment and the estimated health benefits and savings. The key assumptions for this model can be found in the assumptions section.

Number of samples: 13,000 blood samples are delivered from the renal clinic to St. Thomas' laboratories for kidney transplant patients per year (c. 250 per week)

Number of deliveries: A maximum of ten samples can be included in each delivery. Drones operate 24 hours per day and we have conservatively estimated that the drone would on average make one delivery per hour (24 deliveries of 10 samples each per day).[21]

Number of drones: Two drones will be required, with one drone being in operation at a time. The second drone would allow for operations and the network's effectiveness to be maintained whilst one drone is either committed, charging, or requiring maintenance. Note that under the current use case the drones would operate below capacity.

Drone cost: The approximate cost of a drone of this specification is £25,000. Accounting for the constant innovation in drone technology, we have assumed this price to decrease to £10,000 between now and its first day of operation.

Cost of wider supporting infrastructure: Three FTE members of staff would be required to run the network for 24 hours at an annual costs of c. £107,000. Training cost for each staff member is estimated at c. £1,500[22]. Fixed infrastructure from fitting landing spots to existing buildings are estimated at £5,000. Maintenance and replacement costs are estimated at 5 per cent of the drone cost per year.

Cost of delivery: Given the low cost of charging such appliances, we assume a medium marginal cost of using the drone of £0.02 per sample, i.e. £0.20 per delivery (after accounting for salary and infrastructure, primarily drawn from the cost of charging and electricity).

Social benefits: For this use case, we have excluded an assessment of the social benefits given small volumes and existing efficiencies within the NHS in the delivery of post kidney transplant blood samples. However, it is likely that social benefits will unlock at scale.

Drones enable timely deliveries at low marginal costs - however, they require significant upfront investment.

The use case, as defined, is of limited scope and reflects the need to provide a solid proof of concept prior to deploying drone technology at a larger scale and for more sensitive

---

21 Please note that in this particular use case the drone would be operating significantly below full capacity.Additional pathology test samples (e.g. biochemistry tests) could be included in this same set of drone deliveries but have been exempted from this analysis.

22 The baseline 2018 salary estimate was £35,000; this was uprated to 2019 prices using recent OBR CPI estimates found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

samples and tests. Benefits in this use case are more limited, stemming exclusively from the relatively lower marginal cost of delivery by drone compared to the couriers.

At the scale of a single link serving Guy's and St Thomas' hospitals, our modelling suggests the cost and time savings to the NHS are negligible, arising from a small saving in the cost of delivering samples between these two hospitals. However a medical delivery network operating at scale would unlock economic benefits that this individual link would not on its own.

For patients, the difference in speed of getting these samples transported by drone rather than by the current courier service is small, as 95 percent per cent of samples are already processed the day they are collected.

As such, our modelling indicates that this use case would not be economically feasible on its own, although drone usage for different treatments, or at a different scale could be. Given the need to prove the technological capacity prior to operating at this scale, the use case is best viewed as a proof of concept, rather than a definitive view of the economic returns to deploying drones.

Using drones at scale can lead to cost savings

Insofar as the fixed infrastructure of the network permits a sufficient number of drones to operate, then even with the samples not delivering any improved health outcomes, the use case would become economically feasible if the number of deliveries increased. If the capacity of a network of six drones [23] were leveraged to deliver approximately 800 deliveries per day, then the fixed cost of the investment in drone technology would repay its total costs in Y12, before delivering significant savings in the future. This scale is possible; newborn blood spot screening alone accounts for approximately 160 deliveries per day for St Thomas' hospitals, so combined with other tests it is possible that such a scale could be reached.

23 Beginning with three in Y1, increasing to four in Y6, five in Y9 and six in Y11.

Annual cost, annual cost savings, and annual social benefit, alternative scale of delivery, Y1-Y12 (2019 prices)

Source: WPI analysis

Notably, this scenario does not account for efficiencies in intra-hospital transfers, or from traffic reductions, nor for the fact that some of the samples included in this scenario may deliver larger health benefits from the improved journey time.

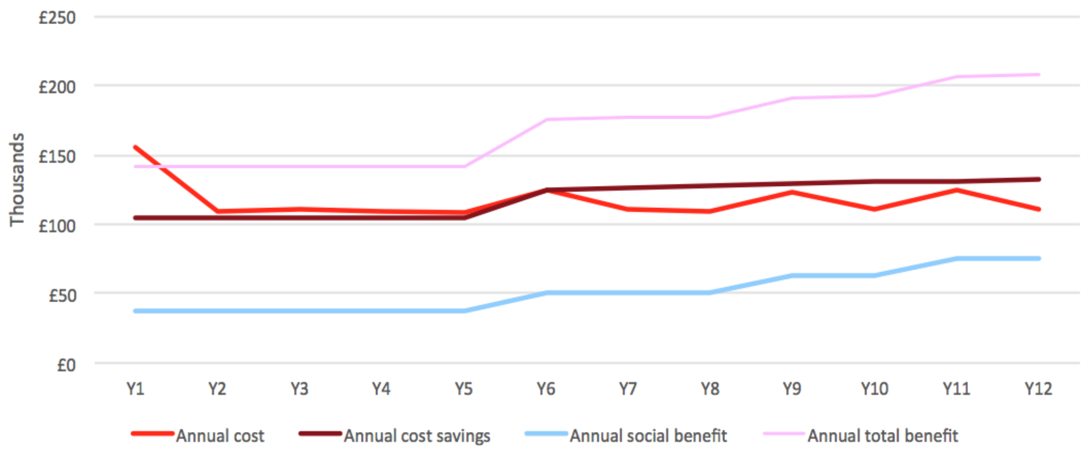
Depending on the type of sample and mode of delivery, drones can help improve medical outcomes for patients

The use case modelled does not account for the fact that drones could help create social value by tackling other forms of inefficiency within the system; for example by reducing congestion caused by large-scale transfer of samples between hospitals, eliminating the delays caused by intra-hospital transfers or improving the efficiencies within laboratories. To model this, an assumption was made that there would be a 0.25 percent per cent increase in efficiency per drone deployed and that a one percent per cent increase in efficiency would be associated with social benefit of £50,000.[24] In practice this is a per-drone contribution to wider social benefits that acts as a proxy for the other sources of economic impact that have not been explicitly modelled.

The following chart displays the results of our analysis of the 800 deliveries per day scenario when including the social benefits.

24 This is an indicative model as there was no obvious way to value the dynamic and distributed effects from a reduction in congestion, or how the costs of intra-hospital delays would change.

Annual cost, annual private benefits, annual social benefit, and annual total benefit, Amended scenario with social impact, Y1-Y12 (2019 prices)



Source: WPI analysis

The results of this model indicate that whilst the cost savings generated by the drone deployment would not be sufficient to justify the investment in the first years, the difference that the social benefit makes, means that by Y5 the annual social benefits combined with efficiency benefits outstrip the costs of the technology. Notably this is assuming that there are no health benefits derived from each treatment, so the returns are purely driven by logistical cost savings and efficiency gains. This illustrates that a sufficient scale that creates efficiencies within the network could also mean that this use of drone technology becomes economically feasible.

It is worth noting that there are a number of other samples that are delivered at scale and that would bring about significant health benefits for patients, e.g. swabs for respiratory virus infections or blood culture bottles to support the rapid identification of sepsis. These use cases could reduce deaths, hospital acquired infections and bed stay days all with a demonstrable health-economic benefit.

Conclusions and recommendations of the technical and economic feasibility study

Conclusions

The London use case in summary could have strong social benefits and is feasible in principle. However, there are a number of challenges that need to be overcome in order to make this use case a reality.

The key challenges (C1-7), based on our analysis, are

C1. The development of a drone system that can operate safely, securely and reliably beyond visual line of sight in London's complex environment, while maintaining appropriate levels of privacy.

C2. The provision of suitably managed urban airspace. In the first instance air corridors could be identified with defined width and height, to help manage interaction with other airborne systems.

C3. The development of key elements of drone and drone systems technology, particularly with respect to automated systems that remove routine elements of human interaction, eventually moving to a fully autonomous system.

C4. Achieving the scale of service that is needed in order to achieve economic viability.

C5. The impact of noise from drones in close proximity to hospitals is currently unknown. Although hospitals have high levels of sound insulation, understanding of the effect of possible local drone operations on patient well-being is limited.

C6. Operation with high stability and in close proximity to buildings, with consideration to wind gusts, cross winds, building updrafts and downdrafts and wind tunnel effects.

C7. Operation in low light, at night time and in adverse weather, including high winds, rain, snow and poor visibility.

Recommendations

The following recommendations relate directly to the seven challenges outlined above (referenced in brackets).

A. Regulatory change to enable routine drone operations at scale, beyond visual line sight and near people, buildings or vehicles. (C1 and C2)

B. The development of a new form of airspace management to enable safe automated drone operations at scale. (C1 and C2)

C. Electronic conspicuity devices fitted to all air traffic and integrated into a system, to improve safety, security, privacy and positive public perception. (C1 and C2)

D. Secure interfaces into other systems and infrastructure needs to be considered, with the number of interfaces minimised and encrypted. (C1)

E. Development of technologies that can demonstrate safe operation through high levels of redundancy, including secondary and possibly tertiary systems for command and control, navigation, power and propulsion systems. (C1)

F. Development of counter drone systems to identify and manage uncooperative drone operations, either malicious or accidental. (C1)

G. Development of registration and enforcement systems, with appropriate resource to ensure operator accountability. This should include a centralised database showing licensing of operator competency, the platform ID and airworthiness and the capability to provide real-time monitoring of the airspace. (C1, C2 and C3)

H. Requirement to develop tools and standards for the verification and validation of the drone components, platforms and systems, with traceability of the hardware and software supply chains. This should include development of simulation tools to ensure safe operation and validation of autonomous and machine learning systems. (C1 and C3)

I. Development of appropriate safety cases associated with the use case that could be published and used as standard scenarios to support the regulator and the growing UK industry. (C1 and C2)

J. Establishment of clear, accountable ownership and sign-off responsibility over the various aspects of operation. This includes maintaining airworthiness, oversight of system upgrades, assurance of pre-flight checks, the flight, associated safety related flight data and appropriate legal accountability and insurances. (C1 and C2)

K. Integration and interoperability between airspace management systems. This will require both technology solutions as well as co-ordinated standards, legislation and process development. (C2)

L. Coordination with other aligned technology areas around common challenges, which could include collaborations with the robotics and autonomous systems and connected and autonomous vehicle communities. (C3)

M. Development of technologies and regulatory frameworks to allow the systems to scale safely and in line with growing market demand. (C4)

N. An analysis of the impacts of drone noise on the urban environment and population. (C5)

O. Development of capabilities to ensure safe flight during adverse weather conditions and in low light or at night time. (C7)

P. Development of tests that prove out the capability of the platform and system in representative environments. Leading to trials with growing complexity, moving from controlled environments to full public demonstrations. (C1-7)

Technical and economic feasibility study: traffic incident response in the West Midlands

Using drones as a rapid response to respond to road traffic incidents

- Fast observation drones can reach the scene quicker than the emergency services
- Emergency services can obtain aerial imagery of the scene and improve their response
- Drone imagery can also be used to investigate the causes of an incident
- We find this use case is both technically and economically feasible

Introduction

This section outlines the use of drones for response to traffic incidents on the West Midlands road network. Specifically, this use case investigates using drones to provide real-time information prior to first-responder arrival, to support the emergency services during incident response, to photograph, scan and film the scene to reduce road closure time. The drone would act to support first responders by giving them additional information, helping them to respond more effectively to incidents.

Note that the focus of this use case is on responding to and recovering from traffic incidents, rather than preventing them.

We consider a specific case study of response to incidents on the strategic road network in the area between Birmingham and Coventry, covering Solihull.

General discussion

The case for traffic incident response in the West Midlands

Britain's roads are among the safest in the world and have been getting safer over time.[25] However they are still the site of numerous incidents. In the year to September 2017, there were 174,510 casualties with 25,290 people seriously injured and 1,720 people killed in Great Britain.[26] As well as causing death and injury, road traffic incidents cause serious disruption to travel.

25 http://www.worldlifeexpectancy.com/cause-of-death/road-traffic-accidents/by-country/

26 https://www.gov.uk/government/statistics/reported-road-casualties-great-britain-provisional-estimates-july-to-september-2017

The West Midlands region is an interesting testbed for innovative responses to road traffic incidents for a variety of reasons.

- It is a heavily populated area that features several large cities and towns - Birmingham, Solihull, Wolverhampton and Coventry - in close proximity - as well as Solihull which is home to Birmingham International Airport.
- It lies at the heart of England's road network, with major roads including the M1, M5, M6, M40 and M42 motorways and numerous A roads passing through.
- It has a large number of traffic incidents - 5,905 in 2016 in the West Midlands Police area (which covers the same territory as the West Midlands Combined Authority), the largest number of any police force area outside London.[27]
- The West Midlands Strategic Transport Plan places particular importance on the smooth movement of people and freight through the West Midlands metropolitan area.

The use of drones could eventually be scaled up to help all types of emergency services across the West Midlands. The drone network could provide fast initial assessment and ongoing monitoring of emergencies. As AI technology improves, drones may be able to carry out more complex tasks such as summarising key information about an incident.

Future implications of traffic incident response in the West Midlands

There is a longer term prize if we prove this concept

Proving the concept of drones for response to traffic incidents could pave the way for more ambitious drone-operated traffic services.

Drones could proactively monitor traffic for incidents and be first on scene to gather information and send it back to en-route emergency services. They could also gather data to help manage traffic flow - looking for blockages and sending that data to systems that could, for example, change the frequency of traffic lights. They could be used to enforce laws - watching for dangerous driving or unsafe vehicles and sending that information to the police.

Benefits of traffic incident response in the West Midlands

Economic benefits

Deploying drones in traffic incidents is likely to generate savings to emergency services, as well as broader benefits arising from reduced road closures, such as faster journey times, ultimately, lowering levels of disruption.

27 https://data.gov.uk/dataset/cb7ae6f0-4be6-4935-9277-47e5ce24a11f/road-safety-data

Drones can provide fast situational intelligence of any traffic incident, allowing a quicker and more efficient coordination of the appropriate emergency response, as well as allowing intelligence (e.g. photos of the scene) to be taken quickly from an aerial perspective. This could mean:

- More precise deployment of equipment: Having a better vision of the immediate crash site would allow the correct amount of police and ambulance resources to be dispatched. In some cases, this could mean a more appropriate response (for instance medical resources being sent earlier), in other cases it would mean sending fewer resources to more routine incidents which do not require them.
- Reducing time on-site: After a traffic incident a significant portion of police time will be spent taking photos of the scene, statements and evidence. Having a drone in position to capture a highly accurate 3D replica of the crash scene could significantly reduce the time burden.
- Providing more accurate information: Drone deployment could also allow more accurate evidence to be collected, as often evidence such as tyre markings or vehicle positions are obscured after major traffic incidents due to the presence of emergency services altering the scene.

As such, the economic impacts of this drone deployment primarily occur in two areas: during the immediate response to a traffic incident and after the incident, when incident clearance can be expedited and economic benefits delivered.

Social and environmental benefits

Additionally, some of the large economic costs associated with traffic incidents arise from the congestion and pollution caused by built-up traffic following lane closures enacted during the incident and afterwards, during incident clearance. Reducing the time for the latter due to automated video, 3-D mapping and evidence collection would allow lanes to be reopened earlier, increasing traffic flow and reducing the lost economic benefit. Possible benefits from this include:

- Benefits to the economy: For example, reducing the lost output due to workers being delayed, or transportation of key goods being slowed down by congestion.
- Impacts on local communities and economies: This could include reducing noise pollution, congestion and other issues as routes are redirected.
- Accurate information to (air) ambulance services: Timely access to information such as the number of people hurt, the location of the people will inform a more accurate response from the emergency services.
- Reduced externalities: Quickly clearing parts of the strategic road network maintains the traffic flow, reduces congestion and cuts emissions and pollution.[28]

If drones capture the site of an incident prior to emergency services arriving, the police will be able to obtain footage of the scene of an incident, before it is potentially altered by the

28 https://www.sciencedirect.com/science/article/pii/S2352146517305896

arrival or movement of emergency response vehicles. This will support subsequent police investigations, detailing details such as tyre marks or positions of vehicles, which would have been altered by emergency and other vehicles accessing the incident site.

According to a 2010 report by the RAC Foundation, it is possible to take a view on whether a prosecution is likely within 15 minutes[29]. If prosecution is not likely, examination could take as little as 30-60 minutes. However, in practice investigation still takes three to four hours as police also have to produce a report for the coroner and they also have an eye on how they can assist within the civil sphere e.g. in subsequent litigation.[30]

Example: rapid response to a major incident on the West Midlands road network

We explore how such a service would respond to a major traffic incident in an area between Birmingham, Solihull and Coventry, in order to better understand the challenges of this use case

As a test case to explore the technical and economic feasibility of the use of drones in response to traffic incidents, we have focused on the rapid response to a hypothetical major incident on the West Midlands road network between Birmingham, Solihull and Coventry, within a seven-mile radius of Birmingham International Airport, located in Solihull.

We have chosen this location because it has a number of interesting features that help prove the concept. These include:

- Location centred on Birmingham International Airport: this is both an opportunity (for a base of drone operations) and a complicating factor (controlled airspace) which it is useful to understand better.
- Several key roads including the M6, M42 , A38(M), A34, A41, A45 and A452,
- A mixed urban, suburban and rural environment taking in parts of Birmingham, Coventry, their suburbs and the surrounding countryside, as well as Solihull town centre.
- A location where there has been historically a large number of major traffic incidents.
- A region that is very active in the development of new innovative technologies including the Midlands Future Mobility Testbed, utilising over 50 miles of Birmingham and Coventry's roads to establish the Midlands as a world-class UK centre for the development and evaluation of connected and autonomous vehicles.

The choice of a seven-mile radius around Birmingham International Airport is consistent with a rapid response time where eyes could be on scene, assuming clear weather conditions and a high optical zoom camera in under three minutes and at the scene in

29 https://www.racfoundation.org/wp-content/uploads/2017/11/road-accident-delays-yass-april-report.pdf

30 https://www.racfoundation.org/wp-content/uploads/2017/11/road-accident-delays-yass-april-report.pdf

under five minutes;while also taking in a significant area of dense road network and part of both the Birmingham and Coventry urban areas.

In this area of 154 square miles, the West Midlands police responded to 10 fatal, 215 serious and 1,223 slight incidents in 2016[31], meaning this drone could potentially be in service multiple times per day.

Following report of an incident requiring further intelligence, the rapid response drone with a thermal and RGB video camera would be dispatched in order to get eyes on the scene as quickly as possible and stream information back to an operator. A second drone would be on standby, ready to be dispatched to the scene if necessary to take over from the first drone to provide more advanced data capture. This second drone could have a more advanced payload such as a high resolution optical zoom lens or Lidar and would be able to loiter above the scene for long periods. The decision to dispatch the first drone could be made by an operator or automatically based on a set of pre-defined criteria or a particular type of alarm. Both drones could be the same type of high-endurance platform and be required to travel at high speeds and/or circle the site for long periods of time, implying a fixed-wing drone. The initial response drone needs to arrive at the scene quicker, therefore needs a lighter payload, while the second drone would require greater endurance and more advanced payload. To facilitate operations and avoid the need for a runway, launcher or catcher, the drones should be able to take off and land vertically, implying a hybrid VTOL fixed-wing drone.

This analysis is based on the drones being used for three key tasks:

Situational intelligence: a drone can move much faster than emergency services ground vehicles can reach the scene of an incident and this is particularly the case for a fixed-wing drone as these move faster than multi-rotor drones. This allows the emergency services to have a visual on the scene more quickly and begin planning prior to arrival on the scene - this clarifies the extent and seriousness of the incident and would allow rapid estimation of how many police officers, fire appliances and ambulances are likely to be needed and potentially what route they should take to reach the incident. It can also prepare the first responders prior to their arrival at the scene, giving early warning of fire or corrosive substances and even supporting active scene management ahead of their arrival.

Improved response: once first responders are on site, a drone would provide an overview of the crash scene, guide response to casualties, collect evidence and provide information for diversion of traffic.

Faster recovery: the drone would guide the recovery of vehicles, obstructions and debris from the carriageway and direct any essential repairs. It can speed up collection of evidence (such as tyre marks, position of vehicles, debris) in cases of crashes that might result in criminal charges, reopening the road more quickly.

31 Data extracted from http://data.dft.gov.uk/road-accidents-safety-data/dftRoadSafety_Accidents_2016.zip

Technical attributes

This section outlines the key technical attributes that would be required of two drones to operate a traffic incident response service in the West Midlands.

Flight plan

For the purpose of this feasibility study, the drone service for this use case is based at Birmingham International Airport. This has been selected so that the particular challenges of safely integrating manned aircraft with unmanned aircraft can be considered. The operation could in theory use the current air traffic control infrastructure at Birmingham International Airport. The drone would need to operate away from the runway and could be launched for rapid deployment and directly routed to the site of a traffic incident anywhere within a seven-mile radius. As it is not known where the incident could occur there would be no fixed routes. A small amount of pre-flight planning would be required.

Altitude and airspace

The airspace in the West Midlands is dominated by restrictions surrounding Birmingham International Airport (in the centre) and to a lesser extent by Coventry Airport (in the bottom right). Credit: Altitude Angel

Around the West Midlands there are several controlled airspace zones, predominantly surrounding Birmingham (BHM CTR:118.05 SFC-4500ALT) and Coventry (COVENTRY:119.25 SFC-2281MSL) Airports. Several danger areas also exist (around Lichfield and Sutton Coldfield). These are significant as they are close to the M6 and major A roads (A5, A38).

The area of operation for this use case is surrounded by Class D airspace. This airspace is likely to contain high volumes of aircraft. Under current regulation, drone operation in this airspace is not recommended, if it is permitted, it should be within the operator's visual line of sight and following the CAA Drone Code. The operation would require permission to operate beyond visual line of sight (BVLOS) in order to be feasible.

Class D airspace is for instrument flight rules (IFR) and visual flight rules (VFR) flying. This means that air traffic control (ATC) clearance is required (as is a radio) together with mandatory compliance with instructions; there are also speed restrictions of 250 knots below 10,000 feet though this is significantly faster than is required for this use case. If flying under VFR at low level, the drone will need to remain clear of cloud visually. The visibility must be greater than five kilometres and speed must not exceed 140 knots over the city.

Because the operation in the West Midlands is envisioned to be BVLOS, at least in part, it would therefore need to be IFR capable. This is due to VFR flights being premised on the pilot being able to discharge responsibility by unaided visual processes (they can see and avoid the hazard), however BVLOS cannot be achieved under VFR rules - as it cannot be by unaided visual methods - hence must be IFR.

Air traffic zones (airports)

Both Birmingham and Coventry airports are surrounded by air traffic zones. These areas have defined dimensions established around each aerodrome for the protection of aerodrome traffic. At present, the recommendation is to not operate a drone in this area. Permissions from the CAA will initially be required; to be sustainable a specific permission or exemption would need to be granted and to allow drone operation at scale, this would need to be reformed to streamline the process of getting permission to fly here.

Restricted areas (prisons)

The three prisons in the area, HMP Birmingham, HMP/YOI Swinfen Hall and HMP Featherstone are all restricted areas and declared a drone no fly done. Special permission or blanket exemptions from the CAA are required to operate in this area under current rules as it is a high-risk area.

The tallest structure within Birmingham is BT Tower at 152 metres (499 feet). Of the top 10, the majority are residential towers with heights of 76 metres (250 feet) to 122 metres (400 ft).

Operational cruise altitude could vary, however could be based on at least 100 feet obstacle clearance (this is scaled down from the principle of 1000 feet manned aviation obstacle clearance, unless under radar control), both drones would need to operate above 500 feet, which would provide sufficient margin from most obstacles below (not including BT Tower). For the rapid response drone a suggested altitude of 500 feet or 600 feet (above ground level) is recommended depending on the direction of travel. (We propose 500 feet if travelling east or 600 feetwest, following on from manned aviation rules of the air in which aircraft fly at an odd altitude flying east or even when flying west). As altitude separation in this scenario is significantly less than manned aviation, altitude systems need to be designed to a high accuracy especially as operation could take place in Birmingham Airport and within class D airspace. The second recovery drone could have a temporary restricted area put in place (radius and altitude) upon arrival at incident. In both cases a dedicated UTM will need to be designed, able to deconflict both drone and manned aviation traffic and to quickly block off a specific location based on emergency services requirements.

Take off and landing sites

This use case specifically looks at the opportunities and challenges of basing the drones at Birmingham International Airport. There are however a number of possible alternative take-off sites: drones could be positioned at strategically relevant positions along the road network or they could be placed at emergency service buildings such as police or fire stations where they could also support other emergency services (see Bradford use case).

Drone platform requirements

Platform type

- This use case has two potential operating requirements, having eyes on scene as soon as possible arriving rapidly at the incident site prior to first responders, which suggests the use of a fast fixed-wing drone and being able to carry out detailed scans and analysis of the crash scene. This could be provided by a two-drone service. Both could for example, be fixed wing hybrid VTOL platforms with a modular interchangeable payload system for flexibility. This use case will assume the use of two drones and a seamless handover between the two platforms such that there is uninterrupted coverage.
- Different incidents also require different responses. Slight incidents, for example, are estimated to require significantly less than two hours of drone time while serious or fatal incidents would benefit from having a drone deployed to the incident for a longer period of time. Having two or more drones ready for deployment presents the operator with different strategic options for response and a more efficient deployment and use of drones.
- The speed of the platform to arrive at the scene is critical, it is expected that the initial response drone would be launched and would fly at speeds in excess of 80 knots meaning flights times would be approximately 4 minutes 30 seconds within the 154 square mile area. The second drone could fly at much slower cruising speeds to conserve energy.

Propulsion

- As it will operate in a heavily populated area with significant air quality problems, a zero-emission power system would be beneficial and should be a medium-to-long term aim. The first drone would be developed to provide a rapid response and have appropriate power system to support this. The second drone could trade off some payload for longer endurance battery. Battery operations can be affected by extreme temperature variations, in particular very cold weather, which should be considered.
- Endurance: both platforms would need to be able to operate within a seven-mile radius of Birmingham International Airport.

For this use case there are a number of drone types that could be considered. Major incidents can take a long time to clear and although this use case aims to reduce this time significantly the operation could still be a number of hours.

The length of time to clear an incident might lend itself therefore to having more than one drone.

The drone should be designed for a quick turn around of a platform, either through battery swap, use of fuel cell technology or fast-charging batteries.

A fixed wing hybrid platform can extend its duration by flying higher above the scene in a circle or by orienting into the wind when in a hover mode.

There will also need to be consideration for the extra energy drain while providing real-time HD video to the first responders as the camera, image processing and communications required for this need electricity.

Before handover to the secondary drone the charge status needs to be considered prior to returning and should factor in contingency for weather variations (wind), abnormal consumption, likely ATC/UTM re-routes and reaching emergency landing sites.

Payload, sensors and instrumentation

- Payload: The primary payload for the initial response drone would be high-resolution video camera with a high-powered zoom lens providing visibility of the incident site earlier. The second drone would lend itself to even high resolution such as a 4K video camera and possibly Lidar in order to build a very accurate representation of the incident site. Thermal imaging would be beneficial on both drones, in the first instance to identify any heat sources or injured people disoriented and leaving the scene.

If the same drone platform was used these payloads could be modular and interchangeable providing flexibility when scaled. It is recognised that technology developments are constantly enhancing the quality of these sensors. Although Lidar sensors can be expensive they are reducing in cost, size and with enhanced accuracy.

- Sensors and instrumentation: The drone should carry a high resolution camera for remote piloting (this should be separate from the payload) as that camera would not necessarily be pointing forwards. Both drones should carry an ADS-B electronic conspicuity device.

Communications, navigation and control

- Communications
  - A robust communication system will be needed for the following purposes:
  - Control of the drone autonomously, with telemetry data (position, speed, battery status) relayed to pilot/mission controller for tracking and safety monitoring.

- In case of a systems failure the drone pilot should be able to control the drone and land it safely, which would require a first person video as the drone will be flying BVLOS.
- Transmit location to other airspace users and air traffic service providers (e.g. a UTM system or air traffic control) - via an electronic conspicuity device.
- The broadcast of real-time HD video feeds from the crash site to the emergency services.
- Redundancy will need to be built into the communications channels to allow for failure or loss of communications, thus a primary, secondary and possible tertiary communications channel will be necessary.
- The primary communications channel needs secure coverage over the entire journey, as the drone is operating in busy airspace and over urban populated areas, where the risk to people on the ground and air is greater. Bandwidth should be sufficient to transmit telemetry data.
- The cellular mobile network in general meets these criteria, as this has a combination of generally good coverage (especially within city locations), high bandwidth and good security. As infrastructure is generally preexisting, it is readily available and cheap. Additional boosters or infrastructure outside the network area can address any coverage shortfall, with due consideration to any approvals required.
- The transmission of real-time HD video may require different technology. 4G LTE networks may have sufficient bandwidth as long as it can be appropriately secured, future 5G networks would provide greater bandwidth still. There is also the option of the new Emergency Services Network (ESN) being developed with integrated 4G voice and broadband data services.
- Using the mobile cellular network requires drones to support a SIM and connectivity module, so hardware and software can be updated when specifications change. Using drones equipped with a SIM card, existing mobile infrastructure can be used which will facilitate fast growth and reduce costs.
- There are limitations to the use of the mobile spectrum, the network is aimed at optimising signal on the ground, rather than in the air.
- Should the drone experience a systems failure, it is recommended to have a different method for backup control in addition to the mobile network, such as data link control via satellites. Note this will be used for control of the drone and not video feed.

- Navigation and control
  - The drones will be flown BVLOS autonomously, from a control station with a pilot present, able to monitor the flight and take control in case of an emergency.
  - Accurate knowledge of the drone position (latitude, longitude and altitude) is required.

- In manned aviation barometric pressure is the primary means of altitude determination, however this requires all aircraft in the vicinity to be on the same pressure setting which varies. In this case a ground controller would be required to monitor this area. However this system alone would not provide the level of accuracy required at lower altitudes as in this use case.
- Drone position can be obtained from the Global Navigation Satellite System (GNSS) however, this is not accurate enough alone to determine drone altitude to the accuracy required at lower levels. GPS alone is also not suitable for drone navigation as it is prone to data degradation or complete loss of signal due to multipath effects, interference or antenna obscuration, it will be necessary to have other systems present.
- Drone position can be obtained from a global navigation satellite system (GNSS) network. However, this too is not accurate enough alone to determine drone altitude to the accuracy required at lower altitudes. The GPS network alone is also not suitable for drone navigation as it is prone to data degradation or complete loss of signal due to multipath effects, interference or antenna obscuration, it will be necessary to have other systems present.
- An inertial navigation system (INS) (also known as as inertial reference system or more generally an inertial measurement unit), is a self-contained system that does not require input radio signals from a ground navigation facility or transmitter. This system derives attitude, velocity and direction information from measurement of the drone's accelerations given a known starting point, however over time the accuracy of this will also decrease and will require resetting. We recommend that the drone used in this situation use both systems together to improve navigational accuracy and for redundancy.
- A further navigation technology that may be used is the use of vision sensors (e.g. optical cameras, hyperspectral sensors, Lidar), which sense the surrounding area directly and could be used in conjunction with a pre-loaded terrain database to complement existing navigation techniques.These vision sensors would primarily improve take-off and landing ability, with secondary function as a backup navigation source. Currently this is not commonly used for external navigation but could be a way of increasing accuracy of positioning and navigation.
- To ensure safety and minimise risk of collision, the drones should broadcast their location and an ID signal to other airspace users and to any air/unmanned traffic management system. This capability is referred to as 'electronic conspicuity'. The current standard on aircraft is ADS-B, which has been allocated a specific frequency band in the UK (960-1215 megahertz). This has low transmit power levels, low cost and the potential to be interoperable with other ground and air users and would be the default choice at present, though other technologies for broadcasting position may be developed.

- o If drones are to operate in any mode they are required to 'be seen and avoided'. Detect and avoid systems currently alert pilot to other traffic and suggest resolving vectors. We recommend developing DAA systems to autonomously react to any aircraft installed with an electronic conspicuity device (EC). This is a challenge together with the ability to detect traffic not fitted with EC devices (such as birds).

Safety

- We have performed a qualitative risk analysis (SORA – Specific operation risk assessment)[32], to help identify the level of robustness required for all threat barriers based on the three categories of harm: Injury to third parties on the ground, fatalities to third parties in the air (mid-air collision with a manned aircraft) and damage to critical infrastructure. Specific threats have been examined and graded on their perceived risk suggesting a required level of robustness against each threat. Threats include: human error, technical issue with drone, aircraft on collision course, deterioration of external systems supporting drone and an adverse operation condition. This analysis has been performed to help identify areas for further consideration and is not intended to be a safety case.
- The SORA assessment shows the risk of injury to people on the ground is above average as the drones (assumed max characteristic dimension <1m) are potentially operating BVLOS over a controlled area, located inside a populated environment. It is assumed that the harm barrier adaptation in place with have a high level emergency response plan, should the drone encounter any technical difficulties. When examining mid-air collision, based on this operation potentially taking place in an airport environment above 500 feet AGL, the airspace encounter rate is high.
- Safe operation: To mitigate these threats the drone should be designed to interact with UTM systems to dynamically allocate airspace and thereby minimise the risk of collision. Use of ADS-B and detect and avoid devices would further reduce risks of collision. The fixed wing VTOL is likely to loiter for significant periods of time above a crash site where people are working and should have redundant systems where possible.
- Failsafe: The drone should be designed in a way to minimise risk of catastrophic failure affecting people or buildings on the ground. This should include the ability to glide and is likely to mean the use of a parachute device in the case of total loss of power. Mitigations systems in place should consider deconfliction with other emergency responders (National Police Air Service, RAF and air ambulance), should the incident be part of a greater disaster.

Environment

- Noise: The noise impact of the drones for this use case is likely to be low: they do not fly fixed routes and so would not cause blight to any area under a flight path. While they may add noise to the scene of an incident as they loiter overhead, the scene will already be noisy.

32 http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v1.0.pdf

- **Weather/climate:** Current multi rotor drones generally have recommended operating restrictions of 0-40ºC and wind limitations of 19 knots. Fixed wing drones can operate in similar conditions however cross wind limitations can be reduced to 15 knots for take off and landing[33]. As we are potentially operating a hybrid VTOL drone, benefits of higher wind limitations for takeoff/landing and higher cruise wind tolerances can be expected.The drone service must be able to operate year round and therefore needs to be able to operate efficiently and with stability in these conditions, as well as in moderate rain, poor visibility and cold temperatures sub zero degrees (which can cause icing). Drone design should incorporate tolerances in excess of the limitations above to maximise operational time.
- The design considerations should examine the historic maximum wind speeds in the West Midlands, potentially factored against statistical frequency to reduce extremes and balance cost. There are some extreme weather conditions that may prevent operations. We assume that for 3 per cent of the year (around 11 days) they are unable to fly, a figure that roughly mirrors restrictions on aircraft.[34]

Regulatory requirements

- The drone operation will need to take place in Class D airspace, in both air traffic zones (Coventry and Birmingham) and in the restricted areas of West Midlands. As well as permission required to operate in these areas, there is a requirement to define the rules and regulations for drones within this airspace, addressing the interoperability of cooperative and non-cooperative traffic, both manned and unmanned. Drone capability level together with UTM systems should be integrated into these rules.
- The drones are potentially based at Birmingham International Airport and will thus take off and land here. Rules and regulations need to be developed for drone operations at this airport beyond special permissions, as should drone operations become more prominent in the future, normal operating procedures regarding interoperability will need to be defined.
- Both drones will be required to operate autonomously BVLOS and fly over an urban setting within 50 metres of any person, vessel vehicle or structure. Regulation currently requires any commercial operation to prepare a safety case for submission to the CAA that addresses each of the limitations covered by the Air Navigation Order (ANO) above, however this is currently only for VLOS operation for drones weighing <20 kilograms. Regulation will need to address this for BVLOS operations.
- The drone is required to operate over highways and preselect emergency landing sites. Overflight permission is likely to be required from the Highways agency to operate over their facilities and for the allocation of emergency landing sites.

33 Based on Flying High technical forum.

34 In practice drones are likely to have higher vulnerability to adverse weather due to their size and battery life. However, they would have more flexibility to deploy earlier or later compared to scheduled flights and the limits placed on them are unclear until the drone has been created and tested. As such we assume 3 per cent is a reasonable benchmark to apply in this case.

- As this is a emergency response operation the drone maybe required to operate beyond its regulatory limitations in some circumstances. It is suggested that regulation addressed this need with special dispensation should certain conditions be met as is currently the case with VLOS operations (E4506).[35]
- Mobile phone networks are governed by the Wireless Telegraphy Act 2006. For mobile phones, the use of the spectrum by the network operators is licensed to cover the use of transmitters and repeaters which are under their control, while user devices are covered by a general exemption. Cellular repeaters, boosters and enhancers are not accepted devices. In exploring our use case if cellular connectivity is to be used, collaboration with the network provider to increase the infrastructure required to realise the task is imperative. Additional boosters or infrastructure outside will require additional specific exemption.
- As the drone will be using radio equipment, it must comply with Ofcom regulations.[36] Within the UK the use of radio apparatus, including drones, is regulated by law. This ensures only equipment which is safe and does not cause harmful interference is placed on the market. The Ofcom licence and licence exemption state the terms and conditions on the use of radio apparatus.
- This use case will need to comply with the EU General Data Protection Regulation (GDPR)[37], which regulates how organisations can store and process personal data. The GDPR requires organisations to follow principles such as collecting the minimum amount of data needed for the organisation's purpose, keeping the data secure and informing people that their data is being collected. In this use case, data protection will need to be considered when dealing with the video footage that will be collected.

Operations and traffic management

A traffic management system is required to:

- Track drone position so it is visible to both controllers on the ground and operators in the air, both manned and unmanned. Airspace violations can be monitored and dealt with accordingly by managing authority in this way.
- Identify when traffic will conflict and alert user or autonomously deconflict this trafic should no action be taken.
- Be interoperable with all traffic, other UTM systems and air traffic control.

Should drone deployment increase it is recommended to further develop electronic conspicuity devices together with detect and avoid systems, which securely integrate into the flight control system to autonomously react to any potential conflict.

35 https://publicapps.caa.co.uk/docs/33/1233.pdf

36 https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/drones-advice

37 https://ico.org.uk/for-organisations/guide-to-the-general-data-protection-regulation-gdpr/

Security

The security of the drone operating across the West Midlands is of high importance. A security breach could allow attackers to steal data, control or influence the drone, or prevent it from operating. This could have several implications of varying impact. If the rapid response drone is prevented from responding, then it could mean that the emergency services are less able to allocate the correct resources. A security breach that caused the drone to interfere with the activities of the emergency services could cause a lot of harm. Given that sensitive information about the crash and the people involved will be contained in the pictures, their privacy should be protected.

It is not only malicious attacks that are problematic but also to natural interference to signals, signal integrity and the potential for RF saturation which could cause issues. This would require the use of redundant and independent systems such that a threat would need to overcome multiple systems to have a negative impact.

As the drone will be operating BVLOS this will significantly increase the complexity of ensuring the safe and security operation of the drone. The system therefore needs to manage issues while out of line of sight, which may include trade-offs with other aspects of the system such as technology to increase privacy.

It will be important check for security weaknesses across the whole system including areas such as communications, data storage and control software. The system is likely to to be integrated into existing emergency service communication systems such as the Emergency Services Network and these systems will need to be secure. It will also be important to secure the systems that are used to store and analyse the data collected by drones.

Security is not just about having the right technology in place, it's also important to have good security processes. For example, there should be processes in place to regularly test for security weaknesses as well as monitor for and respond to security breaches.

Privacy

Privacy is an important aspect to consider especially as the real time feed from the drone will be of a serious incident that could include a fatality. These images need to be handled with the utmost care and consideration.

The system itself could be managed through a secure network, one option would be to use the Emergency Services Network (ESN), which is currently being developed through the Home Office. It is very important that the data is managed through secure connections and that it is only used by the appropriate emergency services in a manner that helps them complete their job efficiently.

The drone has the potential to fly over private land and be able to see into normally private areas such residences, hotels, schools and businesses. All operations should be consistent with data protection legislation.

The drones should also be operated by a trusted operator and under the jurisdiction of the emergency services. This would reduce concerns around drones being used by system operators to violate privacy. Polling carried out as part of the Flying High project shows that state and emergency services are more trusted than private operators of drones.

To support the adoption and to overcome the challenge of unknown drone systems operating in these areas a recommendation would be for everyone being able to identify the drone and operator, this could be linked to electronic conspicuity devices or even a simple, easily-recognisable livery for the drone (as for existing emergency service vehicles).

Economic and social feasibility

This economic feasibility study outlines the range and scale of potential benefits arising from drone deployment in the West Midlands. Drones would be deployed to assist with traffic management and coordination at three points in time prior to responder arrival, during the response and after the response for an area within a seven miles radius around Birmingham Airport. There are two distinct sources of economic impact:

- Savings to emergency services generated by a more efficient response to traffic incidents.
- Benefits arising from reduced road closures, such as faster journey times and, ultimately, lower levels of disruption.

Key assumptions to the use case

Key parameters to model the economic and social impact are approximate savings on a per-incident basis and external benefits generated in terms of reducing road closures when there are traffic incidents and the associated reductions of congestion and pollution.

Number of incidents: This model is based on the number of incidents in 2017 in the area within a 7 mile radius around Birmingham Airport: 10 fatal incidents, 215 serious incidents and 1,223 slight incidents. Estimates were applied for population growth (0.74 per cent annual increase)[38] to increase these figures over time and minor reductions in the incident rate to reflect improved road safety (-1.96 per cent annual decrease in collisions)[39].

Number of drones: Two drones would be deployed with different technical specifications and functions.

38 This figure is the average population growth in the West Midlands over the past 4 years taken from https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland

39 This figure is the average change in collisions nationally over the past 6 years taken from https://www.gov.uk/government/statistical-data-sets/ras40-reported-accidents-vehicles-and-casualties#excel-data-tables-for-ras40

Drone Cost: Two fixed-wing VTOLs at a cost of £20,000 each. As described above, the drones will have interchangeable pay loads. An additional cost of £5,000 has been included for additional equipment (e.g. cameras).

Supporting infrastructure and staff: 3 FTE members of staff would be required to run the network for 24 hours at an annual costs of c. £107,000. Training cost for each staff member is estimated at c. £1,500[40]. Fixed infrastructure in the form of network integration and the costs of integrating drone functionality are estimated at £50,000. Maintenance and replacement costs are estimated at 5 per cent of the drone cost per year.

Drone deployment: The assumption in the model is that drones can respond to 10 cases per day, or approximately one case every 144 minutes, with no constraints on time of day that responses will occur. We assume that on average 1 per cent of responses will be to fatal incidents, 15 per cent to serious incidents and 84 per cent to slight incidents.

Cost per drone deployment: The cost per deployment is estimated as £0.50.

Savings per incident: Savings arise from a reduction of police and ambulance hours required at an incident site. These were valued using National Audit Office and West Midlands Police data. In addition, a 10 per cent reduction of congestion and lane clearance was priced into the model and a reduction in the social cost of incidents in 0.1 per cent of the cases.

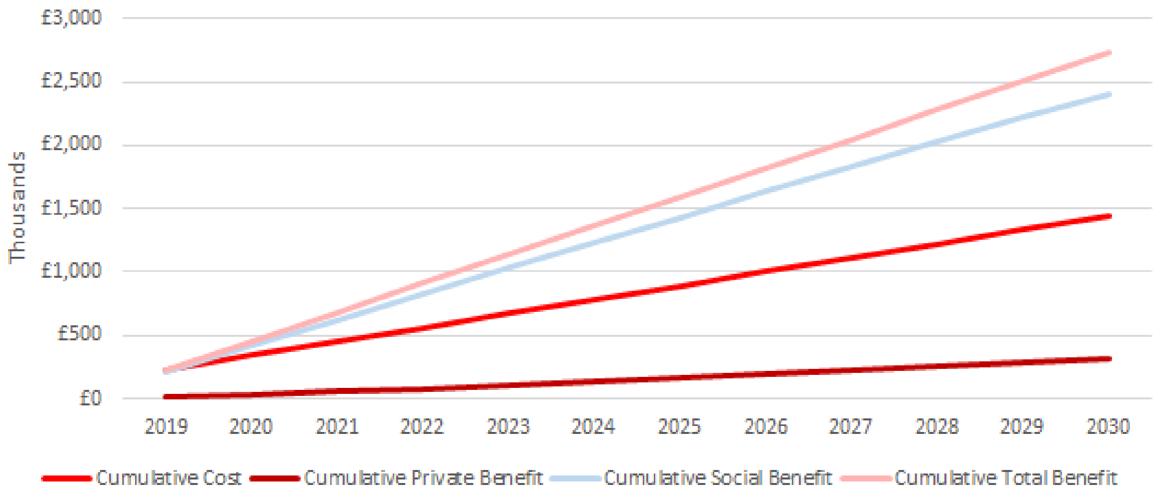
There is a strong economic benefit from using drones as a rapid response to traffic incidents.

Under the assumptions made, the deployment of drone technology in the West Midlands is highly economically feasible. The total economic benefit generated is positive in each year apart from the first, with a cumulative net total benefit of £1.25 million by Y12.

Two factors drive this finding. First, there are small but significant levels of cost savings that increase from £16,000 in Y1 to £31,000p.a.in Y12 as emergency services become better able to use drone technology to respond to emergencies in a timely and effective manner. However, these figures are insufficient to offset estimated costs of approximately £110,000 per year. The social benefit generated is therefore the central driver of economic feasibility. The social cost of incidents is so high that even minor increases in the probability of injuries being treated or responded to promptly generate substantial returns; across the network in Y1 this is estimated to generate over £60,000. These effects are dwarfed from the estimated value of reducing the cost of road clearances, which even under conservative assumptions add up to £140,000 in Y1 from reducing road closure during peak traffic times. Combined, these figures suggest that by Y12 the deployment would have generated over £2.4m worth of social benefit.

40 The baseline 2018 salary estimate was £35,000; this was uprated to 2019 prices using recent OBR CPI estimates found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

Total cost, total cost savings, total social benefit and total benefit, use case defined area, cumulative, Y1-Y12 (2019 prices)



Whilst the case is economically feasible, careful consideration would be required in policy terms to ensure that the economic benefit was captured sufficiently to finance the upfront investment required.

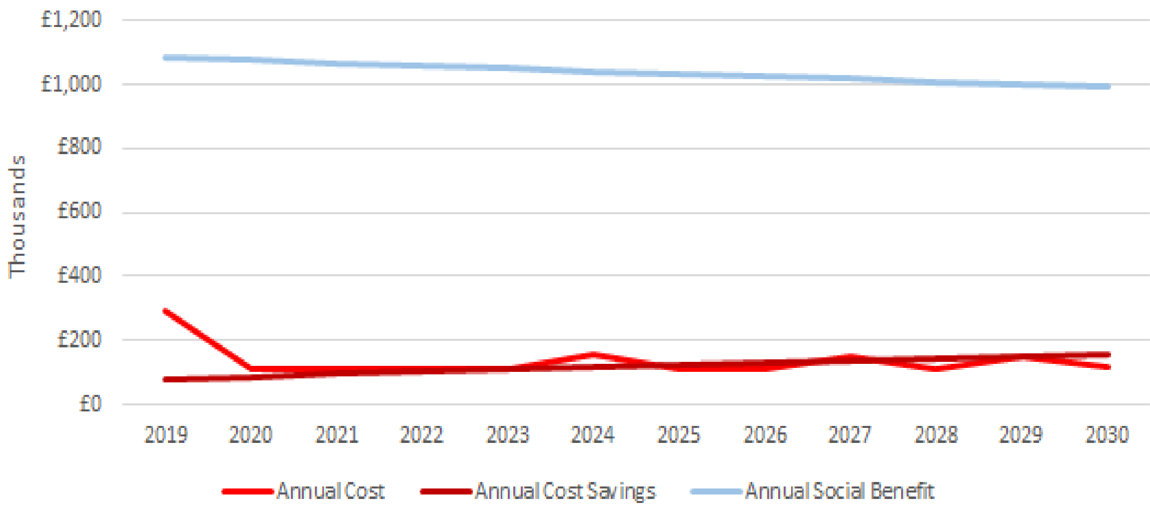
Covering a wider area and improving integration into the wider emergency response system can lead to further benefits

Our findings and the assumptions lead to two key conclusions regarding scalability; namely that benefits will increase with the area covered by the drone technology and the effectiveness of integrating the drone's information into operations.

By deploying drones in other areas that demonstrate a similar frequency of traffic incidents and concentration of traffic, similar returns could be expected. For example, using traffic and incident figures for the entirety of the West Midlands[41] and holding other assumptions constant, our model indicates that the scale is such that by Y12 the model is both economically feasible from a social benefit perspective, but also in terms of annual cost savings relative to annual operating costs:

41 For this scenario we used recent data that suggested there were 5,905 incidents in total, of which 60 were classed as having fatalities and 944 were classified as 'serious'. The rest were assumed to be 'slight'. For the purposes of the analysis we estimated six drones would be required in total to scale up covering this area.

Annual cost, annual cost saving, annual social benefit, West Midlands wide deployment, cumulative, Y1-Y12 (2019 prices)



As such, it is reasonable to believe that these findings are scalable if more drones are deployed across a wider area, but not if more drones are deployed within the same area. The social benefit decreases over time because the number of incidents declines over time due to increases in road safety (even accounting for population growth). This is offset for cost-savings by better/more efficient usage.

The scale of benefits delivered is highly dependent on the extent to which emergency services fully adopt the information gathered by the drone and integrate it into their deployment decisions. In the case where the drone simply provides information to the emergency services, but does not materially change how they operate, then the returns (either to the emergency services, or to wider society) are likely to be unchanged. If, on the other hand, the emergency services made substantial use of the drones to practically eliminate the need for police to take photographic evidence of the scene, to automate large portions of the more manual evidence collection, to substantially reduce the need for emergency responses to traffic incidents to consequently reduce the time taken for recovery, then the benefits would be much larger.

Other examples to achieve greater impact could also include leveraging the platform to help improve incident clearance by automatically re-routing vehicles away from traffic incidents, something which becomes significantly more plausible as vehicle connectivity improves. This again would be represented by a greater difference between costs under the baseline and the adjusted costs after drone deployment, in turn creating an increased level of savings.

Conclusions and recommendations of the technical and economic feasibility study

Conclusions

The West Midlands use case in summary has strong social and public benefits and is feasible in principle. However, there are a number of challenges that need to be overcome in order to make this use case a reality.

The key challenges (C1-6) for traffic incident response in the West Midlands, based on our analysis, are

C1. The development of a drone operation system that can operate safely, securely and reliably beyond visual line of sight, while maintaining appropriate levels of privacy.

C2. The provision of suitably managed unsegregated urban airspace allowing for interaction with other airborne systems, in particular integration with air traffic from Birmingham International Airport.

C3. The development of key elements of drone and drone systems technology, particularly with respect to more automated systems that remove routine elements of human interaction, eventually moving to a fully autonomous system.

C4. Achieving a large scale service with interoperability between all emergency services and fully integrated into the processes and systems for a rapid response by the appropriate organisations.

C5. Being able to operate in low light or at night time and in adverse weather, including high winds, rain, snow and poor visibility.

C6. Achieving high endurance for long dwell-times over the scene of an incident.

Recommendations

The following recommendations relate directly to the five challenges outlined above (referenced in brackets).

A. Regulatory change to enable routine drone operations at scale, beyond visual line sight and near people, buildings or vehicles. (C1 and C2)

B. The development of a new form of airspace management to enable safe automated drone operations at scale. (C1 and C2)

C. Electronic conspicuity devices fitted and integrated into a drone traffic management system to improve safety, security, privacy and assuage public concerns. (C1 and C2)

D. Secure interfaces into other systems and infrastructure needs to be considered with the number of interfaces minimised and encrypted. (C1)

E. Development of technologies that can demonstrate safe operation through high levels of redundancy, including secondary and possibly tertiary systems for command and control, navigation, power and propulsion systems. (C1)

F. Development of counter drone systems to identify and manage unauthorised drone operations, either malicious or accidental. (C1)

G. Development of registration and enforcement systems, with appropriate resource to ensure operator accountability. This should include a centralised database showing licensing of operator competency, the platform ID and airworthiness and the capability to provide real-time monitoring of the airspace. (C1, 2 and 3)

H. Requirement to develop tools and standards for the verification and validation of the drone components, platforms and systems, with traceability of the hardware and software supply chains. This should include development of simulation tools to ensure safe operation and validation of autonomous and machine learning systems. (C1 and C3)

I. Development of appropriate safety cases that could be published and used as standard scenarios to support the regulator and the growing UK industry. (C1 and C2)

J. Establishment of a clear, accountable ownership and sign-off of the various aspects of operation. This includes maintaining airworthiness, oversight of system upgrades, assurance of pre-flight checks, the flight, associated safety related flight data and appropriate legal accountability and insurances. (C1 and C2)

K. Integration and interoperability between airspace management systems. This will require both technology solutions as well as co-ordinated standards, legislation and process development. (C2)

L. Coordination with other aligned technology areas around common challenges. These could include collaborations with the robotics and autonomous systems and connected and autonomous vehicle communities. (C3)

M. There is an opportunity to develop technologies along with the Emergency Services Network being developed by the Home Office. (C4)

N. Development of technologies and regulatory frameworks to allow the systems to scale safely and in-line with growing market demand. (C4)

O. Development and integration of processes and standards to alert all the relevant organisations that need to respond to a major traffic incident. These processes should be able to scale to incorporate all incident types and all emergency services. (C4)

P. Development of capabilities to ensure safe flight during poor weather conditions and during low light or at night time. (C5)

Q. Development of high endurance platform technology to ensure extended coverage and support during a major incident. This should include the development of systems that seamlessly handover from one drone to another. (C6)

R. Development of tests that prove out the capability of the platform and system in representative environments. Leading to trials with growing complexity, moving from controlled environments to full public demonstrations. (C1-C6)

Technical and economic feasibility study: Southampton-Isle of Wight medical delivery

A fast connection across the Solent and to nearby cities for essential medical deliveries

- Using drones for medical deliveries bypasses a slow and expensive ferry service
- A service like this would fulfil a clear need for ad hoc deliveries
- We find this use case to be technically and economically feasible

Introduction

This section outlines the use of drones to carry urgent items over relatively long distances (around 10 to 20 miles) across the Solent from Southampton to the Isle of Wight, a route with no ground transport connection. We consider the general opportunity for medical delivery across the Solent, then focus specifically on the opportunity for transport of blood and blood products between hospitals in Southampton, the Isle of Wight, Portsmouth and Bournemouth.

In the longer term this type of drone could be used for a number of medium-distance drone freight applications, particularly across water to locations such as the Scottish Islands.

General discussion

The case for medical delivery by drone in the Solent region

Medical delivery by drone could provide a cheaper, faster connection to an island that currently has limited connectivity with the mainland.

Although the Isle of Wight is only three to five miles across the Solent from the mainland and close to the cities of Southampton, Portsmouth and Bournemouth, transport between these locations is slow and expensive.

Currently, the island is connected to the mainland by ferries and hovercrafts, as there is no bridge or tunnel. The Isle of Wight, with a population of approximately 140,000 is, after Northern Ireland, the most populated area in the UK not to have a fixed link to the mainland of Great Britain.

A return ferry ticket using Red Funnel or Wightlink ferries can cost around £100 for a car and £200 for a van when booked the day before.[42]

This can particularly affect medical logistics between mainland facilities in Southampton and Portsmouth and St Mary's Hospital Isle of Wight, as shipments are often required at short notice and urgently.

Drones could be an appropriate solution to improving connectivity to the island, providing a faster, less costly and potentially round the clock delivery service. As shown in the table below, a drone, in comparison to a car in the morning rush hour, can unlock time savings of over two hours for Isle of Wight deliveries, more than an hour for Portsmouth and up to 40 minutes to Bournemouth. These are conservative estimates assuming that a car is readily available at the hospital. Actual courier times would likely to be even higher. Another key challenge related to deliveries to the Isle of Wight is the dependency on ferry timetables.

Travel times from Southampton General Hospital to selected medical facilities[43]

		weekday, 8:30am		Weekday, 7:00pm	
Southampton General Hospital to	Drone flight time (at 70 knots)	Car driving time	Time saving	Car driving time	Time saving
Bournemouth General	17′	35-55′	19-39′	30-45′	13-28′
Portsmouth QA	12′	40-75′	28-63′	30-40′	18-28′
St Mary's - Isle of Wight	12′	120-140′	108-128′	120′	108′

Medical logistics in the UK are complex and involve multiple different supply chains and actors. Deliveries to and from medical institutions in the UK are not consolidated or handled by a single entity, but different health service providers and hospital departments coordinate shipments separately and may have quite different supply chains and use different logistics companies. However drones could bring efficiencies to some of these parts of the supply chain.

The Solent region provides the NHS with an opportunity to test and build a medical delivery network handling all types of urgent deliveries. This would be particularly useful in the case of pathology (see also London use case). The NHS is planning to join together the 105

42 Ticket prices checked with Wightlink and Red Funnel Ferries on 5 July 2018 for travel on 6 July 2018.

43 Calculated based on drone specification outlined in this feasibility study and road travel times from Google Maps

individual pathology services within English NHS hospitals into 29 pathology networks.[44] Drones could be used in these networks to increase the speed and lower the cost of transporting samples between hospitals. The NHS will then be able to build on this system and test out other ways of using the drones to improve efficiency.

Drones could also help more broadly with the delivery needs of the Isle of Wight. Eventually there could be regular commercial drone deliveries across the Solent for urgent items such as documents and spare parts.

Future implications of drones for Southampton-Isle of Wight medical delivery

There is a longer term prize if we prove this concept

As the cost of drone transport reduces, the items delivered could expand beyond urgent, high value items such as medical equipment into conventional cargo delivery. They could also deliver to other locations where natural barriers such as the sea, mountains or estuaries make transport difficult. This would make it easier for people living in remote areas to access necessary goods and services. Archipelagoes such as the Hebrides could build drone networks delivering post or packages between islands.

Drones could cooperate with other forms of transport. Autonomous delivery vans could drive to a remote area and then have drones carry out the final leg. Shipping companies could send drones out to their ships with spare parts or medical equipment, rather than using slower and costlier boats.

In the long run, delivery drones could be part of an integrated autonomous delivery system. Someone on the Isle of Man wanting to deliver a package could go to a delivery point and choose delivery options based on package weight and urgency. The system would then pick the best route and combination of land, sea and air transport to get the package to its destination.

Benefits of medical delivery by drone across the Solent

Economic benefits

Drones can save money

The key advantage of drone delivery is the ability to deliver goods in a fraction of the time taken by conventional courier services. In Switzerland where drones are already being used to connect hospitals in Lugano as well as hospitals in Bern, the drone is 2.5 times as fast as bike or van couriers over a distance of approximately five kilometres.[45] The drones' ability to fly directly across the Solent reduces delivery times by up to two

44 https://improvement.nhs.uk/resources/pathology-networks/

45 http://www.20min.ch/schweiz/bern/story/Post-Drohne-verschickt-Blutproben-in-5-Minuten-24142778

hours (see table above) which might open up new opportunities for deliveries that were previously not possible because of the significant time it takes to cross the Solent by car and ferry. Another important factor is predictability: drones can fly at any time and are not reliant on the availability of couriers or ferry timetables. This makes deliveries more predictable and services more reliable.

The second key economic benefit of deploying drones for medical deliveries is related to cost. Whilst upfront investment can be significant, the marginal cost of additional flights is negligible. Based on quotes from DHL and Royal Mail, current deliveries from Southampton to the Isle of Wight can cost up to £183 for a package of 100*100*60cm and a maximum weight of 10 kilograms. In comparison to the marginal cost of recharging the batteries of a drone, the cost savings per additional delivery are significant.

This implies that drones have the potential to reconfigure medical logistics by allowing types and frequencies of delivery to happen which are currently not feasible. Medical logistics are currently largely on a hub-to-hub model with regular deliveries of multiple packages between logistics hubs in each hospital. This increased connectivity between hospitals,particularly with the Isle of Wight, has the potential to unlock new service models and deliver better care to patients.

Social benefits

Drones can contribute to patients' health

More reliable and timely delivery of medical goods is likely to have a significant impact on patients' physical health. The impact of this is hard to quantify as it depends on the specific item or good being delivered; in some cases it might save lives and in others it might contribute to a better patient experience due for instance to faster access to test results. For the hospital, a timely and reliable access to goods can have the impact of reduced bed days and more efficient intra-hospital processes. In the longer run, the high speed of a drone relative to couriers could expand the range at which hospitals integrate their pathology services, thereby unlocking the potential for further integration and greater efficiencies.

Example: Delivery of Blood from Southampton to the Isle of Wight, Portsmouth and Bournemouth

We explore a specific connection carrying blood products across the Solent and to nearby cities

As a test case to explore the technical and economic feasibility of medical deliveries across the Solent, we have chosen to focus specifically on the delivery of blood and platelets from NHS Blood and Transplant using the helipad at Southampton General Hospital to St Mary's Hospital Isle of Wight (16 miles), Queen Alexandra Hospital Portsmouth (16 miles) and Royal Bournemouth Hospital (21 miles).

The required blood units would be sent from a drone located in close proximity to the central blood depository at Southampton General and fly autonomously to a docking station either located at Queen Alexandra Hospital Portsmouth, Royal Bournemouth Hospital or St Mary's on the Isle of Wight. This study assumes the drone would be operated autonomously and beyond visual line of sight of an operator who could intervene in case of anomaly.

We have chosen these hospitals as they are the main hospitals in the Solent region. We have selected ad hoc and emergency blood products shipped from Southampton General Hospital as a test case for medical deliveries as they are shipped frequently from Southampton to hospitals around the region and involve short notice ad hoc and occasional emergency shipments.

The quantities shipped in ad hoc deliveries are light enough that they could be transported by a mid-sized drone (the payload, including blood, containment and coolant, would weigh up to around 10 kilograms; the drone itself around another 15 kilograms or so). Drones could also be used for regular shipments, if quantities are either reduced per shipment or through use of a heavy lift drone, but this study will focus on ad-hoc deliveries as these make best use of the speed, cost and delivery hour benefits that drones could bring and heavy lift drones are currently mostly at the R&D stage.

Movement of blood and blood products is coordinated by NHS Blood and Transplant, who collect, screen, analyse, process and supply donations of blood in addition to stem cells, organs and tissue donations on behalf of the NHS. NHS Blood and Transplant Southampton, based at the Southampton General Hospital, manages this process for medical institutions across a large area of southern England. Blood products are shipped from the central hub in Southampton General Hospital by vehicle and ferry to the Isle of Wight. Significant volumes are also delivered to Queen Alexandra Hospital Portsmouth and Royal Bournemouth hospitals,so these have also been considered in this analysis. Queen Alexandra Hospital in Portsmouth is of particular importance because it is the location of South of England Procurement Services, which coordinates much of the medical supply to the Isle of Wight.

According to data obtained from NHS Blood and Transplant, in 2017 there were a total of 656 emergency or ad hoc deliveries from the Southampton NHS Blood and Transplant.

Stock Holding Unit to the hospitals in Portsmouth, Bournemouth and the Isle of Wight. [46]		
	Ad-hoc deliveries	Emergency deliveries
St Mary's Hospital on the Isle of Wight	107	1

46 Source: NHS Blood and Transplant

Queen Alexandra Hospital Portsmouth	238	3
Royal Bournemouth Hospital	271	36
Total	616	40

Blood is currently transported in units of 500ml and must be temperature-controlled (generally -2 to 4°C depending on the product[47]). There are special containers for short journeys, made of thermally insulating plastic, weighing five to seven kilograms. It is recommended not to transport more that six units of blood (approx 3.5 kilograms in total) in a small container, making a total payload of 8-10 kilograms should current containers be used. Frozen products will additionally need to be packed with dry ice, which is usually packaged in 500 gram bags. There are currently transport time limits for blood products, with the most restrictive being three hours (for platelets). For regular deliveries volumes vary from 10 to 100+ units per order, using anything from one to 20 boxes. It is thus expected that, at least in the near term, the drone connection would be mostly used for ad hoc and emergency deliveries.

Technical attributes

Flight plan

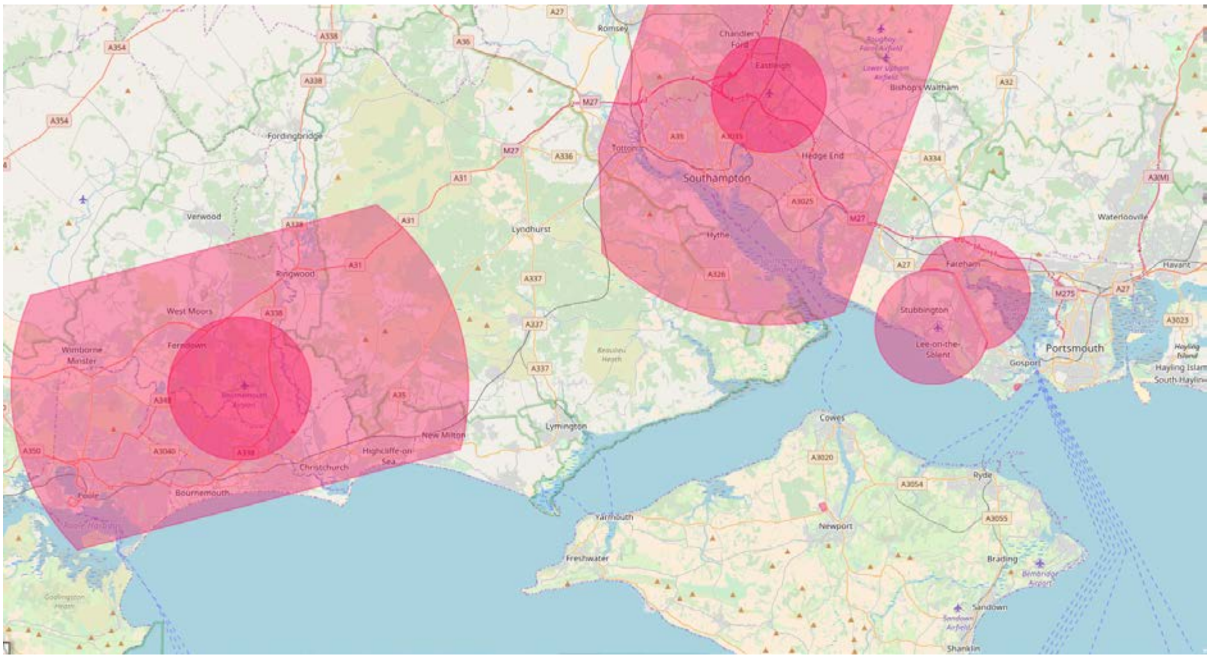
Flight paths

The proposed routes are over open water and parks/forests. This is in order to avoid buildings and highly populated areas, reducing risk and nuisance.

47 http://hospital.blood.co.uk/media/29151/18-capacity-and-time-limitations-for-temperature-control-effective-14-08-17.pdf

Airspace and altitude

These routes involve flying through several areas of controlled airspace, including the Solent Control Area (varies from 1,500-3,000 feet up to 5,500 feet) and Southampton Control Zone (surface up to 2000 feet), which are Class D airspace requiring notification to ATC for through flights. It would also traverse the Southampton Aerodrome Traffic Zone (ATZ) and Lee-on-Solent and Portsmouth/Fleetlands AT, which are regulated high-risk areas requiring permission from ATC to enter. In addition, HMP Parkhurst is located very close to St Mary's hospital on the Isle of Wight and this is designated as a high-risk area and a no-fly zone for drones.



The airspace around Southampton includes Class D airspace around several airports. Credit: Altitude Angel

The flight path to the Isle of Wight would entail flying over the port of Southampton, which could require permission from the Associated British Ports for overflight, especially if the port is used for emergency landing site designation, though the legal framework is not currently clear. Maritime traffic should be kept aware of drone flights, for instance via an ABP Notice to Mariners. The flight path to Portsmouth follows railway lines, for which permission from Network Rail should be sought. The flight path to Bournemouth General crosses over the New Forest crown lands, which does not currently permit operations of drones (or indeed, any low altitude aircraft) without special permission.

This drone operation in Southampton is envisioned to fly BVLOS and would thus need to be IFR capable. VFR flights are premised on the pilot being able to discharge responsibility by unaided visual processes (they can see and avoid hazards), which is not possible for BVLOS flight and so the drones will have to use IFR.

Routine BVLOS flights will need either special exemption from the CAA or updated legislation taking into account capability of the drone and surrounding infrastructure.

The tallest structure within Southampton are shipping container port cranes at 120 metres (413 feet). Of the top 10 tallest buildings, the majority are towers with heights of 51 metres (167 feet) to 80 metres (263 ft). Operational cruise altitude could vary but could be based on at least 100 feet obstacle clearance (scaled down from 1000 feet manned aviation obstacle clearance, unless under radar control), the drone would need to operate above 513 feet, which would provide sufficient margin from the obstacles below.
A suggested altitude of 600 feet or 700 feet (above ground level/sea level based on location) is recommended depending on the direction of travel. We propose 700 feet if travelling east or 600 feet west, following on from manned aviation rules of the air in which aircraft fly at an odd altitude flying east or even when flying west). As altitude separation in this scenario is significantly less than manned aviation, altitude systems would need to be designed to a high accuracy especially as the operation could take place within Class D airspace.

Take off and landing sites

There are helipads at all four hospitals; we propose that this service would reuse this existing infrastructure. The proposed drone for this use case is significantly larger than those in London's use case or in existing medical delivery services such as Matternet, which use bespoke landing platforms or pods.

- Origin: Blood would be moved from NHS Blood and Transplant on Coxford Road, Southampton and loaded into the drone at Southampton General Hospital.
- The simplest take-off and landing points would be the helipads already at each of the four locations, as to transport to and from a runway would increase time and cost. This would require the drone to have vertical take off and landing (VTOL) capability.
- As the helipads currently have air traffic it is considered that factors such as take-off and landing noise are negligible as the drone will be quieter than a helicopter.

Drone platform requirements

Platform type

- The platform will need to be of significant size to carrying the maximum payload of around ten kilograms (ten units of blood plus coolant and container), which is a larger payload than most current commercial drones.
- The larger payload and long distance propulsion system than the other use cases examined in the Flying High project will result in a higher mass,so the drone may no longer be classed as a Small Unmanned Aircraft according to the CAA. Should the drone weight exceed 20 kilograms (Category B - 20 kilograms to 150 kilograms), it would become subject to additional airworthiness requirements, in particular drone design, safety management processes and pilot competencies. In this category there is a particular focus on the potential failures of the drone and its control

systems, the consequence and severity of these and how they are to be mitigated or managed for the operations to be undertaken.

- The relatively long distances for a drone (approximately 22 miles from NHS Blood and Transplant in Southampton to Royal Bournemouth), mean a long endurance platform will be required, currently implying a fixed-wing platform.
- The speed of the platform is important due to the distances and the possible need to respond to an emergency delivery. The longest route of 22 miles to Bournemouth would take 16 minutes 30 seconds at 70 knots. Due care and consideration needs to be made towards the payload as the blood pouches do have a G force limitation of 3G, acceleration and deceleration needs to be be controlled.

Propulsion

- As the flight should be a return route to and from hospitals that are more than 20 miles away and could include flights across the Solent, a number of propulsion technologies could be considered. In the short term this could be a fossil fuel hybrid electric platform. With advancements in battery and fuel cell technology, in the medium to longer term it is conceivable that a battery electric or hybrid fuel cell battery electric platform could perform the journeys. Consideration could be made for charging the drone directly or the use of a battery swap or refill if fuel cells are used.

Endurance

- The platform performance should be sized for a return journey to its intended destination, which could be 42+ miles with appropriate redundancy for weather variations, abnormal consumption, potential reroutes and emergency landings.

Payload, sensors and instrumentation

- Payload:
    - Secure, waterproof, impact resistant and lockable payload that is easy to release / eject. An automated docking station with refueling / charging capability would be desirable.
    - The payload will need to be thermally insulated and temperature controlled (-2 to 4C)[48]
- Sensors and instrumentation: The drone should carry a high resolution camera for remote piloting and ADS-B electronic conspicuity device

Communications, navigation and control

- The drones will be flown BVLOS autonomously, from a control station with a pilot present, able to monitor the flight and take control in case of an emergency.
- Communications
    - A robust communication system will be needed for the following purposes:

48 http://hospital.blood.co.uk/media/29151/18-capacity-and-time-limitations-for-temperature-control-effective-14-08-17.pdf

    - Control of the drone autonomously, with telemetry data (position, speed, battery status) relayed to pilot/mission controller for tracking and safety monitoring.
    - In case of a systems failure the drone pilot should be able to control the drone and land it safely, which would require a first person video as the drone will be flying BVLOS.
    - Transmit location to other airspace users and air traffic service providers (e.g. a UTM system or Air Traffic Control) - via an electronic conspicuity device.
- Redundancy will need to be built into the communications channels to allow for failure or loss of communications, thus a primary, secondary and possible tertiary communications channel will be necessary.
- The primary communications channel needs secure coverage over the majority of the journey, in particular over busy airspace and the urban populated areas, where the risk to people on the ground and air is greater. Bandwidth should be sufficient to transmit telemetry data.
- The cellular mobile network in general meets these criteria, as this has a combination of generally good coverage (especially within city locations), high bandwidth and good security. As infrastructure is generally preexisting, it is readily available and cheap. Additional boosters or infrastructure outside the network area can address any coverage shortfall, with due consideration to any approvals required.
- The transmission of real-time HD video may require different technology. 4G LTE networks may have sufficient bandwidth as long as it can be appropriately secured, future 5G networks would provide greater bandwidth still. It should be noted that latency in the communications network may be an issue if this is used for navigation and control.
- Using the mobile cellular network requires drones to support a SIM and connectivity module, so hardware and software can be updated when specifications change. Using drones equipped with a SIM card, existing mobile infrastructure can be used which will facilitate fast growth and reduce costs.
- There are limitations to the use of the mobile spectrum. Although coverage is good in the towns and cities and Ofcom reports generally good coverage in the area,[49] it can be patchy in rural areas and particularly at sea. In addition the network is aimed at optimising signal on the ground, rather than in the air.
- Should the drone experience a systems failure, it is recommended to have a different method for backup control in addition to the mobile network, such

49 https://checker.ofcom.org.uk/mobile-coverage

as data link control via satellites. Note this will be used for control of the drone and not video feed.

- Navigation and control
    - Accurate knowledge of the drone position (latitude, longitude and altitude) is required.
    - In manned aviation barometric pressure is the primary means of altitude determination, however this requires all aircraft in the vicinity to be on the same pressure setting which varies. In this case a ground controller would be required to monitor this area. However this system alone would not provide the level of accuracy required at lower altitudes as in this use case.
    - Drone position can be obtained from a global navigation satellite system (GNSS) network. However, this too is not accurate enough alone to determine drone altitude to the accuracy required at lower altitudes. The GPS network alone is also not suitable for drone navigation as it is prone to data degradation or complete loss of signal due to multipath effects, interference or antenna obscuration, so it will be necessary to have other systems present.
    - An inertial navigation system (INS) (also known as as inertial reference system or more generally an inertial measurement unit), is a self-contained system that does not require input radio signals from a ground navigation facility or transmitter. This system derives attitude, velocity and direction information from measurement of the drone's accelerations given a known starting point, however over time the accuracy of this will also decrease and will require resetting. We recommend that the drone used in this situation use both systems together to improve navigational accuracy and for redundancy.
    - A further navigation technology that may be used is the use of vision sensors (e.g. optical cameras, hyperspectral sensors, Lidar), which sense the surrounding area directly and could be used in conjunction with a pre-loaded terrain database to complement existing navigation techniques.These vision sensors would primarily improve take-off and landing ability, with secondary function as a backup navigation source. Currently this is not commonly used for external navigation but could be a way of increasing accuracy of positioning and navigation.
    - To ensure safety and minimise risk of collision, the drones should broadcast their location and an ID signal to other airspace users and to any air/unmanned traffic management system. This capability is referred to as 'electronic conspicuity'. The current standard on aircraft is ADS-B, which has been allocated a specific frequency band in the UK (960-1215 megahertz). This has low transmit power levels, low cost and the potential to be interoperable with other ground and air users and would be the default choice at present, though other technologies for broadcasting position may be developed.

  - If drones are to operate in any mode they are required to 'be seen and avoided'. Detect and avoid systems currently alert pilot to other traffic and suggest resolving vectors. We recommend developing DAA systems to autonomously react to any aircraft installed with an electronic conspicuity device (EC). This is a challenge together with the ability to detect traffic not fitted with EC devices (such as birds).

Safety

- We have performed a qualitative risk analysis (SORA – Specific operation risk assessment), to help identify the level of robustness required for all threat barriers based on the three categories of harm: Injury to third parties on the ground, fatalities to third parties in the air (mid-air collision with a manned aircraft) and damage to critical infrastructure. Specific threats have been examined and graded on their perceived risk suggesting a required level of robustness against each threat. Threats include: human error, technical issue with drone, aircraft on collision course, deterioration of external systems supporting drone and an adverse operation condition. This analysis has been performed to help identify areas for further consideration and is not intended to be a safety case.
- The SORA assessment shows the risk of injury to people on the ground is high as the drone (max characteristic dimension <3m) is likely flying more than 500 feet over a populated environment. It is assumed that the harm barrier adaptation in place will be a high level emergency response plan, should the drone encounter any technical difficulties. When examining mid-air collision, based on altitude and airspace class, the airspace encounter rate is high, as is the risk. Based on this information it is recommended that the highest level of robustness is required for all systems to combat these threats.
-
- Safe operation:To mitigate these threats, the drone should be designed to interact with UTM systems to dynamically allocate airspace and thereby minimise the risk of collision. Use of ADS-B and detect and avoid devices would further reduce risks of collision. The development of drones rules of the air would aid in traffic deconfliction should differing levels of EC be used, drone corridors would be an example of this. Operating at less busy times, random routes away from airways and restricting time of flight would reduce encounter rates with other aircraft.
- Failsafe: The drone should be designed in a way to minimise risk of catastrophic failure affecting people or buildings on the ground. This should involve building in redundancy to maximising glide range and reducing kinetic energy closer to the ground, to extend range (in cases of engine failure) and minimise impact respectively.

Environment

- Noise: The noise generated by this use case could affect many people in towns and cities such as Southampton, it could be annoying to people enjoying the peace of the New Forest and could affect the health of people in the hospitals that the drone will travel between. Because there will be regular deliveries, the noise could be particularly annoying for people who live or work under the flight paths. The fixed-wing design of the drone is likely to be quieter than multirotor drones of the same size, but the drone is relatively heavy (compared to other drones examined in the Flying High project.). Specific operating procedures limiting power during various stages of flight can be developed to mitigate noise. The drone will likely use existing helipads and are likely to be significantly quieter than helicopters. However, the drone may cause additional annoyance if its flights are more frequent or if the noise is more annoying than helicopter noise. The noise impact of the drone could be reduced by using a quieter drone or flying a route that is mostly over water.

- Weather/climate: Current multi rotor drones generally have recommended operating restrictions of 0-40°C and wind limitations of 19 knots. Fixed wing drones can operate in similar conditions however cross wind limitations can be reduced to 15 knots for take off and landing[50]. As we are potentially operating a larger hybrid VTOL drone, benefits of higher wind limitations for takeoff/landing and higher cruise wind tolerances can be expected. The drone service must be able to operate year round and therefore needs to be able to operate efficiently in these conditions, as well as in moderate rain, poor visibility and cold temperatures sub zero degrees (consider icing). Drone design should also consider effects of corrosion from operation over a sea environment.
- The design considerations should examine the historic wind speeds in Southampton and the Solent area, potentially factored against statistical frequency to reduce extremes and balance cost. There are some extreme weather conditions that may prevent operations. We assume that for 3 per cent of the year (around 11 days) the service is unable to operate, a figure that roughly mirrors restrictions on aircraft.[51]

Regulatory requirements

- The drone operation will need to take place in Class D airspace and in the restricted areas of Southampton, Lee-on-Solent and Portsmouth/Fleetlands Air traffic zones. As well as permission required to operate in these areas, there is a requirement to define the rules and regulations for drones within this airspace, addressing the interoperability of cooperative and non-cooperative traffic, both manned and unmanned. Drone capability level together with UTM systems should be integrated into these rules.
- The drone will be required to operate autonomously beyond visual line of sight (BVLOS) and fly over an urban setting within 50m of any person, vessel vehicle or structure. Regulation currently requires any commercial operation to prepare a safety case for submission to the CAA that addresses each of the limitations covered by the Air Navigation Order (ANO) above, however this is currently only for VLOS operation for drones weighing <20 kilograms. Regulation will need to address this for BVLOS operations.

50 Based on Flying High technical forum.

51 In practice drones are likely to have higher vulnerability to adverse weather due to their size and battery life. However, they would have more flexibility to be deployed earlier or later compared to scheduled flights. The limits placed on them are unclear until the drone has been created and tested. As such we assume 3 per cent is a reasonable benchmark to apply in this case.

- Overflight permission may to be required from the Associated British Ports (ABP) and Network Rail to operate over their facilities and for the allocation of emergency landing sites. Relevant riparian (riverside) local authority and landowner consent where the drone flight and exclusion area will impact on adjacent land, permissions will all potentially be required. If appropriate, a ABP Notice to Mariners will need to be issued and river traffic controlled by the ABP.
- Mobile phone networks are governed by the Wireless Telegraphy Act 2006. For mobile phones, the use of the spectrum by the network operators is licensed to cover the use of transmitters and repeaters which are under their control, while user devices are covered by a general exemption. Cellular repeaters, boosters and enhancers are not accepted devices. In exploring our use case if cellular connectivity is to be used, collaboration with the network provider to increase the infrastructure required to realise the task is imperative. Additional boosters or infrastructure outside will require additional specific exemption.
- As the drone will be using radio equipment, it must comply with Ofcom regulations.[52] Within the UK the use of radio apparatus, including drones, is regulated by law. This ensures only equipment which is safe and does not cause harmful interference is placed on the market. The Ofcom licence and licence exemption state the terms and conditions on the use of radio apparatus.
- This use case will likely have to comply with the Network and Information Systems Regulation 2018.[53] It applies to 'operators of essential services', which includes healthcare organisations. It requires them to take technical and organisational measures to manage security risks, such as having processes for incident handling.
- This use case will need to comply with the EU General Data Protection Regulation (GDPR),[54] which regulates how organisations can store and process personal data. The GDPR requires organisations to follow principles such as collecting the minimum amount of data needed for the organisation's purpose, keeping the data secure and informing people that their data is being collected. In this use case, data protection will need to be considered when dealing with patient data and any video footage collected.

Operations and traffic management

An unmanned traffic management system is required to:

- Track drone position so it is visible to both controllers on the ground and operators in the air, both manned and unmanned. Airspace violations can be monitored and dealt with accordingly by managing authority in this way.
- Identify when traffic will conflict and alert user or autonomously deconflict this traffic should no action be taken.
- Be interoperable with all traffic, other UTM Systems and ATC.

52 https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/drones-advice

53 http://www.legislation.gov.uk/uksi/2018/506/contents/made

54 https://ico.org.uk/for-organisations/guide-to-the-general-data-protection-regulation-gdpr/

- Should drone deployment increase it is recommended to further develop electronic conspicuity devices together with detect and avoid systems, which securely integrate into the flight control system to autonomously react to any potential conflict. Traffic lanes should be developed with specified rules and regulations defined.

Security

A security breach could allow attackers to steal data, control or influence the drone, or prevent it from operating. This could have several implications of varying impact. For example, if an attacker disrupted the drone then its payload could be delayed or lost, meaning that there could be a significant delay to receipt of blood, in the 40 instances in 2017 where these were delivered through blue light services this could have an impact to life. There is also the risk that the drone could be used for malicious purposes, especially as the drone will fly near important infrastructure such as railway lines, shipping lanes and the port of Southampton.

It is not only malicious attacks that are problematic but also to natural interference to signals, signal integrity and the potential for RF saturation which could cause issues. This would require the use of redundant and independent systems such that a threat would need to overcome multiple systems to have a negative impact.

As the drone will be operating BVLOS this will significantly increase the complexity of ensuring the safe and security operation of the drone. The system therefore needs to manage issues while out of line of sight, which may include trade-offs with other aspects of the system such as technology to increase privacy.

It will be important check for security weaknesses across the whole system including areas such as communications, data storage and control software. For example, it may be possible for attackers to interfere with signals from command so it's important for communications to be encrypted and robust against jamming. It's also important to look at what is connected to the drone system: attackers can sometimes gain access to one system through another, connected system. In this case, it would mean checking the security of systems like navigation software or supply chain management software. The physical security of the drone and the payload is also important, as it could be stolen from the takeoff or landing area or compromised during flight. The implications of this could be severe in the context of an urgent medical delivery.

Security is not just about having the right technology in place, it's also important to have good security processes. For example, there should be processes in place to regularly test for security weaknesses as well as monitor for and respond to security breaches

Privacy

The drone will be fitted with a camera, which would be used should the mission controller need to pilot the drone from a first person view in case of a system failure, or possibly for more general navigation. The drone will be flying over a densely populated urban area and would be able to see into normally private areas such as residences, hotels, schools and businesses and to capture images of individuals and vehicles. However, there is no need to store captured images or video after the mission has been completed, unless there was a need to analyse these in case of an incident. Operation should be consistent with data protection legislation.

The drones should also be operated by a trusted operator and under the jurisdiction of the NHS. This would reduce concerns around drones being used by system operators to violate privacy. Polling carried out as part of the Flying High project shows that state and emergency services are more trusted than private operators of drones.

To support the adoption and to overcome the challenge of unknown drone systems operating in these areas a recommendation would be for everyone being able to identify the drone and operator, this could be linked to electronic conspicuity devices and an open component of a UTM system.

Economic and social feasibility

This economic feasibility study initially focuses on the deployment of drones for the transfer of medical resources between Southampton General Hospital, Queen Alexandra Hospital in Portsmouth and St Mary's Hospital in the Isle of Wight. There are three key sources of economic impact:

- Savings to the NHS and its partners from more efficient transportation due to lower marginal delivery costs and faster and more reliable deliveries.
- Health benefits that accrue to patients as a consequence of quicker testing.
- Benefits to the wider health network as a result of more efficient treatment including reductions in 'bed blocking' and improved intra-hospital transferring of samples.

Due to data limitations we use a series of assumptions to provide a hypothetical rate of return given scale and provide comment on how sensitive the results would be to changes in those assumptions.

Key assumptions to the use case

Key parameters to model the introduction of drones in this use case are the volume and cost of deliveries, the level of drone deployment, estimated health benefits and savings.

Number of deliveries: The model is based on a total of 656 ad hoc and emergency deliveries between NHS Blood and Transplant Southampton and hospitals in Portsmouth, Bournemouth and Portsmouth per year. One delivery can include multiple goods up to a total weight of 10 kilograms. We assume that this number grows by one percent p.a.

Number of drones: Given short flight times, one drone is sufficient for this volume of deliveries.

Cost of drone: The estimated cost of this model of drone is £50,000 (based on estimates on the SPOTTER platform). We take an upper and lower estimate of £35,000 and £65,000 respectively to reflect the possible variation in this cost. This drone is comparably more expensive than the drones in the other use cases, because of its ability to carry a higher payload, to fly longer and to safely operate in turbulent weather conditions in this area.

Cost of wider supporting infrastructure: Three FTE members of staff would be required to run the network for 24 hours at an annual costs of c. £107,000. Training cost for each staff member is estimated at c. £1,500[55]. Because the drone would use existing helipads, there are no additional infrastructure costs. Maintenance costs are assumed at **5 per cent** of the drone's total cost annually.

Cost of delivery: Given the low cost of charging drones, we assume a medium marginal cost of using the drone of £0.50 per delivery (after accounting for salary and infrastructure, primarily drawn from the cost of charging and electricity).

Current delivery costs are estimated based on quotes provided by Royal Mail for same day deliveries (Bournemouth and Southampton) and DHL for next day delivery (Isle of Wight).

Delivery to	Ad-hoc delivery	Emergency delivery (+50 per cent)
Portsmouth	£38	£57
Bournemouth	£108	£162
Isle of Wight	£183	£275

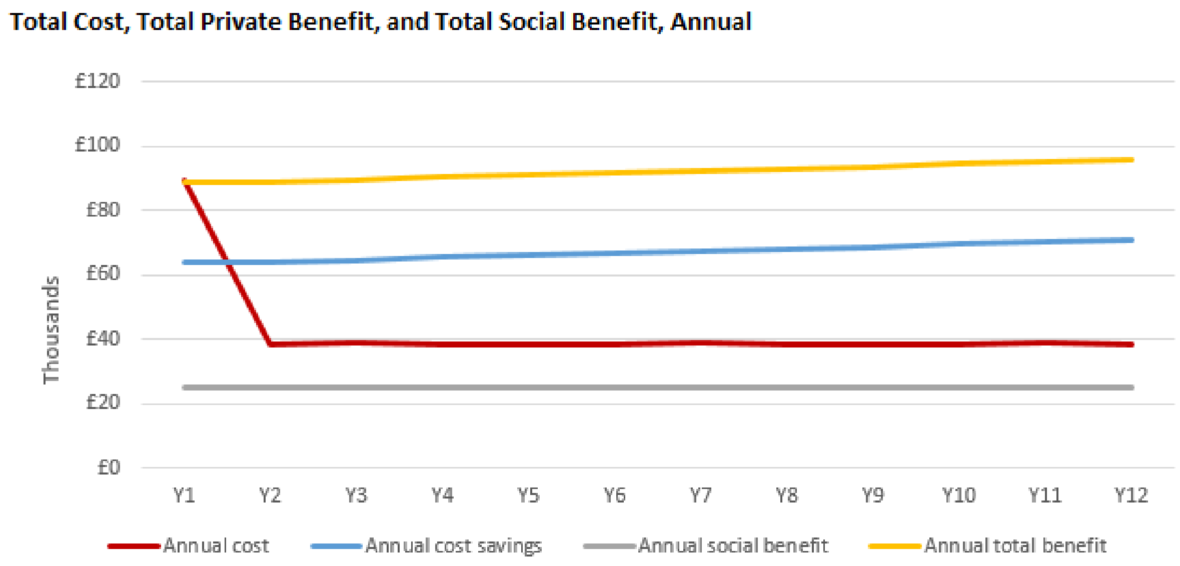
Social benefits: We have not modelled any health benefits in this model due to the lack of data available. However, we have assumed that improved delivery times and increased reliability of drone deliveries will improve the efficiency of hospital operations in the network. To model this, an assumption was made that there would be a 0.5 per cent increase in efficiency per drone deployed and that a 1 per cent increase in efficiency would be associated with social benefit of £50,000.[56]

Deploying a drone to connect the hospitals can unlock significant savings and improve the efficiency of the hospital network

As can be seen, the deployment of drones for emergency and ad-hoc deliveries between NHS Blood and Transplant Southampton and the three hospitals in Portsmouth, Bournemouth and the Isle of Wight is highly economically feasible.

55 The baseline 2018 salary estimate was £35,000; this was uprated to 2019 prices using recent OBR CPI estimates found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

56 This is an indicative model as there was no obvious way to value the dynamic and distributed effects of intra-hospital deliveries.



The total annual benefit is primarily driven by cost savings per delivery. As described above, the flight of a drone in comparison to conventional means of delivery and/or bluelight deliveries is significantly cheaper leading to savings of more than £60,000 in Y1.

Using drones at scale can transform the scale and efficiency of current delivery networks in the South

There is significant potential of using the drone for other types of medical goods and on alternative routes. To test scalability, we are exploring three elements: the scale of service; the type of goods; and the level of deployment.

This use case is extremely sensitive to scale because savings are delivered on a per delivery basis as such naturally increase as the amount of deliveries increases. This means in practice that economic feasibility is driven by scale and the ability to use drones to meet that increased scale. Based on the current scenario of 656 deliveries, the drone is operating below capacity. Particularly when accounting for the fact that the drone can fly during night time as well, there is significant opportunity to increase the savings while keeping fixed costs stable.

Depending on the type of medical good transported, the model could generate even more benefits due to higher social value. For example, if it were to be proved that there would be substantial health and wellbeing benefits from a faster delivery – for instance by quicker pairing of organs with recipients – then this would mean each delivery would have an attached social benefit. Crucially, this would require not just that the deployment provided a mechanism for this to occur, but also that the arrangements in the status quo prevent it from happening.

An increased frequency of flights and the resulting higher levels of connectivity between hospitals can create social value by tackling other forms of inefficiency within the system. To model this, an assumption was made that there would be a 0.5 percent increase in efficiency per drone deployed and that a one percent increase in efficiency would be associated with social benefit of £50,000.[57] In practice this is a per-drone contribution to wider social benefits that acts as a proxy for the other sources of economic impact that have not been explicitly modelled.

Conclusions and recommendations of the technical and economic feasibility study

Conclusions

The Southampton use case in summary could have strong social benefits, and is feasible in principle, but there are a number of challenges that need to be overcome in order to make this use case a reality.

The key challenges for medical delivery by drone across the Solent, based on our analysis, are

C1. The development of a drone system that can operate safely, securely and reliably beyond visual line of sight, across the Solent while maintaining appropriate levels of privacy.

C2. The provision of suitably managed unsegregated urban airspace allowing for interaction with other airborne systems.

C3. The development of key elements of drone and drone systems technology, particularly with respect to automated systems that remove routine elements of human interaction, eventually moving to a fully autonomous system.

C4. Achieving the scale of service that is needed in order to demonstrate economic and social feasibility.

C5. Operating across all weather conditions including high winds, rain, snow and poor visibility; and in low light or at night time, in order to ensure a robust and reliable service.

Recommendations

The following recommendations relate directly to the five challenges outlined above (referenced in brackets).

57 This is an indicative model as there was no obvious way to value the dynamic and distributed effects from a reduction in congestion, or how the costs of intra-hospital delays would change.

A. Regulatory change to enable routine drone operations at scale, beyond visual line sight and near people, buildings or vehicles. (C1 and C2)

B. The development of a new form of airspace management to enable safe automated drone operations at scale. (C1 and C2)

C. Electronic conspicuity devices fitted to all air traffic and integrated into a system, to improve safety, security, privacy and positive public perception. (C1 and C2).

D. Secure interfaces into other systems and infrastructure needs to be considered with the number of interfaces minimised and encrypted. (C1)

E. Development of technologies that can demonstrate safe operation through high levels of redundancy, including secondary and possibly tertiary systems for command and control, navigation, power and propulsion systems. (C1)

F. Development of counter drone systems to identify and manage unauthorised drone operations either malicious or accidental. (C1)

G. Development of registration and enforcement systems, with appropriate resources to ensure operator accountability. This should include a centralised database showing licensing of operator competency, the platform ID and airworthiness, and the capability to provide real-time monitoring of the airspace. (C1, C2 and C3)

H. Requirement to develop tools and standards for the verification and validation of the drone components, platforms and systems, with traceability of the hardware and software supply chains. This should include development of simulation tools to ensure safe operation and validation of autonomous and machine learning systems. (C1 and C3)

I. Development of an appropriate safety case for this application, that could be published and be used as standard scenarios to support the regulator and the growing UK industry. (C1 and C2)

J. Establishment of a clear, accountable ownership and sign-off responsibility over the various aspects of operation. This includes maintaining airworthiness, oversight of system upgrades, assurance of pre-flight checks, the flight, associated safety related flight data and appropriate legal accountability and insurances. (C1 and C2)

K. Integration and interoperability between airspace management systems. This will require both technology solutions as well as co-ordinated standards, legislation and process development. (C2)

L. Coordination with other aligned technology areas around common challenges. This could include collaborations with the robotics and autonomous systems and connected and autonomous vehicle communities. (C3)

M. Development of technologies and regulatory frameworks to allow the systems to scale safely and in line with growing market demand. (C4)

N. Development of capabilities to ensure safe flight during poor weather conditions and during darkness. (C5)

O. Development of tests that prove out the capability of the platform and system in representative environments. Leading to trials with growing complexity, moving from controlled environments to full public demonstrations. (C1-5)

Technical and economic feasibility study: construction and regeneration in Preston

Using drones for urban regeneration and infrastructure by supporting construction contractors

- Aerial imagery and sensing provides real-time information to construction managers
- Greater information helps construction contractors complete projects quicker and at lower cost
- Drones can help take workers out of risky environments
- We find that this use case is both technically and economically feasible providing access to restricted airspace is made possibleIntroduction

This section outlines the use of drones to support urban regeneration by improving the efficiency of large-scale construction projects such as major buildings, roads and railway lines.

Drones can be used for a range of tasks relating to construction, including surveying land, monitoring build progress, inspecting quality of work and supporting health and safety. We consider the general opportunity for use of drones in urban regeneration and construction projects, then focus specifically on one example of this: the technical and economic factors relating to the use of drones in the development of the upcoming Preston Western Distributor and East-West Link Road, which will connect Preston to a new junction on the M55.[58]

General discussion

The case for construction and urban regeneration in Preston

Urban regeneration is an important topic for Preston at this point in time, particularly in the context of the Preston, South Ribble and Lancashire City Deal.[59] The city deal is an agreement between the government and four local partners: Lancashire County Council, Lancashire Enterprise Partnership, Preston City Council and South Ribble Borough Council. It includes an investment of over £340 million in transport infrastructure, including work on the Preston Western Distributor Road.

58 http://www.lancashirelep.co.uk/city-deal/near-you/north-west-preston/preston-western-distributor.aspx

59 http://www.lancashirelep.co.uk/city-deal.aspx

There are other major construction projects planned in Preston that could benefit from the use of drones, including the New Ribble Bridge, refurbishment of Preston station and the University Master Plan.

Potential uses for drones in construction projects such as these include:

- 3D modelling for BIM / VR walkthrough.
- Impact analysis e.g. on wildlife.
- Siting of radio masts.
- Terrain modelling and classification.
- Progress monitoring.
- Monitoring asset use.
- Monitoring stockpiles and cross checking in BIM.
- Site security e.g. change detection.
- Checking procedures are being followed.
- Hazard to work identification.
- Safety checks on roads (signage, workforce protection).
- Compare results to plans.
- Assess that buildings meet regulations.
- Anomaly detection.
- Measurement of air quality or building emissions standards.
- Maintenance monitoring.

Research by PwC projects that the global market for drones in construction is likely to be around $45.2bn annually by 2030, making it one of the key use cases for drones.[60]

As the technology becomes more mature, drones could be used for the monitoring and imaging of many different construction projects. There could be a system with multiple drones that would operate simultaneously across the worksite to monitor different aspects of the project. For example, they could help assess the progress of a project, calculate the amount of resources used, check for incorrect or low-quality work and identify health and safety risks.

60 https://www.pwc.pl/en/publikacje/2016/clarity-from-above.html

Future implications of drones for construction and urban regeneration in Preston

There is a longer term prize if we prove this concept

Proving the concept of routine use of drones in construction and urban regeneration opens up more ambitious possibilities for how they could be used in future. Drones can help construction site managers with monitoring and inspecting. They are already being used to inspect railways, power networks and oil and gas systems.

In the future, drones could autonomously search for, diagnose and repair infrastructure problems. They could also work in groups - coordinating to cover a large infrastructure project more quickly.

As robotic technology improves, drones could start to help with the construction itself. They could deliver tools and materials to workers scattered across large, multilevel construction sites. They might also be used to perform construction tasks such as painting large, high surfaces. Using drones and other robotic systems in construction might change how construction is done. For example, buildings might be built out of more standardised parts that can easily be put together by machines.

Benefits of drones for construction and urban regeneration in Preston

Economic benefits

Drones save money and drive efficiency in construction

The use of drones in construction, even at the scale that currently exists, already generates substantial benefits and efficiencies. [61] Through our engagement with experts and stakeholders in this sector, it is clear that drones in construction bring a number of economic benefits.

Routine monitoring of a construction project from above generates better quality information for building site management, can make for faster surveying times as a drone can quickly scan over a large site and can provide real-time or frequently refreshed information on the building site.

Better-informed planning decisions could ensure construction costs are realistic, avoiding waste of public funds and reducing disruption to residents and businesses.Drones can support improved financial estimating: for example knowledge of land state prior to development better informs construction cost estimates. This reduces risk of large capital projects.
The information provided by drones can reduce site downtime by performing rapid

61 https://connect.bim360.autodesk.com/drones-in-construction-projects

investigation of anomalies and in construction sites where workers have to operate at height (such as tall buildings and bridges) mitigates risk to personnel by reducing the need to work at height. Drones equipped with high-resolution cameras provide a safer, easier method of inspecting high structures and can provide real-time footage to spot anomalies.

Drones can reduce the cost of asset maintenance and enable more frequent inspection of hard-to-reach areas. This enables more accurate and regular inspection, enabling monitoring the emergence of defects over time.

A central driver of these benefits is the ability to integrate the information collected by drones into construction information management systems.

Social benefits

Better information means safer construction sites

A targeted deployment of drones can help reduce the exposure of humans to hazardous situations. According to statistics from HSE, there were 30 fatal injuries and 5,055 non-fatal accidents on English construction sites in 2016/17.[62] Of those non-fatalities 49 per cent were from working at height, 10 per cent being struck by a vehicle, 10 per cent trapped by something collapsing. Drones can reduce the time spent on site, reduce the need to carry out work at height, as well as help improving site security by periodically monitoring structures and helping to detect emerging hazards.

While, the use of drones cannot eliminate the risks on construction sites altogether, drones can offset the need to put people in harm's way by providing imagery from optical cameras or Lidar throughout all construction phases from surveying to construction, handover and snagging to maintenance. With the drone ensuring that less people are on site checking stockpiles, or measuring the build, this helps to reduce the possibility of someone being struck by a vehicle.

Finally, with accurate real-time information on what is on site, its position and quantities, stockpiles of hazardous materials can be kept to a minimum can be mapped and fed back to the site manager.

Environmental benefits

Quicker and more efficient construction means less environmental impact

We assume that the deployment of drones in construction sites would have significant external effects, particularly in the case of reducing carbon dioxide and other greenhouse gas emissions, partially by reducing the time taken to engage in construction, therefore the output per site. In addition, drones could also be used to detect any potential impact on wildlife and monitor the air quality in and around the site. This will improve knowledge about the construction site's influence on the natural environment, allowing the team to

62 http://www.hse.gov.uk/statistics/industry/construction/

take appropriate measures to mitigate potential negative influences and involve experts from the start.

Example: using drones to support the construction of a new road project in Preston

We explore the forthcoming construction of the Preston Western Distributor Road to better understand the challenges of this use case

As a test case to explore the technical and economic feasibility of drones in construction and urban regeneration, we have chosen to focus on a forthcoming construction project immediately west of Preston. This includes the Preston Western Distributor, a new dual carriageway connecting the A583 with the M55 at a new junction, plus a road linking this dual carriageway to the western side of the city of Preston.

This project has been chosen as it is representative of major infrastructure construction projects worldwide, but also as an example of a significant forthcoming construction project in Preston - by far the largest transport project in the Lancashire Growth Deal.[63] The construction project is due to start in autumn 2019 with an expected construction period of 3.5 years.

The site presents interesting and complex technical and regulatory challenge, including:

- Construction of a junction on an existing motorway while minimising disruption to traffic.
- Construction of new roads, both through sparsely populated areas of countryside and near housing.
- Construction of two major viaducts.
- The diversion of the Hodder aqueduct (crossed twice) and the risks associated with working in hazardous environments over waterways, railways and motorways.
- A nearby sensitive site with restrictions on overflight (Westinghouse Springfields nuclear fuel facility).[64]

The specific use case modelled here will consider both the use of the drone and also aspects of data management and data exchange. It will be broadly representative of other large-scale construction or regeneration projects.

This project has the potential to utilise drones in a number of different ways. At its most simple, drones could be used to monitor the progress of the project. This is an application that the construction industry is already using drones for and there are several companies producing drone software to help with this.

63 http://www.lancashirelep.co.uk/lep-priorities/growth-deal.aspx

64 https://www.niauk.org/event-listing/engineering-technology-solutions-exhibition/

By using a drone, the construction contractors will be able to save money on hiring aircraft or surveyors, save time walking around the site monitoring progress and be able to make more frequent and more accurate measurements of progress. The drone also provides the opportunity to gain access to higher risk areas and also can give a unique and more complete aerial perspective.

This would be useful across all phases of the project. In the planning stage, a drone could make surveying cheaper. During the earthworks stage, progress could be monitored and optical and Lidar imagery used to make calculations such as the volume of piles of earth. And the drone could continue monitoring progress against design during the build phase.

This can already be largely automated with current technology: there is software available to give a drones a flight pattern that they can follow automatically to capture images of every part of the site. For this use case, we propose extending this principle to operation beyond visual line of sight - an approach which would make particular sense on a very large construction site like this one.

Collecting data is an important aspect for construction sites: getting the right data the first time and to a high level of accuracy can create significant savings in time and cost across the whole project by reducing errors and wastage, reducing the risk of not completing jobs on time. Lidar scans can provide a level of detail that can enhance the accuracy of the construction design and build phases and provide near-real-time information to design teams, who may be far from the site itself.

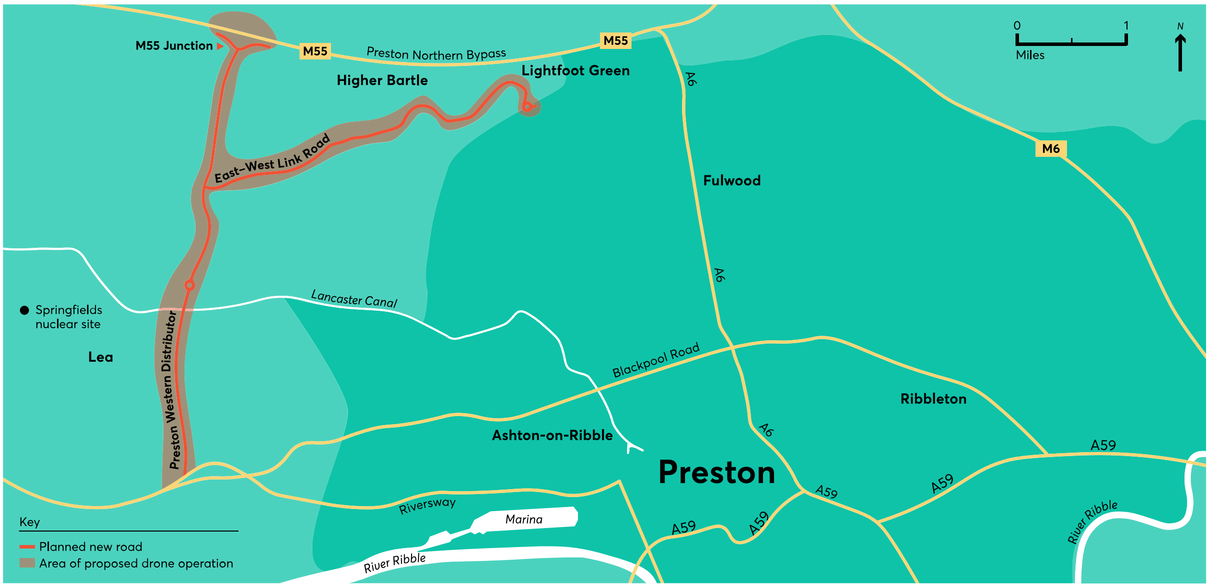
Client management is also an important role, where being able to provide accurate and regular updates on progress and areas where the customer may need to make additional decisions. This helps with the management of the customer and provides a more positive experience on these complex and expensive projects.

Building information management (BIM) software provides a common platform for data collection, management and exchange, adding metadata and volumes can greatly enhance the potential for lower cost, faster, more accurate construction builds.

Technical attributes

This section outlines the key technical attributes that would be required of a drone to support construction of the Preston Western Distributor Road project in the ways set out above.

Flight plan



This use case would require routine low-speed operation (hovering and scanning) of a large area covering the construction of the road. This would include surveying the entire site prior to commencement of construction, followed by regular flights over areas of active construction throughout the lifetime of the project.

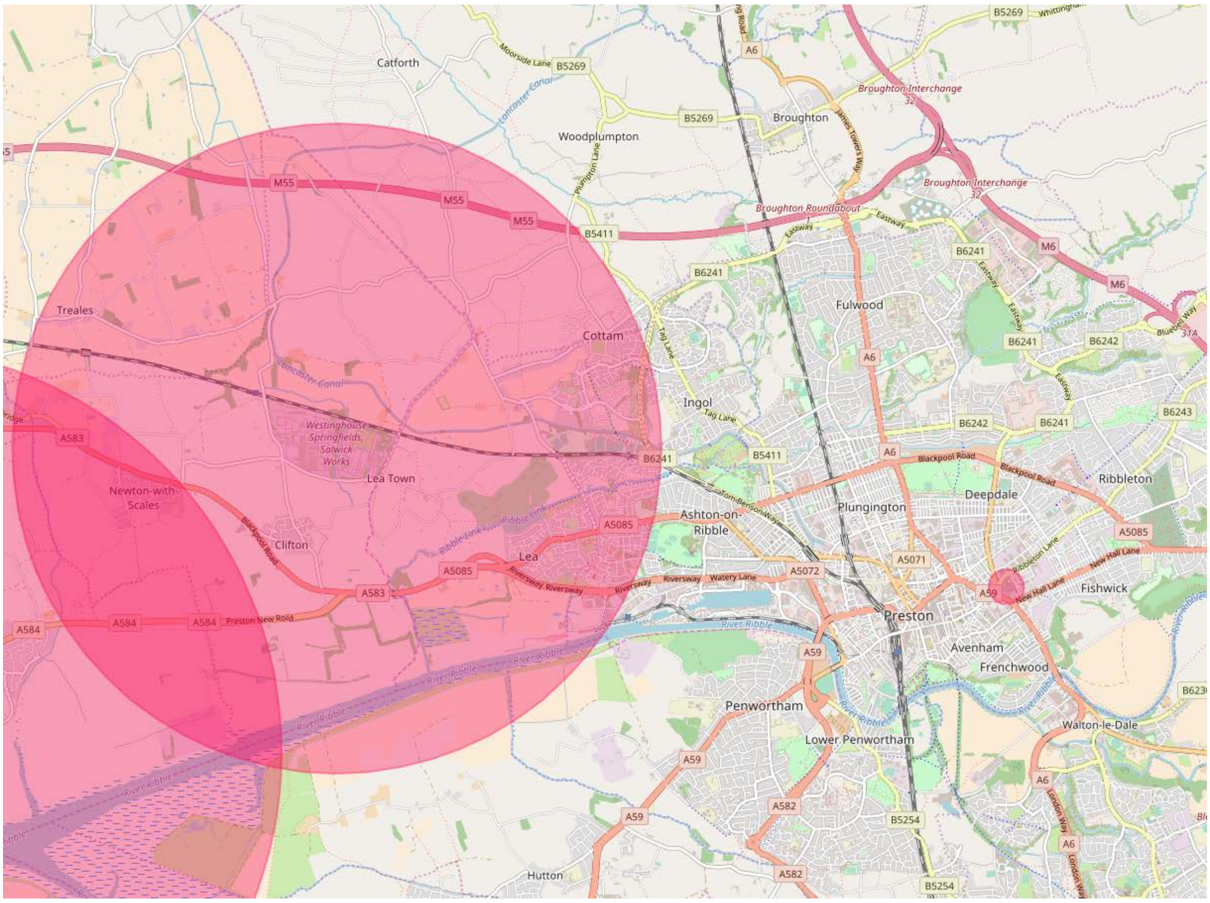
The main elements of the scheme are:

- The new M55 junction at the northern end of the site, on an active motorway.
- The Preston Western Distributor, a new 2.65-mile road linking the new junction to the A583 road through a sparsely-populated area (but crossing an active railway line).
- The East-West Link Road, a new road linking the Western Distributor with the western suburbs of Preston, including construction near existing residential areas.

Airspace and altitude

Preston is covered by Class G airspace. In Class G airspace, aircraft may fly when and where they like, subject to certain rules. Although there is no legal requirement to do so, many pilots notify air traffic control of their presence and intentions and pilots take full responsibility for their own safety, although they can ask for help. Air traffic control can provide pilots in Class G airspace with basic flight information service to support their safe flight. An alerting service is also provided if necessary to notify appropriate organisations regarding aircraft in need of assistance (for instance search and rescue).

In Class G airspace, aircraft must fly slower than 250 knots when below 10,000 feet in altitude. The drone for this use case would fly substantially lower and slower than this. Below 10,000 feet, aircraft, if flying according to VFR, must remain visually clear of cloud with visibility greater than five kilometres.



The airspace west of Preston is dominated by the R312 area around Westinghouse Springfields, in which operation under current regulation is strictly controlled. Warton Aerodrome's zone is also visible on the western edge of the map. Credit: Altitude Angel.

Westinghouse Springfields, a nuclear fuel production installation in Salwick, known as R312 is identified as a high risk area of operation, with operation of drones hazardous or prohibited under current regulation. This covers much of the proposed construction site.

Air operations in R312 are restricted in this area from the surface to 2,100 feet. In addition, under current regulations, flight is permitted at down to 1,670 feet for the purpose of landing at Blackpool Airport or in airspace lying south of a straight line joining 534644N 0024454W to 534513N 0025044W for the purpose of landing at or taking off from Warton Aerodrome. Flight is also permitted for the purpose of landing at or taking off from the helicopter landing area at Westinghouse Springfields.

Flight for this use case would be significantly below 2,100 feet altitude and require access to R312. As such, unless special permission was given, under current regulations this would prevent routine drone use in much of this construction site: feasibility depends on either regulatory change (likely supported by technical measures such as a UTM) or ad-hoc permission being granted for this use case.

This drone operation in Preston is envisioned to fly BVLOS, given the large size of the site and would thus need to be instrument flight rules (IFR) capable. Visual flight rules (VFR) flights are premised on the pilot being able to discharge responsibility by unaided visual processes (they can see and avoid hazards), which is not possible for BVLOS flight, so the drones will have to use IFR.

Routine BVLOS flights will need either special exemption from the CAA or updated legislation taking into account capability of the drone and surrounding infrastructure. Flights will need to be conspicuous to ATC and any other drone operators, requiring a UTM system of some kind, although as the construction site is not located within a congested urban area this might not need to be as comprehensive as in the other use cases investigated as part of the Flying High project.

The tallest structure within Preston is the Church of St Walburge at 94 metres (308 feet). Of the top 10, the majority are offices with heights of 48 (157 feet) metres to 63 metres (207 feet).

As the operation in Preston is taking place on a redevelopment site, a range of altitudes will potentially be needed (from ground level to the highest structure). Should the drone operate along a route (for instance along the M55), operational cruise altitude could vary, however should have at least 100 feet obstacle clearance (this is scaled down from the principle of 1000 feet manned aviation obstacle clearance, unless under radar control). In this case the drone would need to operate above 408 feet, which would provide sufficient margin from the obstacles below. A suggested altitude of 500 feet or 600 feet (above ground level) is recommended depending on the direction of travel. (We propose 500 feet if travelling east or 600 feetwest, following on from manned aviation rules of the air in which aircraft fly at an odd altitude flying east or even when flying west). As altitude separation in this scenario is significantly less than manned aviation, altitude systems need to highly accurate; this is particularly the case given the restrictions on use of airspace around Westinghouse Springfields and Warton Aerodrome.

Assuming that the drones are not the only users of airspace in operation in the area, UTM will need to be designed, able to deconflict both drone and manned aviation traffic with the ability to block off specific locations as required.

Take-off and landing points

As this use case does not need to link with a logistics supply chain and will be carrying out routine flights in a relatively uncongested area, it would not require fixed take-off/landing infrastructure on the ground. The drone could be launched from any suitable flat area on or near the construction site.

Drone platform requirements

Platform type

- The platform is likely to be a multi-rotor drone that can routinely cover a 5 mile construction site. Overall speed is not a critical factor in this use case, it will need to have the capability to fly slowly and precisely including the ability to hover with great stability.

Propulsion

- Zero-emissions power system: Battery-operated electric drones would be appropriate for this use case, as increasingly emissions are tracked and reported on construction sites and this would minimise harmful emissions. Weather and temperature conditions need to be considered and the ability to rapidly charge between routine flights without significant battery degradation would be advantageous. Battery swap is an opportunity and or the use of other energy vectors such as hydrogen, which may be more frequently used on construction sites for vehicles to meet overall emission requirements.
- Endurance: The platform should have sufficient endurance in order to complete a number of tasks in a single flight. The intention would be that the drone could complete a full suite of assessments outlined previously. It is envisioned longer-term with advances in battery technology that the drone could fly for more than 45 minutes, with the ability to swap over battery packs the drone could be operational for extended periods of time.

Payload, sensors and instrumentation

- Payload: High resolution optical camera, thermal camera, Lidar. Note that there is currently a tradeoff between price, weight and accuracy for Lidar scanners and that further development may be needed for affordable Lidar scanners to be sufficiently accurate at an acceptable weight and price point for this use case.
- Sensors and instrumentation: the drone should have a camera for navigation (this may not be the same camera as the payload camera as this will not necessarily be pointing in the right direction), it should also carry an ADS-B electronic conspicuity device.

Communications, navigation and control

The drones will be flown BVLOS with a high level of automation, from a ground control station with a pilot present, able to monitor the flight and take control in case of an emergency.

- Communications
- A robust communication system will be needed for the following purposes:
    - Control of the drone, with telemetry data (position, speed, battery status) relayed to pilot/site controller for tracking and safety monitoring.
    - In case of a systems failure the drone pilot should be able to control the drone and land it safely, which would require a first person video as the drone will be flying BVLOS.
    - Transmit location to other airspace users and air traffic service providers (e.g. a UTM system or air traffic control) - via an electronic conspicuity device.

- Redundancy will need to be built into the communications channels to allow for failure or loss of communications, thus a primary, secondary and possible tertiary communications channel will be necessary.
- The primary communications channel needs secure coverage over the majority of the route, in particular over busy airspace, the urban populated areas and the M55 where the risk to people on the ground and air is greater. Bandwidth should be sufficient to transmit telemetry data.
- The cellular mobile network generally meets these criteria, as this has a combination of generally good coverage (especially within city locations), high bandwidth and good security. As infrastructure is generally preexisting, it is readily available and cheap. Additional boosters or infrastructure outside the network area can address any coverage shortfall, with due consideration to any approvals required.
- The transmission of real-time HD video may require different technology. 4G LTE networks may have sufficient bandwidth as long as it can be appropriately secured, future 5G networks would provide greater bandwidth still.
- Using the mobile cellular network requires drones to support a SIM and connectivity module, so hardware and software can be updated when specifications change. Using drones equipped with a SIM card, existing mobile infrastructure can be used which will facilitate fast growth and reduce costs.
- There are limitations to the use of the mobile spectrum. Although coverage is good in the towns and cities it is worth noting it can be patchy in rural areas (much of the construction site is in the countryside west of Preston), although Ofcom reports generally good mobile reception on all four network operators in the area. In addition the network is aimed at optimising signal on the ground, rather than in the air.
- Should the drone experience a systems failure, it is recommended to have a different method for backup control in addition to the mobile network, such as data link control via satellites. Note this will be used for control of the drone and not video feed.

- Navigation and control
- Accurate knowledge of the drone position (latitude, longitude and altitude) is required.
- In manned aviation barometric pressure is the primary means of altitude determination, however this requires all aircraft in the vicinity to be on the same pressure setting which varies. In this case a ground controller would be required to monitor this area. However this system alone would not provide the level of accuracy required at lower altitudes as in this use case.
- Drone position can be obtained from a global navigation satellite system (GNSS) network. However, this too is not accurate enough alone to determine drone altitude to the accuracy required at lower altitudes. The GPS network alone is also not

suitable for drone navigation as it is prone to data degradation or complete loss of signal due to multipath effects, interference or antenna obscuration, so it will be necessary to have other systems present.

- An inertial navigation system (INS) (also known as as inertial reference system or more generally an inertial measurement unit), is a self-contained system that does not require input radio signals from a ground navigation facility or transmitter. This system derives attitude, velocity and direction information from measurement of the drone's accelerations given a known starting point, however over time the accuracy of this will also decrease and will require resetting. We recommend that the drone used in this situation use both systems together to improve navigational accuracy and for redundancy.
- A further navigation technology that may be used is the use of vision sensors (e.g. optical cameras, hyperspectral sensors, Lidar), which sense the surrounding area directly and could be used in conjunction with a pre-loaded terrain database to complement existing navigation techniques. These vision sensors would primarily improve take-off and landing ability, with secondary function as a backup navigation source. Currently this is not commonly used for external navigation but could be a way of increasing accuracy of positioning and navigation.
- To ensure safety and minimise risk of collision, the drones should broadcast their location and an ID signal to other airspace users and to any air/unmanned traffic management system. This capability is referred to as 'electronic conspicuity'. The current standard on aircraft is ADS-B, which has been allocated a specific frequency band in the UK (960-1215 megahertz). This has low transmit power levels, low cost and the potential to be interoperable with other ground and air users and would be the default choice at present, though other technologies for broadcasting position may be developed.
- If drones are to operate in any mode they are required to 'be seen and avoided'. Detect and avoid systems currently alert pilot to other traffic and suggest resolving vectors. We recommend developing DAA systems to autonomously react to any aircraft installed with an electronic conspicuity device (EC). This is a challenge together with the ability to detect traffic not fitted with EC devices (such as birds).

Safety

- We have performed a qualitative risk analysis (SORA – Specific operation risk assessment),[65] to help identify the level of robustness required for all threat barriers based on the three categories of harm: Injury to third parties on the ground, fatalities to third parties in the air (mid-air collision with a manned aircraft) and damage to critical infrastructure. Specific threats have been examined and graded on their perceived risk suggesting a required level of robustness against each threat. Threats include: human error, technical issue with drone, aircraft on collision course, deterioration of external systems supporting drone and an adverse operation

65 http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v1.0.pdf

condition. This analysis has been performed to help identify areas for further consideration and is not intended to be a safety case.

- The SORA assessment shows the risk of injury to people on the ground is low as the drone is relatively small (max characteristic dimension <1m) and envisaged to operate in Class G airspace primarily in a sparsely populated environment. It is assumed that the harm barrier adaptations required will be minimal as the risk to people on the ground is small. Note this could become significant post-development should the M55 link road become operational and full of traffic while the drone was still in use: the risk to people on the ground would become much larger. When examining the risk of a mid-air collision, based on this operation taking place in class G airspace with minimal traffic, the airspace encounter rate is low and therefore the the risk is low. The level of robustness for this use case across most categories of threat is low or optional. Operating procedures to handle the deterioration of external systems supporting the drone operation must still be of medium robustness.
- Safe operation: To mitigate these threats construction site staff are likely to be wearing PPE and so risk to people on the ground is low if managed correctly. UTM, ADS-B and detect and avoid devices would mitigate risk of mid-air collision.
- Failsafe: Minimal failsafes are required due to low population density in the area of operation however there should be consideration using of a parachute device in the case of total loss of power.

Environment

- Noise can annoy people, disturb sleep, impair cognitive performance and increase the risk of cardiovascular disease.[66] The impact of noise depends on many factors including what the drone sounds like, what kinds of manoeuvres it makes and the context in which it is operating.[67] The noise generated by this use case could affect people living near the construction area. However, the impact is likely to be very low as the drone will be operating largely away from built-up areas and the construction site will already be generating a lot of noise. As a relatively small multi-rotor drone, noise levels produced by the drone would in any case not be particularly high.
- This use case may need to comply with existing noise-related regulation. This could include aviation noise regulation, health and safety regulation, environmental protection regulation and local planning rules.
- Weather/climate: Current multi rotor drones generally have recommended operating restrictions of 0-40°C and wind limitations of 19 knots, these can be more restrictive during take off and landing. The drone service must be able to operate year round and therefore needs to be able to operate efficiently and with stability in these conditions, as well as in moderate rain, poor visibility and cold temperatures sub zero degrees (which can cause icing). Drone design should incorporate tolerances in excess of the limitations above to maximise operational time.

---

66 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3971384/

67 https://wrightacoustics.com/white-paper

- The design considerations should examine historic wind speeds in Preston, potentially factored against statistical frequency to balance cost with availability to reduce extremes and balance cost. There are no significant tall structures that disrupt airflow however extreme weather conditions that may prevent operations. We assume in this analysis that for 3 percent of the year (around 11 days) they are unable to fly, a figure that roughly mirrors restrictions on aircraft.[68]

Regulatory requirements

- The drone operation will need to take place in Class G airspace and in the restricted areas of Warton Aerodrome Traffic Zone and Westinghouse Springfields. Springfields is a high risk area nuclear facility as is likely to restrict drone operation regardless. As well as permission required to operate in these other areas, there is a requirement to define the rules and regulations for drones within this airspace, addressing the interoperability of cooperative and non-cooperative traffic, both manned and unmanned. Drone capability level together with UTM systems should be integrated into these rules.
- The drone will be required to operate autonomously BVLOS and fly over an urban setting within 50 metres of any person, vessel vehicle or structure. Regulation currently requires any commercial operation to prepare a safety case for submission to the CAA that addresses each of the limitations covered by the Air Navigation Order (ANO) above, however this is currently only for VLOS operation for drones weighing <20 kilograms. Regulation will need to address this for BVLOS operations.
- The drone is required to operate over highways and preselect emergency landing sites. Overflight permission is likely to be required from Highways England to operate over their facilities and for the allocation of emergency landing sites.
- Mobile phone networks are governed by the Wireless Telegraphy Act 2006. For mobile phones, the use of the spectrum by the network operators is licensed to cover the use of transmitters and repeaters which are under their control, while user devices are covered by a general exemption. Cellular repeaters, boosters and enhancers are not accepted devices. In exploring our use case if cellular connectivity is to be used, collaboration with the network provider to increase the infrastructure required to realise the task is imperative. Additional boosters or infrastructure outside will require additional specific exemption.
- As the drone will be using radio equipment, it must comply with Ofcom regulations.[69] Within the UK the use of radio apparatus, including drones, is regulated by law. This ensures only equipment which is safe and does not cause harmful interference is placed on the market. The Ofcom licence and licence exemption state the terms and conditions on the use of radio apparatus.

---

68 In practice drones are likely to have higher vulnerability to adverse weather due to their size and battery life. However, they would have more flexibility to deploy earlier or later compared to scheduled flights and the limits placed on them are unclear until the drone has been created and tested. As such we assume 3 per cent is a reasonable benchmark to apply in this case.

69 https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/drones-advice

- This use case will need to comply with the EU General Data Protection Regulation (GDPR),[70] which regulates how organisations can store and process personal data. The GDPR requires organisations to follow principles such as collecting the minimum amount of data needed for the organisation's purpose, keeping the data secure and informing people that their data is being collected. In this use case, data protection will need to be considered when dealing with the images that will be collected.

Operations and traffic management

A traffic management system is required to:

- Track drone position so it is visible to both controllers on the ground and operators in the air, both manned and unmanned. Airspace violations can be monitored and dealt with accordingly by managing authority in this way.
- Identify when traffic will conflict and alert user or autonomously deconflict this trafic should no action be taken.
- Be interoperable with all traffic, other UTM systems and air traffic control.

Should drone deployment increase it is recommended to further develop electronic conspicuity devices together with detect and avoid systems, which securely integrate into the flight control system to autonomously react to any potential conflict.

Security

A security breach could allow attackers to steal data, control or influence the drone, or prevent it from operating. This could have implications of varying scale and impact. A security breach could cause safety risks in an environment that is already hazardous. In addition, the imagery captured by the drone will be commercially sensitive for the construction company.

It is not only malicious attacks that are problematic but also to natural interference to signals, signal integrity and the potential for RF saturation which could cause issues. This would require the use of redundant and independent systems such that a threat would need to overcome multiple systems to have a negative impact.

As the drone will be operating BVLOS this will significantly increase the complexity of ensuring the safe and security operation of the drone. The system therefore needs to manage issues while out of line of sight, which may include trade-offs with other aspects of the system such as technology to increase privacy.

It will be important check for security weaknesses across the whole system including areas such as communications, data storage and control software. It's also important to look at what is connected to the drone system: attackers can sometimes gain access to one system through another, connected system. In this case, it would mean checking the security of

70 https://ico.org.uk/for-organisations/guide-to-the-general-data-protection-regulation-gdpr/

connected systems such as building information management systems or web applications used to analyse the imagery from the drones.

Security is not just about having the right technology in place, it's also important to have good security processes. For example, there should be processes in place to regularly test for security weaknesses as well as monitor for and respond to security breaches.

Privacy

Privacy is an important aspect to consider across a construction site as the drone will be collecting information on the movements of site personnel, the public and operate near to businesses, residences and schools.

The intent is for the drone to survey the specific construction areas only, although the optical field may include areas outside the construction site. This use case includes inspection of an infrastructure build on the M55 motorway.

The data the drone captures needs to be processed and handled by appropriately trained individuals; it is also likely that notices would be required informing anyone entering the construction site that a drone will be recording activities on site.

As the drone will be collecting live information, it can be compared to closed circuit television, which is governed by the CCTV Code. All operations should be consistent with data protection legislation.

Economic and social feasibility

This economic feasibility study outlines the range and scale of potential benefits arising from drone deployment in Preston. The specific projects analysed are the new M55 junction, linked to the Preston Western Distributor and the East West Link Road. After discussion with the project team and other specialists it is clear that there is huge scope for drone deployment in many of the large-scale construction projects that will occur in the next ten years. This EFS outlines the estimated total costs of deployment and the likely benefits that would arise from deployment in this case. It also highlights the scalability of these findings and their policy implications.

We have modelled the benefits of drone deployment in urban regeneration projects as an exogenous 'shock' to productivity which generates significant savings.

Key assumptions to the use case

Key parameters to model the introduction of drones are described below. The key assumptions for this model can be found in the appendix at the end of this report.

Project duration and cost: Based on conversations with Project Directors and city representatives, we estimated a project duration of 42 months (3.5 years), construction costs of approximately £140m. Our model is built on an estimated cost and duration overrun of a) 20 per cent and b) 40 per cent. This is aligned with industry averages and conversations with the city stakeholders.

Number of drones: One drone would be deployed covering all three major construction projects around the M55 link road

Cost of drone: The cost of a drone of this specification at current market rates is **£26,000**, assuming that drones would be purchased at the start of the project.

Cost of wider supporting infrastructure: Deployment would be automated and supervision of drone flights would be taken up by construction site management. Hence, there are no additional staff costs. However, to account for additional qualifications, we have assumed a training cost of £15k for each construction site manager for the entire duration of the project. Cost to manage and change current processes and systems is estimated to be a one-off cost of £1,000,000. We have made a high assumption to account for all costs related to a full integration into existing systems, e.g. BIM and the need to update data analysis programmes etc.

Productivity benefits: We assume that productivity and efficiency are in this case interchangeable. Whilst workers might be more productive, we do not model this as leading to a reduction in workers, but rather to a faster construction process. A 10 per cent increase in productivity would therefore translate to a reduction in construction time of 10 per cent. As such, we have made the assumption that drone deployment and integration would improve productivity, bringing construction productivity partially in line with the (higher) rates of manufacturing productivity.[71] [72] In this case our medium assumption was a productivity increase of 10 per cent. In practice, the cost savings delivered by this assumed productivity increase reflect a number of different savings that could be delivered, including reduced wastage, better maintenance and more frequent inspections and monitoring. We evaluate these effects based on their aggregate impact, rather than any one individual set of benefits.

Social benefits: We have included a proxy to model the reduction of carbon dioxide and other greenhouse gas emissions. Noise pollution was not modelled considering the distance of the specific construction sites to any significantly built-up areas. Similarly, estimates for the benefits to workers' health or improved safety on the site have not been included in this analysis.

The use of drones for urban regeneration projects is highly economically feasible because it reduces cost and time overrun

The results of the model indicate that, under the assumptions made in our medium scenario, this deployment of drone technology in Preston is highly economically feasible. Under our assumptions, the total net benefit is, accounting for all costs, is approximately £15.7 when assuming a 40 percent cost and time overrun and £13.9m when assuming a 20 percent cost and time overrun. This suggests a use case that is extremely economically feasible, with results being driven by cost savings delivered through increased productivity. The nature of this use case does mean, however, that the majority of these returns are delivered at the

---

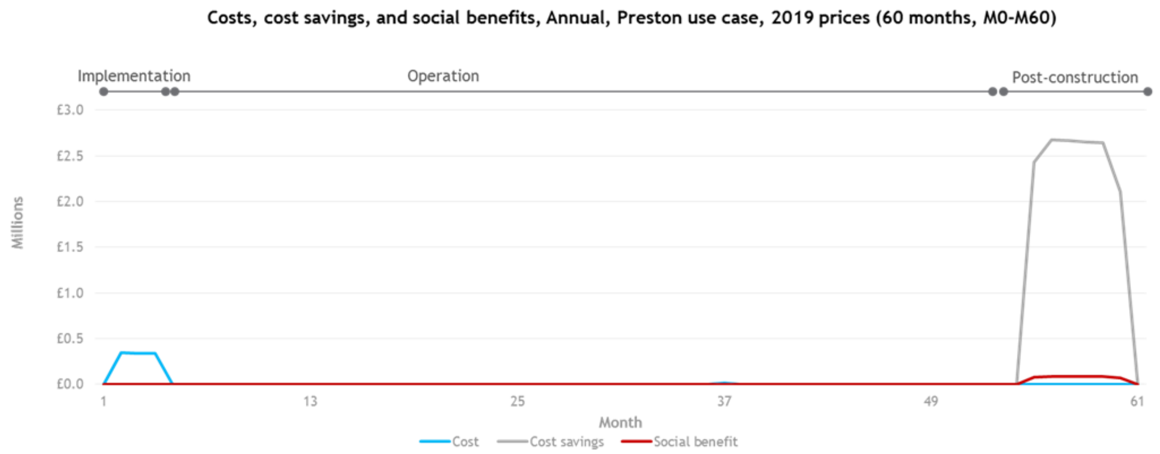
71 https://policy.ciob.org/wp-content/uploads/2016/05/CIOB-Productivity-report-2016-v4_single.pdf page7 and

https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/labourproductivitybyindustrydivision

72 http://wpieconomics.com/publications/off-site-construction/

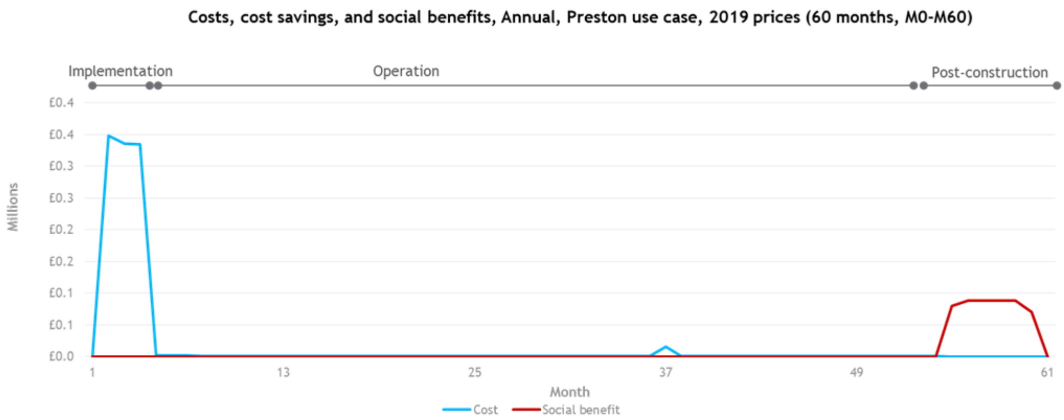
end of the project; meaning that the extent to which the returns would be delivered is heavily dependent on the assumption that the drone deployment unlocks significant productivity gains. This question is explored further in the 'scalability' section.

As can be seen from the graph below (which illustrates the 40 per cent run over scenario), there are three key phases to consider in terms of the estimated impacts of the drone deployment:



Implementation: substantial up-front costs, driven by a combination of implementation, training, purchase of the drone systems and integration into the operational systems; **operation:** productivity improvements of the construction site and constant costs for maintenance, salaries and other associated requirements; **post-construction:** assuming constant staffing levels, increased productivity will lead to a shorter construction period: cost and pollution savings that would otherwise be incurred can be avoided. This manifests itself in the model as significant cost savings and social benefits compared to the baseline.

The consequence is that between months 54 and 59 in our 40 per cent overrun modelling scenario, there are significant savings in terms of monthly construction costs (approximately £2.5m per month) and reduced costs of pollution (approximately £90,000 per month). For the scenario where time and cost overrun is estimated at 20 per cent, the savings would occur in months 46-51 at approximately £2.3m per months. In both scenarios, the time period the drone reduces the construction by is reasonably short but given the high monthly costs, the benefits are substantial. The scale of the benefits delivered distorts this picture somewhat. Showing only costs and social benefits (for the 40 per cent overrun scenario), it can be seen that whilst the social benefits are still considerable, there do not exist at a scale that would justify this deployment purely on social grounds.



Crucially, despite the fact that these benefits are concentrated in a short period, they are sufficiently large that they justify the up-front investment required to deliver them. Accounting for the upfront investments and on-going costs and assuming a 10 per cent productivity increase, the net present value of this investment is between £12.4m (20 per cent overrung scenario) and £14.1m (40 per cent overrun scenario). This would suggest that, if they deliver on their potential, the use of drones integrated into BIM systems in construction projects would deliver substantial returns that would make this an extremely feasible deployment of the technology.

There is significant interest and opportunity to leverage this technology for other urban regeneration projects

Aside from this use case, there is significant interest in how drones could be used to improve construction processes across Preston in the next decades, as well as across the country as a whole. As such, how scalable these findings are is extremely important.

Our findings and the assumptions lead to two key conclusions regarding scalability. First, the impacts are heavily dependent on the assumed productivity increases, meaning that the feasibility will depend on how well project managers integrate drone intelligence into their operations. Second, they depend on the scale of the construction project and its projected overrun.

Scale and nature of construction

There is no reason that the same benefits could not be derived from other similar projects, providing the same logic is used in terms of the drone's real-time intelligence being used as part of an integrated construction process to deliver quicker and more efficient construction processes. Three points should, however, be considered in relation to scale.

The first is that with larger projects there would be a higher technological requirement and also a need for more drones. In practical terms this would simply raise the cost level at the beginning of the project as more staff need to be employed and a greater level of infrastructure built to support the deployment. As such, the scale of the costs may need to adapt to account for this fact.

The second component to consider is the raw size of the project. In practical terms – the benefits delivered from increased productivity are proportional to the scale of the project; in that a 10 per cent increase in productivity will result in (holding other items constant) a 10 per cent reduction in costs and social costs. In practice, however, the estimated productivity gains may need to vary depending on the nature of the construction project and the drone deployment.

Last, the results in this model are predicated on an assumed overrun of 40 per cent, as stated in the assumptions. It should be noted that as the potential of technology and new construction processes begins to be realized it may significantly reduce projected overruns due to improved planning and coordination. As such, over time the assumption of large overruns may need to be reduced and how much of this can be explicitly attributed to drones is unclear. This is a consideration which may limit scalability to some degree in the future.

Conclusions and recommendations of the technical and economic feasibility study

Conclusions

The Preston use case could have strong economic and public benefits. The use case is technically feasible, in principle, but the restricted area around the Westinghouse Springfields nuclear facility is a notable barrier that could prevent drone operations over much of the M55 link road construction area. Outside of this, there are a number of other challenges that need to be considered in order to make this use case a reality.

The key challenges (C1-4) for drone-based surveying of construction and urban regeneration in Preston, based on our analysis of this case study, are

C1. The development of a drone system that can operate safely, securely and reliably beyond visual line of sight, while maintaining appropriate levels of privacy.

C2. The provision of suitably managed, unsegregated airspace allowing for interaction with other airborne systems. (as noted above a key challenge for the specific example of the M55 link road development, is that operation is required within the restricted airspace of the Westinghouse Springfields nuclear fuel facility).

C3. The development of key elements of drone and drone systems technology, with automated data feeds into the building information management (BIM) system and more automated systems that remove routine elements of human interaction, eventually moving to a fully autonomous system.

C4. Being able to operate in low light, at night time and in adverse weather conditions, including high winds, rain, snow and poor visibility.

Recommendations

The following recommendations relate directly to the the four challenges outlined above (referenced in brackets).

A. Regulatory change to enable routine drone operations at scale, beyond visual line of sight and near people, buildings or vehicles. (C1 and C2)

B. The development of a new form of airspace management to enable safe automated drone operations at scale. (C1 and C2)

C. Electronic conspicuity devices fitted to all air traffic and integrated into a traffic management system, to improve safety, security, privacy and positive public perception. (C1 and C2)

D. Secure interfaces into other systems and infrastructure with the number of interfaces minimised and encrypted. (C1)

E. Development of technologies that can demonstrate safe operation through high levels of redundancy, including secondary and possibly tertiary systems for command and control, navigation, power and propulsion systems. (C1)

F. Development of counter drone systems to identify and manage unauthorised drone operations, either malicious or accidental. (C1)

G. Development of registration and enforcement systems, with appropriate resources to ensure operator accountability. This should include a centralised database showing licensing of operator competency, the platform ID and airworthiness and the capability to provide real-time monitoring of the airspace. (C1, C2 and C3)

H. Requirement to develop tools and standards for the verification and validation of the drone components, platforms and systems, with traceability of the hardware and software supply chains. This should include development of simulation tools to ensure safe operation and validation of autonomous and machine learning systems. (C1 and C3)

I. Development of appropriate safety cases associated with the use case that could be published and used as standard scenarios to support the regulator and the growing UK industry. (C1 and C2)

J. Establishment of a clear, accountable ownership and sign-off responsibility over the various aspects of operation. This includes maintaining airworthiness, oversight of system upgrades, assurance of pre-flight checks, the flight, associated safety related flight data and appropriate legal accountability and insurances. (C1 and C2)

K. Integration and interoperability between airspace management systems. This will require both technology solutions as well as co-ordinated standards, legislation and process development. (C2)

L. Investigate the possibility of flying partially within the restricted airspace of Westinghouse Springfields nuclear fuel facility. This could be linked to more dynamic airspace management and electronic conspicuity. (C2)

M. Artificial intelligence (AI) developments to support the processing of data feeds to provide valuable and real-time information on all aspects of the construction site, including safety-relevant information, integrated with BIM systems. (C3)

N. Coordination with other aligned technology areas around common challenges which could include collaborations with the robotics and autonomous systems and connected and autonomous vehicle communities. (C3)

O. Development of capabilities to ensure safe flight during adverse weather conditions and at night time. (C4)

P. Development of tests that prove out the capability of the platform and system in representative environments. Leading to trials with growing complexity, moving from controlled environments to full public demonstrations. (C1-4)

Technical and economic feasibility study: supporting the fire and rescue service in Bradford

Using drones as a rapid response to respond to fires

- Fast observation drones can reach the scene quicker than the emergency services
- Emergency services can get aerial imagery of the scene and improve their response
- Drone imagery can also be used to manage and inform firefighters' response to the fire's evolution in real time
- We find this use case is both technically and economically feasible

Introduction

This section explores the use of drones to support the West Yorkshire Fire and Rescue Service in responding to incidents in and around Bradford.

Drones could provide high-quality information to support operational planners and controllers to direct resources when an alarm has been sounded by arriving on the scene faster than any other means, or to provide real-time information to officers on the ground that otherwise would be impossible to collect. We consider the general opportunity for use of drones in support of West Yorkshire Fire and Rescue Service, and then focus specifically on one example of this: drone deployment for rapid eyes on scene and gathering live operational intelligence, operating from a city centre fire station.

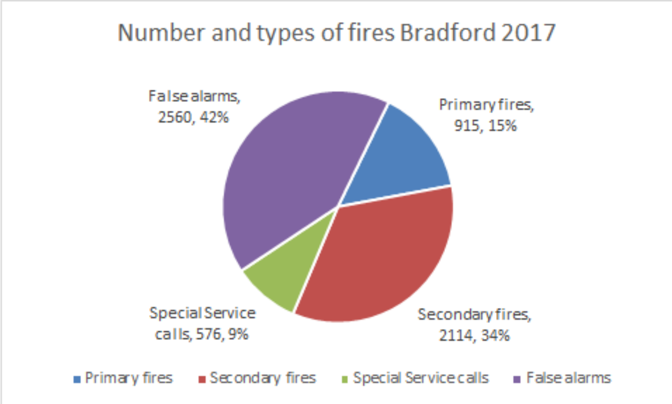
General discussion

The case for fire and rescue drones in Bradford

The City of Bradford Metropolitan District Council aims to leverage emerging technology to support local goals, which include safe and healthy communities. Considering the opportunities of drone technology, local stakeholders have indicated that drones could offer benefits to the community by supporting the emergency services, in particular the West Yorkshire Fire and Rescue Service (WYFRS), which operates eight stations in Bradford

District.Bradford has had several major fire incidents in recent years, such as the Drummond Mill[73] and Prospect Mill[74] fires in 2016, in addition to major flooding, most recently in 2015[75].

Piloting the use of drones for fire and rescue in Bradford would also align with a number of current innovation initiatives in the city. These include WYFRS currently investigating whether fire plans could be made more effective using drones to capture detailed mapping data about these high-risk sites (capturing highly detailed 2D and 3D models that would then be augmented with other data sources, such as locations of utilities to create interactive, real-time maps). Additionally, the University of Bradford is exploring a possible project with WYFRS to capture data from wearable devices worn by firefighters when attending incidents.



Number and type of incidents reported to WYFRS in Bradford District 1.4.2017 - 31.03.2018. (Source: WYFRS)

In the year to April 2018 there were 6,165 incidents reported to WYFRS in Bradford District. 42 percent of FRS call outs in the district were false alarms, mostly caused by faulty apparatus, 33 percent were secondary fires (fires outside or in derelict property) and 15 percent primary fires (fires in property building/cars). The remaining nine percent were 'special service' call outs such as road traffic collisions rescuing people trapped in lifts.

Drones are beginning to be used by fire and rescue services across the UK, including in Greater Manchester,[76] the West Midlands[77] and Kent.[78]

WYFRS invested in a drone in February 2018,[79] and has been conducting a six-month trial on the use of drones, initially limited to the daytime, with applications including assessing the extent of damage caused by a fire, understanding the risks posed by an incident location, and recording an incident response for training purposes. Their drone team operates across the county pre-mapping high risk sites, responding to incidents and supporting the incident commander in real time, collecting and assessing post-incident information for crew debriefing and management discussions, and providing information to the general public. There is however a wide range of broader or more ambitious possible

73 https://www.bbc.co.uk/news/uk-england-leeds-35436802

74 http://www.thetelegraphandargus.co.uk/news/14638571.VIDEOS___PICTURE_GALLERY__50_fire_fighters_tackle_huge_mill_blaze/

75 http://www.thetelegraphandargus.co.uk/news/14169271.Counting_the_cost_of_the_Bradford_Boxing_Day_floods/

76 https://zoinet.org/wp-content/uploads/2018/01/12.Manchester.pdf

77 https://www.wmfs.net/16054/

78 http://www.kent.fire-uk.org/about-us/glossary/drone-unmanned-aerial-vehicle-uav/

79 http://www.westyorksfire.gov.uk/news/fire-service-invests-in-drone-technology-to-give-a-new-perspective-on-blazes-and-other-rescues/

applications, some of which will require new technology and regulatory exemption or change.

At the moment drone operations are generally limited to what is laid out in the Air Navigation Order 2016 (400 feet altitude and 500 metres horizontal distance from the operator). There is an exemption for the emergency services in short term-reactive situations that relaxes some of these rules[80] (WFRYS currently holds permission to operate outside some of the limitations, based on a detailed operations manual), but new technology and operation procedures could allow for new types of operation. If drones were able to fly beyond the line of sight of an operator, potentially autonomously, they could be used to get to the scene of an incident faster than conventional vehicles.

The uses of drones to support fire and rescue services can be broken down by phases of incident:

Planning: Map the district to develop and update fire plans for high-risk sites

- Provide an up to date high-definition map and model of each site.
- Augment digital maps and models with other data sources and data points, such as locations of hydrants, fire exits, dry risers, location of utilities, etc.

Response: Real time disaster assessment

- Mobile observation post to provide real time information for the incident commander to effectively coordinate emergency response. The incident commander could also request the drone to carry out specific tasks such as observing a particular location. The visual feed from the drone can be augmented with information from other data sources.
- Gas monitoring (toxic/radioactive).
- Search, primarily to identify people in danger. Secondarily to quantify risk of structural failure.

Recovery: Damage assessment of critical infrastructure post-disaster that would otherwise be impossible to reach

- Provide up to date accurate mapping data of disaster area.
- Damage assessment, to visually inspect to identify extent of damage and any hazardous structural issues.

In the longer term, the use of drones could eventually be scaled up to help all types of emergency services across Bradford. A citywide emergency drone network could provide fast initial assessment and ongoing monitoring of emergencies. As AI technology improves, drones could carry out more complex tasks such as identifying people in trouble. This network could also support related non-emergency FRS work such as assessing structures that might be at risk of fire.

80 http://publicapps.caa.co.uk/docs/33/1233.pdf

Future implications of using fire and rescue drones in Bradford

There is a longer term prize if we prove this concept

Use of mapping data in conjunction with other data sources and Internet of Things (IoT) sensors could generate predictive response to fire incidents.

For large-scale emergencies such as floods, riots or moorland fires, drones could provide the aerial overview needed to understand the full situation. Working in groups, autonomous drones could provide complete coverage of a disaster area and also search for survivors or alert responders to new dangers. They could use sensors such as infrared and gas sensors to give responders a comprehensive understanding of an emergency.

As well as providing intelligence on a situation, drones could actively intervene in emergencies. They could drop floatation devices to people at risk of drowning, dump water on moorland fires, or rescue people from burning buildings.

These different capabilities could be integrated into a drone team for emergency services. This team could have different drone swarms for monitoring a situation, for providing communications networks (for instance, temporary nodes to provide coverage), and for intervening, all communicating with each other and with the human responders.

Benefits of using drones to support the fire and rescue service

Time savings

Drones save time, particularly around false alarms

At present, the scale of resources deployed for a fire incident is determined by WYFRS control based on the Pre-Determined Attendance (PDA) for a particular incident type and location, plus any information WYFRS receive from the caller. There are different responses depending on, for example, whether it is an automated fire alarm, an alarm where a person can see fire and/or smell smoke and for special interest buildings such as schools and hospitals. In the majority of cases, the actual nature of the fire will only become apparent when fire and rescue services arrive on the scene. Having eyes on the site allows trained operators to make further decisions about the required resources. Based on data from the WYFRS, it took on average 6 minutes 34 seconds between alert to arrival in 2016/17; though this figure varies between urban and rural communities (where risk is often lower). This is already fast, but every second counts in an emergency scenario, plus getting to an incident with a drone quickly could lead to more efficient allocation of resources if information can be quickly gathered. This has the effect of protecting WYFRS resources for incidents where there is a risk to life or property, particularly if the drone can eliminate or reduce responses to false alarms.

Cost savings

Drones help the fire and rescue service make more efficient use of resources

Since 2010-11, government funding for fire and rescue services has changed in both scale and structure. According to an NAO report from 2015, total government funding for stand-alone authorities in England fell on average by 27.8 per cent in real terms since 2010.[81] At the same time, according to data from the Association of British Insurers, the direct cost of fires and other emergencies, as well as the indirect costs such as traffic congestion are spiralling across the country.[82]

Drones are a cost-effective alternative to conventional response methods by emergency services, particularly helicopters. There is a substantial opportunity to use drones across blue light services, enabling more coordinated and novel approaches to incident responses.

Cost savings occur from a more targeted response to fires and a less expensive way of monitoring long burning fires. Waste or recycling sites, for example, are sometimes subject to fires burning over an extended period of time, requiring an appliance to be on site 24/7 in case the fire flares up again. A drone could be used instead and either constantly hover or do a regular patrol flight to identify hotspots alerting control if there was a flare up, or the temperature increased by a certain number of degrees. The appliance (and four firefighters) at the scene could then be freed up to go to other incidents.

Social benefits

Drones can improve safety and save lives

In addition to direct cost and time savings, the use of drones can improve the safety of firefighters and everyday citizens. Thermal imaging can allow firefighters to locate hotspots within a fire, directing firefighters to cool those areas or ensure that the seat of the blaze is being tackled. This could also be used to assess the safest route to help firefighters reach people trapped within a site. More generally drones can reduce the need to place responders in hazardous environments, reducing the risk of injury or long-term health consequences e.g. from exposure to fumes and heat.

Environmental benefits

Drones can redue the risk of environmental damage

Real time, aerial data from the drone will enable a more targeted response. Being able to more quickly stop the spread of fire can reduce the quantity of toxic fumes being emitted by fires and reduce the risk of destruction of nature or surrounding buildings. Reduced emissions is particularly important for protecting human life in densely populated environments such as cities. Drones can access areas before, during and after fires that

81 https://www.nao.org.uk/wp-content/uploads/2015/11/Impact-of-funding-reductions-on-fire-and-rescue-services-A.pdf

82 https://www.fbu.org.uk/policy/2015/firefighters-and-response-medical-incidents

would otherwise be impossible or dangerous to reach which enables a more effective post-disaster damage assessment. These visual inspections will also enable faster investigations of the site and more targeted reconstruction.

Example: Drones for rapid response data capture and operational intelligence from a fire station in central Bradford

We explore drones flying BVLOS, on autopilot from Bradford fire station to the location of a fire in the surrounding district

As a test case to explore a boundary-pushing utilisation of drones by West Yorkshire Fire and Rescue Service (WYFRS), we have chosen to focus on deployment of a rapid response and operational intelligence drone. This would be flown to the site of an incident from Bradford Fire Station, one of the eight fire stations in Bradford District.

This is an illustrative example of how a future drone service could look. Indicative calculations have been developed by the project team, underpinned by data from WYFRS. Assumptions have been made to illustrate possible efficiencies which could be realised, though these are based on yet to be developed or proven ways of working.

The drone would perform the following functions:

1. First response to an incident, to get eyes on the scene quicker than road transport allows, to quickly report details of the call out such as precise location, whether it is a false alarm, and provide situational awareness to firefighters, such as the number of people in the vicinity and any risk to nearby buildings.
2. Provide operational intelligence during an emergency response, including:
    - Identifying people trapped in buildings.
    - Identifying structural damage and risks to structural integrity.
    - Monitoring gases to identify potential toxic fumes.
3. Post-incident damage assessment.

Following report of an incident requiring further intelligence, the rapid response drone with a thermal and video camera would be dispatched in order to get eyes on the scene as quickly as possible and stream information back to an operator. A second drone would be on standby, ready to be dispatched to the scene if necessary to take over from the first drone to provide more advanced data capture. This second drone could have a more advanced payload such as a high resolution optical zoom lens, toxic gas detection equipment, hyperspectral camera or Lidar, and would be able to loiter above the scene for long periods. The decision to dispatch the first drone could be made by an operator or automatically based on a set of pre-defined criteria or a particular type of alarm. Both drones could be the same type of high-endurance platform, and be required to travel at high speeds and/or circle the site for long periods of time, implying a fixed-wing drone. The initial response drone needs to arrive at the scene quicker, and therefore needs a lighter payload, while the second drone would require greater endurance and more advanced payload. To facilitate operations and avoid the need for a runway, launcher or catcher, the drones should be able to take off and land vertically, implying a hybrid VTOL fixed-wing drone.

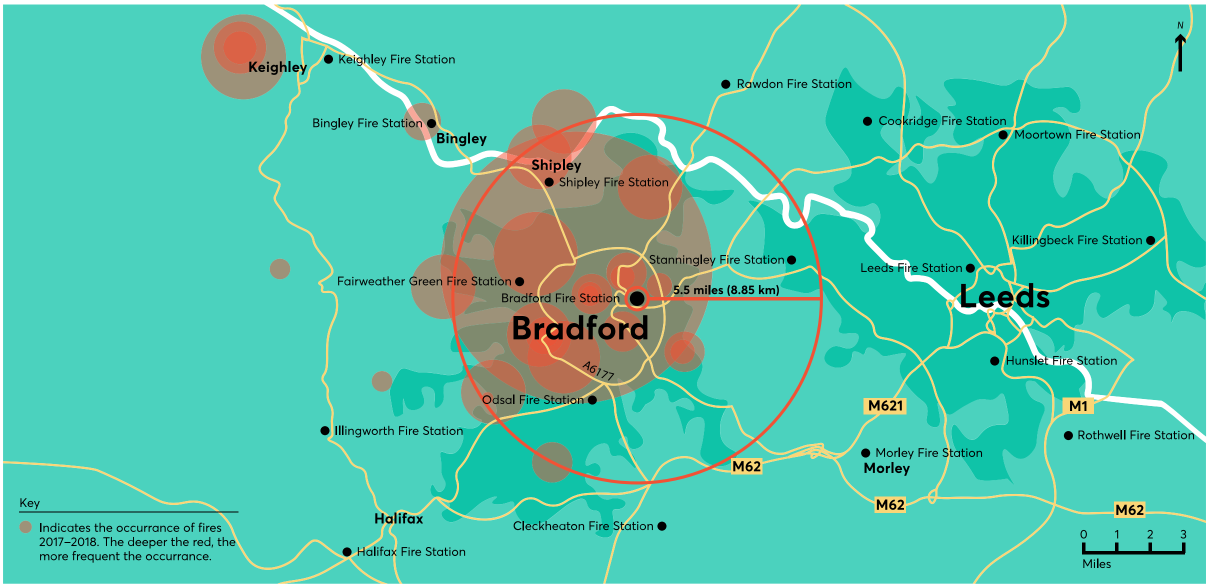
A single service would be able to cover the majority of incidents reported in Bradford District in 2017-18, which were clustered around Bradford itself and the nearby town of Bingley, also part of the City of Bradford Metropolitan District Council. The drones would need to cover an area with a radius of approximately 5.5 miles, totalling around 95 square miles.

Although the analysis is based around deployment in the coverage area of Bradford Fire Station, using two drones, there is potential to scale up to increased capacity and deployment from more stations (reducing the endurance required for each platform). It is envisioned that the drones would operate in a highly automated fashion, flying BVLOS to the scene of an incident with a high level of automation and transmitting imagery back to a control station, that would relay information as needed to the incident commander.

Technical attributes

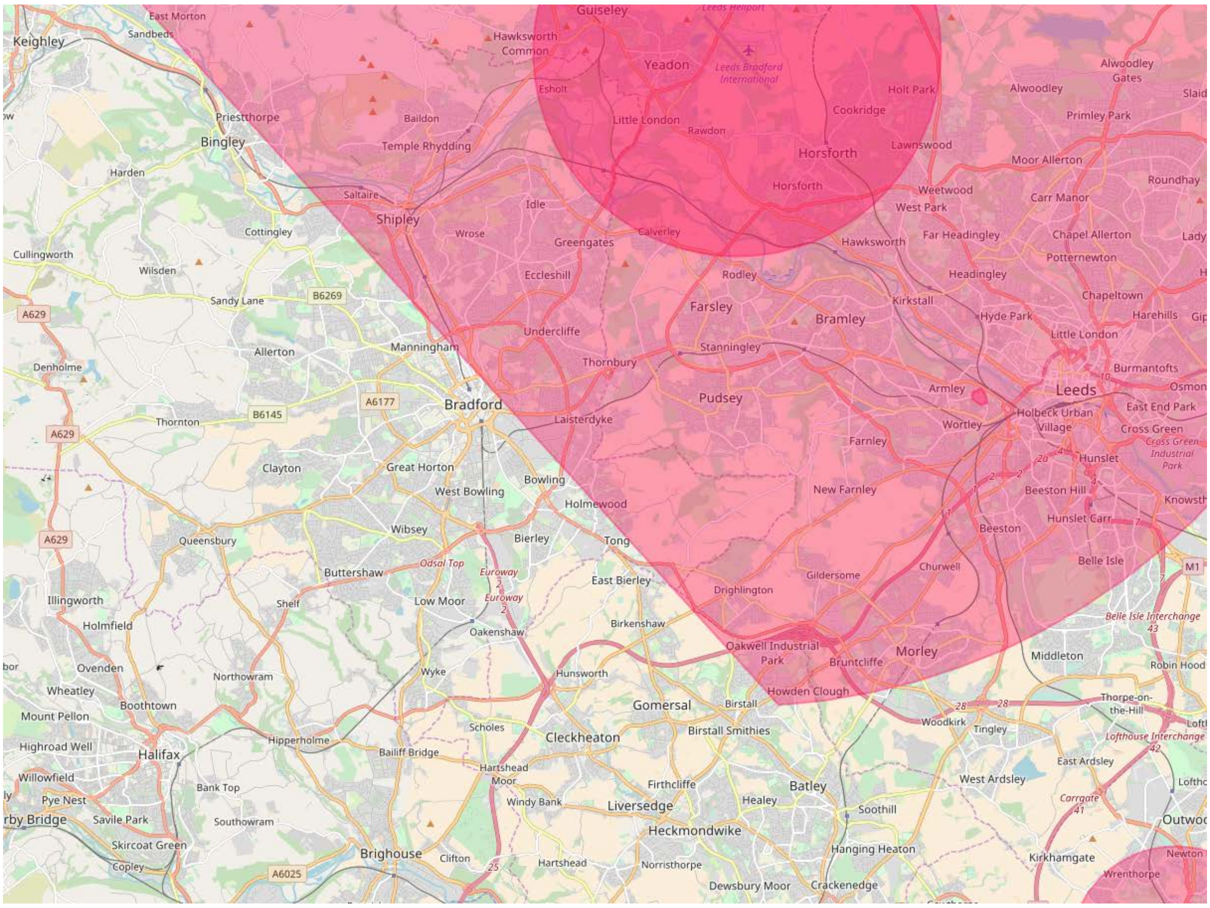
Flight plan

The drones would take off from Bradford Fire Station and proceed directly to the location of the call out. Therefore they would not follow a fixed route, and could be required to operate anywhere within the 5.5 miles radius coverage area. The service would require adequate pre-selected emergency landing sites defined with a relevant return home route programmed and updated at various stages of flight.



Airspace and altitude

Leeds Bradford Air Traffic Zone and International Airport airspace covers half the district and is Class D airspace from the surface to 8500 feet. Under current regulations clearance from Air Traffic Control (ATC) is required to operate in Class D airspace if the drone is over 7kg, and there will need to be communication between the operator and ATC.



Approximately half of Bradford is covered by the airspace of Leeds-Bradford Airport which, under current regulations, would restrict many operations. Credit: Altitude Angel

The other half of the airspace in Bradford District is unrestricted (Class G) to 2500 feet, then becomes Class D airspace to 8500 feet. Under current regulation, drone operations are prohibited within 1 kilometre of an airport boundary, above 400 feet and beyond visual line of sight of the operator. This means a safety case would have to be made and an exemption sought from the CAA (see "Regulatory requirements" section below for more info).

The operation in the Bradford is envisioned to be BVLOS and would therefore need to be IFR capable. This is due to VFR flights being premised on the pilot being able to discharge responsibility by unaided visual processes (they can see and avoid the hazard), however BVLOS cannot be achieved under VFR rules - as it cannot be by unaided visual methods - hence must be IFR.

The tallest structure within the area of operation is Lister Mills at 76 metres (249 feet) (the chimney on the mill). Of the top 10 tallest buildings, the majority are residential; with heights of 43 metres to 37 metres. Operational cruise altitude could vary, however if it were based on at least 100 foot obstacle clearance (scaled down from 1000 foot manned aviation obstacle clearance, unless under radar control) then both drones would need to operate above 349 feet. A suggested altitude of 400 feet or 500 feet (above ground level) during travel to the incident site is recommended depending on the direction of travel. 500 feet if travelling east or 400 feet west, following on from manned aviation rules of the air (odd altitude flying east or even when flying west). Once on site, the drone may need to fly lower. As altitude separation in this scenario is significantly less than manned aviation, altitude systems need to be designed to a high accuracy especially as operation could take place in close proximity to Leeds Bradford Airport and within Class D airspace.

The second recovery drone could have a temporary restricted area in place (radius and altitude), depending on incident type and location, should the drone need to be on task longer. In both cases a dedicated UTM will need to be designed, able to deconflict both drone and manned aviation traffic and to quickly block off a specific location based on emergency services requirements.

Take off and landing sites

This use case specifically looks at basing the drones at WYFRS's Bradford Fire Station on Leeds Road in Bradford, and the drone would be expected to take off and land here, except in case of the need for an emergency landing. To avoid the need for a runway or launcher it is expected that the drone would take off and land vertically. In the long term the drones could be positioned at multiple fire stations and could also respond to different types of emergency, providing multi-operation opportunities depending on the need per each emergency service.

Drone platform requirements

Based on the requirements of the use case and of the flight plan outlined above, the drone would require the following features.

Platform Type

- This use case requires the drone to have eyes on scene as soon as possible arriving rapidly at the incident ahead of the FRS, so a high-speed system will be necessary. The service also needs to monitor the fire while possibly providing more detailed information, loitering overhead for a longer period of time. This could be provided by a two-drone service. A single design could accommodate both of these requirements, for instance a fixed wing hybrid VTOL platform with a modular interchangeable payload system for flexibility. This use case will assume the use of two drones of the same type (but potentially different payloads) and a seamless handover between the two such that there is uninterrupted coverage when the second drone takes over.
- The speed of the platform to arrive at the scene is critical, it is expected that the initial response drone would be launched and would fly at speeds in excess of 80 knots meaning flights times would be approximately 3 minutes 30 seconds within the 95 sq mile area. Depending on the design, the second drone may be able to fly at slower cruising speeds to conserve energy.

- Propulsion: as it will operate in a heavily populated area with significant air quality problems, a zero emission power system would be beneficial and should be a medium-to-long term aim. The first drone would be developed to provide a rapid response and have appropriate power system to support this. The second drone could have a larger battery to increase endurance and power available to payload, at the expense of performance.
- Endurance: Both platforms would need to be able to operate within a 5.5 mile radius of Bradford Fire Station, requiring endurance to cover the 11 mile return journey plus time at the scene, which we are estimating to be 1-2 hours before the drone needs to return to base for recharge, refuel or battery swap. The initial drone being launched and responding rapidly, while the second would be able to conserve power by attending the scene at a slower more power efficient cruising speed. Given that fires can burn for days or weeks, it may be that the drones have to be deployed alternately to the scene to provide continuous information.

  A fixed wing hybrid VTOL can be augmented to extend its endurance and thus time on task, together with implementation of operational efficiencies such as flying higher or pitching into wind in hover mode.

  The ability to quickly battery swap or the use of fuel cell technology to enable fast refuelling would therefore be beneficial.

  There would be a seamless handover from one platform to another which would factor in appropriate energy requirements.

Payload, sensors and instrumentation

- Payload: The primary payload for the initial response drone would be a video camera with a high-powered zoom lens providing visibility of the incident site earlier. The second drone could lend itself to having an interchangeable payload that could include higher resolution video, a range of spectral/infrared cameras and possibly Lidar in order to build a very accurate representation of the incident site.

  If the same drone platform was used these payloads could be modular and interchangeable providing flexibility when scaled. It is recognised that technology developments are constantly enhancing the quality of these sensors. Accurate Lidar sensors are currently expensive but the price is expected to drop.
- Sensors and instrumentation: The drone should carry a high resolution camera for remote piloting as the payload camera would not necessarily be pointing forwards. It should also carry an ADS-B electronic conspicuity device.

Communications, navigation and control

- The drones will be flown BVLOS autonomously, from a control station with a pilot present, able to monitor the flight and take control in case of an emergency.
- Communications:
  - A robust communication system will be needed for the following purposes:

        - Control of the drone autonomously, with telemetry data (position, speed, battery status) relayed to pilot/mission controller for tracking and safety monitoring.
        - In case of a systems failure the drone pilot should be able to control the drone and land it safely, which would require a first person video as the drone will be flying BVLOS.
        - Transmit location to other airspace users and air traffic service providers (e.g. a UTM system or Air Traffic Control) - via an electronic conspicuity device.
    - Redundancy will need to be built into the communications channels to allow for failure or loss of communications, thus a primary, secondary and possible tertiary communications channel will be necessary.
    - The primary communications channel needs secure coverage over the majority of the journey, in particular over busy airspace and the urban populated areas, where the risk to people on the ground and air is greater. Bandwidth should be sufficient to transmit telemetry data.
    - The cellular mobile network generally meets these criteria, as this has a combination of generally good coverage (especially within city locations), high bandwidth and good security. As infrastructure is generally preexisting, it is readily available and cheap. Additional boosters or infrastructure outside the network area can address any coverage shortfall, with due consideration to any approvals required.
    - The transmission of real-time HD video may require different technology. 4G LTE networks may have sufficient bandwidth as long as it can be appropriately secured, future 5G networks would provide greater bandwidth still. There is also the option of the new Emergency Services Network (ESN) being developed with integrated 4G voice and broadband data services.
    - Using the mobile cellular network requires drones to support a SIM and connectivity module, so hardware and software can be updated when specifications change. Using drones equipped with a SIM card, existing mobile infrastructure can be used which will facilitate fast growth and reduce costs.
    - Ofcom reports generally good mobile reception on all four network operators in the area, however there are limitations to the use of the mobile spectrum in terms of coverage, bandwidth and latency. In addition the network is aimed at optimising signal on the ground, rather than in the air.
    - Should the drone experience a systems failure, it is recommended to have a different method for backup control in addition to the mobile network, such as data link control via satellites or different control frequencies. Note this will be used for control of the drone and not video feed.
- Navigation and control
    - Accurate knowledge of the drone position (latitude, longitude and altitude) is required.

  - In manned aviation barometric pressure is the primary means of altitude determination, however this requires all aircraft in the vicinity to be on the same pressure setting which varies. In this case a ground controller would be required to monitor this area. However this system alone would not provide the level of accuracy required at lower altitudes as in this use case.
  - Drone position can be obtained from a global navigation satellite system (GNSS) network. However, this too is not accurate enough alone to determine drone altitude to the accuracy required at lower altitudes. The GPS network alone is also not suitable for drone navigation as it is prone to data degradation or complete loss of signal due to multipath effects, interference or antenna obscuration, and so it will be necessary to have other systems present.
  - An inertial navigation system (INS) (also known as as inertial reference system or more generally an inertial measurement unit), is a self-contained system that does not require input radio signals from a ground navigation facility or transmitter. This system derives attitude, velocity, and direction information from measurement of the drone's accelerations given a known starting point, however over time the accuracy of this will also decrease and will require resetting. We recommend that the drone used in this situation use both systems together to improve navigational accuracy and for redundancy.
  - A further navigation technology that may be used is the use of vision sensors (e.g. optical cameras, hyperspectral sensors, Lidar), which sense the surrounding area directly and could be used in conjunction with a pre-loaded terrain database to complement existing navigation techniques.These vision sensors would primarily improve take-off and landing ability, with secondary function as a backup navigation source. Currently this is not commonly used for external navigation but could be a way of increasing accuracy of positioning and navigation.
- To ensure safety and minimise risk of collision, the drones should broadcast their location and an ID signal to other airspace users and to any air/unmanned traffic management system. This capability is referred to as 'electronic conspicuity'. The current standard on aircraft is ADS-B, which has been allocated a specific frequency band in the UK (960-1215 megahertz). This has low transmit power levels, low cost and the potential to be interoperable with other ground and air users and would be the default choice at present, though other technologies for broadcasting position may be developed.
- If drones are to operate in any mode they are required to 'be seen and avoided'. Detect and avoid systems currently alert pilot to other traffic and suggest resolving vectors. We recommend developing DAA systems to autonomously react to any aircraft installed with an electronic conspicuity device (EC). This is a challenge together with the ability to detect traffic not fitted with EC devices (such as birds).

Safety

- We have performed a qualitative risk analysis (SORA – Specific operation risk assessment),[83] to help identify the level of robustness required for all threat barriers based on the three categories of harm: Injury to third parties on the ground, fatalities to third parties in the air (mid-air collision with a manned aircraft) and damage to critical infrastructure. Specific threats have been examined and graded on their perceived risk suggesting a required level of robustness against each threat. Threats include: human error, technical issue with drone, aircraft on collision course, deterioration of external systems supporting drone and an adverse operation condition. This analysis has been performed to help identify areas for further consideration and is not intended to be a safety case.
- The SORA assessment shows the risk of injury to people on the ground is medium/high (being conservative as it depends on where the fire is specifically), as the drone is potentially relatively large (assumed max characteristic dimension <3m) operating BVLOS over controlled areas and potentially located inside a populated environment. It is assumed that the harm barrier adaptation in place will be a medium level emergency response plan, should the drone encounter any technical difficulties. When examining mid-air collision depending on location, the airspace encounter rate is medium/high, and therefore the risk is too. If the drone is required to operate above 500 feet (for instance to gather toxic or radioactive gas samples) the air risk class is increased to high. The level of robustness for this use case is medium to high across most categories of threat.

  Safe operation: To mitigate these threats, the drone should be designed to interact with UTM systems to dynamically allocate airspace and thereby minimise the risk of collision. Use of ADS-B and detect and avoid devices would further reduce risks of collision. The payload should be designed to be impact resilience and cause minimal damage to 3rd parties on ground should impact occur.
- Failsafe: The drone should be designed in a way to minimise risk of catastrophic failure affecting people or buildings on the ground. This should involve building in redundancy, ability to glide and is likely to mean the use of a parachute device in the case of total loss of power. Mitigations systems in place should consider deconfliction with other emergency responders (National Police Air Service, Coastguard, RAF and air ambulance), should the fire be part of a greater disaster.

Environment

- Noise: The noise impact of the drones for this use case is likely to be low: they do not fly fixed routes and so would not cause blight to any area under a flight path. While they may add noise to the scene of an incident as they loiter overhead, the scene will already be noisy.
- Weather/climate: Current multi rotor drones generally have recommended operating restrictions of 0-40°C and wind limitations of 19 knots. Fixed wing drones can operate in similar conditions however cross wind limitations can be reduced to

83 http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v1.0.pdf

15 knots for take off and landing[84]. As we are potentially operating a hybrid VTOL drone, benefits of higher wind limitations for takeoff/landing and higher cruise wind tolerances can be expected.The drone service must be able to operate year round and therefore needs to be able to operate efficiently and with stability in these conditions, as well as in moderate rain, poor visibility and cold temperatures sub zero degrees (which can cause icing). Drone design should incorporate tolerances in excess of the limitations above to maximise operational time.

- The design considerations should examine the historic maximum wind speeds in the West Midlands, potentially factored against statistical frequency to reduce extremes and balance cost. There are some extreme weather conditions that may prevent operations. We assume that for three percent of the year (around 11 days) they are unable to fly, a figure that roughly mirrors restrictions on aircraft.[85]

Regulatory requirements

- The drone operation will need to take place in Class D airspace. As well as permission required to operate BVLOS in this area, there is a requirement to define the rules and regulations for drones within this airspace, addressing the interoperability of cooperative and non-cooperative traffic, both manned and unmanned. Drone capability level together with UTM systems should be integrated into these rules.
- Both drones will be required to operate autonomously and BVLOS and may need to fly over an urban setting within 50 metres of any person, vessel vehicle or structure. Regulation currently requires any commercial operation to prepare a safety case for submission to the CAA that addresses each of the limitations covered by the Air Navigation Order (ANO) above, however this is currently only for VLOS operation for drones weighing <20kg.
- As this is a emergency response operation the drone maybe required to operate beyond its regulatory limitations in some circumstances. It is suggested that regulation addressed this need with special dispensation should certain conditions be met as is currently the case with VLOS operations (E4506)[86].
- Mobile phone networks are governed by the Wireless Telegraphy Act 2006. For mobile phones, the use of the spectrum by the network operators is licensed to cover the use of transmitters and repeaters which are under their control, while user devices are covered by a general exemption. Cellular repeaters, boosters and enhancers are not accepted devices. In exploring our use case if cellular connectivity is to be used, collaboration with the network provider to increase the infrastructure required to realise the task is imperative. Additional boosters or infrastructure outside will require additional specific exemption.

84 Based on Flying High technical forum.

85 In practice drones are likely to have higher vulnerability to adverse weather due to their size and battery life. However, they would have more flexibility to deploy earlier or later compared to scheduled flights, and the limits placed on them are unclear until the drone has been created and tested. As such we assume 3% is a reasonable benchmark to apply in this case.

86 https://publicapps.caa.co.uk/docs/33/1233.pdf

- As the drone will be using radio equipment, it must comply with Ofcom regulations.[87] Within the UK the use of radio apparatus, including drones, is regulated by law. This ensures only equipment which is safe and does not cause harmful interference is placed on the market. The Ofcom licence and licence exemption state the terms and conditions on the use of radio apparatus.
- This use case will need to comply with the EU General Data Protection Regulation (GDPR),[88] which regulates how organisations can store and process personal data. The GDPR requires organisations to follow principles such as collecting the minimum amount of data needed for the organisation's purpose, keeping the data secure, and informing people that their data is being collected. In this use case, data protection will need to be considered when dealing with the video footage that will be collected. Mirroring existing police standards may be an option.

Operations and traffic management

A traffic management system is required to:

- Track drone position so it is visible to both controllers on the ground and operators in the air, both manned and unmanned. Airspace violations can be monitored and dealt with accordingly by managing authority in this way.
- Identify when traffic will conflict and alert user or autonomously deconflict this trafic should no action be taken.
- Be interoperable with all traffic, other UTM systems and air traffic control.
- Direct drones into particular lanes that give higher priority to emergency response units would be one way to manage this operation in the context of a high volume of urban drone traffic.

Should drone deployment increase it is recommended to further develop electronic conspicuity devices together with detect and avoid systems, which securely integrate into the flight control system to autonomously react to any potential conflict.

Security

The security of the drone operating across Bradford is of high importance. A security breach could allow attackers to steal data, control or influence the drone, or prevent it from operating. This could have several implications of varying impact. If the rapid response drone is prevented from responding then the fire service might be less able to allocate the correct resources to a fire. Also, given that a fire is already a risky situation, the presence of a drone could cause additional risk if it was not managed properly. A security breach that led to the drone interfering with the activities of firefighters could be particularly dangerous. A data breach could also be damaging - the drone will be collecting information about the fire that could be sensitive for the people involved.

87 https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/drones-advice

88 https://ico.org.uk/for-organisations/guide-to-the-general-data-protection-regulation-gdpr/

It is not only malicious attacks that are problematic but also to natural interference to signals, signal integrity and the potential for RF saturation which could cause issues. This would require the use of redundant and independent systems such that a threat would need to overcome multiple systems to have a negative impact.

As the drone will be operating BVLOS this will significantly increase the complexity of ensuring the safe and security operation of the drone. The system therefore needs to manage issues while out of line of sight, which may include trade-offs with other aspects of the system such as technology to increase privacy.

It will be important to check for security weaknesses across the whole system including areas such as communications, data storage, and control software. For example, it will be important to use a secure communications system such as the Emergency Services Network. It will also be important to secure the systems that are used to store and analyse the data collected by drones.

Security is not just about having the right technology in place, it's also important to have good security processes. For example, there should be processes in place to regularly test for security weaknesses as well as monitor for and respond to security breaches.

Privacy

Privacy is an important aspect to consider. Images captured by the drones need to be handled with the utmost care and consideration.

The system itself could be managed through a secure network, one option would be to use the Emergency Services Network (ESN), which is currently being developed through the Home Office. It is very important that the data is managed through secure connections and that it is only used by the appropriate emergency services in a manner that helps them complete their job efficiently.

The drone could fly over private land and be able to see into normally private areas such residences, hotels, schools and businesses. All operations should be consistent with data protection legislation.

The drones should also be operated by a trusted operator and under the jurisdiction of the emergency services. This would reduce concerns around drones being used by system operators to violate privacy. Polling carried out as part of the Flying High project shows that state and emergency services are more trusted than private operators of drones.

To support the adoption and to overcome the challenge of unknown drone systems operating in these areas a recommendation would be for everyone being able to identify the drone and operator, this could be linked to electronic conspicuity devices or even a simple, easily-recognisable livery for the drone (as for existing emergency service vehicles).

Economic and social impact

This economic feasibility study outlines the range and scale of potential benefits arising from deploying drones to support fire and rescue services in Bradford. There are three sources of economic impact:

- Savings to the fire service generated by more efficient resource utilisation in fire incidents (for instance by preventing an over-allocation of resources, by correctly allocating specialist equipment and by using a drone to take on observation functions).
- Savings to the fire service from quicker and more appropriate deployment of appliances in response to false alarms (for instance by providing an early indication that the call might be a false alarm, by investigating possible sources through the transmission of real-time data).
- Safety and health benefits that accrue from a better informed, more effective, and more timely response to fires (for instance by reducing the risk of victim injury and fatality and by reducing operator risk).

Key assumptions to the use case

Key parameters for this model are the number of fire incidents and false alarms, the level of drone deployment and associated costs, the estimated cost savings from improved resource utilisation, the estimated social benefit from improved safety outcomes. All data provided below is for a medium scenario; detailed assumptions are listed in the appendix at the end of this document.

Number of drones: Two drones of different specifications will be deployed. This assumes the same drone platform but carrying different payload.

Drone cost: High spec drone £25,000, lower spec drone to monitor fires on site £20,000. (Note that this cost does not include the price of a high-accuracy Lidar scanner or hyperspectral camera at current prices.)

Number of fire incidents and false alarms: Based on 2017 fire data from Bradford District, we developed our model based on 3,029 fire incidents and 2,560 false alarms p.a. (this excludes special service calls). In line with Bradford's annual population growth over the past 15 years, we have applied an annual growth rate of fires and false alarms of 0.85 per cent.

Number of incidents per drone: The drones could be deployed 24 hours per day, with fast recharging being enabled by switching batteries. We apply a conservative assumption that a drone could be deployed to 10 incidents or false alarms per day.

Supporting infrastructure and staff: 3 FTE members of staff would be required to run the network for 24 hours at an annual costs of c. £107,000 p.a. And a one off training cost of

£1,345 per staff member[89]. Fixed infrastructure in the form of network integration are estimated at £100,000. Maintenance and replacement costs are estimated at c. 5 per cent of the drone cost per year. The cost of deployment in terms of fuel and electricity per flight is conservatively estimated at £5.00.

Cost savings for fires and false alarms: The benefit of deploying a drone to a fire or false alarm is proxied by the cost of deploying one appliance for one hour: c. £284[90]. We estimate the amount of cases where this saving is delivered to be 10 per cent of fire incidents cases, and 20 per cent of false alarms.[91] We assume the amount of cases to increase by 10 per cent per year, meaning that, for example, 22 per cent of false alarm cases in Y2 would have savings applied to them.

Improved safety outcomes: Based on all fire incidents in 2017, there was a victim fatality in 0.2 per cent of cases, a victim injury in 3.2 per cent of cases[92], and an operator injury in 1.5 per cent of cases[93]. To value the likelihood of reducing these injuries, we assumed a reduced injury rate for victims of fires of 10 per cent, a reduced death rate for victims of 10 per cent, and a reduced operator injury for victims of 10 per cent. These rates are applied to the total cost of injuries and fatalities from fires provided by the former DCLG (now MHCLG) of £2,099,890.[94]

Network benefits: To account for the broader social impact, such higher rates of recovery for properties affected by fires, higher levels of conservation, and better mapping of disaster areas and patterns, we attached a value associated with a 1 per cent efficiency increase in the operation of the network estimated at £52,000 p.a.[95]

---

89 The baseline 2018 salary estimate was £35,000; this was uprated to 2019 prices using recent OBR CPI estimates found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

90 The cost of one FRU appliance per hour, http://www.wyfs.co.uk/wp-content/uploads/2015/10/Special-Service-Charges.pdf, £265, uprated from original 2016 prices to 2019 values using OBR CPI forecasts found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

91 Appliance are deployed extremely quickly after notification of a suspected fire, so appliances would continue to be deployed (but then stood down) in many cases where a drone identifies that a fire is a false alarm.

92 Evidence from Bradford fire data 2016. There were a reported 99 injuries and a reported 6 fatalities out of 3029 type 1 and type 2 fires responded to.

93https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/562334/fire-statistics-data-tables-fire0508.xlsx The number of operator injuries in 2016-17 was 2523, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/707406/fire-and-rescue-incident-dec17-hosb0818.pdf, there were 170,000 fires responded to in 2016-17, page 9

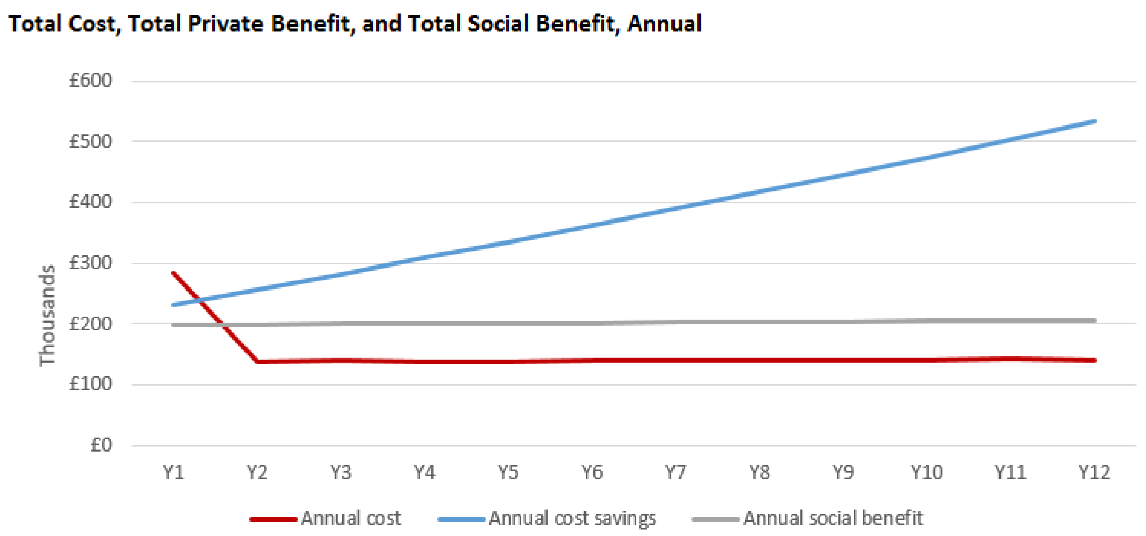
94Note that the cost of injuries from fires was drawn from a 2011 report from the Department for Communities and Local Government, which calculated a cost of £185,000 in 2008 prices (http://webarchive.nationalarchives.gov.uk/20120919203945/http://www.communities.gov.uk/documents/corporate/pdf/1838338.pdf, page 30). This has been uprated to produce an in-year estimate of £235,442 for 2019.This figure was applied to injuries for both victims and operators. For fatalities, the figure of £1,650,000 from 2008 was used. This was again uprated by inflation to produce a final figure of £2,099,890.

95 Based on a total budget of the West Yorkshire Fire and Rescue Service of c. £81,912,000, of which Bradford District costs are approximately £21,297,000. We estimate an efficiency gain of 0.25 per cent of this budget, estimated at £52,000 .

Using drones to support fire services is economically feasible

Even under our medium assumptions about the operational effectiveness of drones, the significant savings garnered from reduced responses to false alarms and more efficient deployment mean that after the initial cost has been paid out in Y1 the cost savings significantly outstrip operating costs in every other year.

These savings increase over time, both as a function of assumed better adoption and integration, and as the number of fire incidents and false alarms increase over time. The result is that by Y4 it is predicted that the total cost of the initial implementation will be recouped completely, with cost savings after this point representing net savings to the fire services as a whole. These are not insignificant; we estimate annual cost savings of approximately £530,000 per year by Y12. In addition, whilst the social benefits generated do not exceed costs on their own, the reduction in danger to operators and victims is significant, and further demonstrates the economic feasibility of this approach.



Source: WPI analysis (medium scenario)

The benefits are even higher when drones are operated at scale

Benefits are likely to increase with greater geographical coverage

The use case findings presented above only apply to a radius of 5.5 miles from WYFRS' Bradford Fire Station on Leeds Road, but still deliver significant benefits. Given our assumptions about the scale of fire incidents and the capacity of drones, two drones will be enough to meet the needs in the entire District. To explore the feasibility of deploying additional drones at other stations, we recommend an assessment of likely flight times and fire hotspots in the district.

Insofar as other areas have similar geographies in terms of urban concentration and fire levels, then the same benefits could be delivered elsewhere. Our findings indicate that deployment of more drones across a wider area would, holding all other things constant (e.g. integration into operations), mean that similar benefits could be generated, and that these would increase with scale.

A greater integration of drone intelligence will improve the response of emergency services

As noted in the assumptions, the scale of the benefits delivered by this deployment of drone technology is dependent primarily on the extent to which it materially changes how operations are conducted. If the drone is simply used to replicate existing tactics and there is otherwise no change in operations, then benefits are unlikely to materialise. If, on the other hand, the capacity of the drone is fully utilised to create smarter and more efficient responses, then the benefits are likely to be substantial.

This demonstrates that the scalability of these economic benefits is also heavily dependent on the extent to which the fire services use new technologies to change their response patterns. For example, after several years of running the drone it may be possible to use it to triage responses and have the drone as an automatic response to a possible false alarm, rather than deploying an appliance. This type of response would deliver significantly higher savings than if the drone was merely used to augment responses.

Further benefits can be unlocked by integrating drone technology with other emergency services

A third way to scale impact is integration with other emergency services. By integrating with police and medical resources, drones could help, for example, to coordinate traffic responses or responses to floods and other natural disasters.

Whilst this is not modelled in this feasibility study, it is obvious that this would increase the benefits that would stem from an investment in drones, thereby increasing the feasibility of this use case. As such, it is best to view the results at the lower end of potential gains from the use of drones in emergency and disaster response, and there is the distinct possibility that these benefits could be further scaled with proper integration with other services.

Conclusions and recommendations of the technical and economic feasibility study

Conclusions

The Bradford use case in summary could have strong social and public benefits. The use is feasible in principle, but there are a number of challenges that need to be considered in order to make it a reality.

The key challenges for this application of drones to support the fire & rescue service in Bradford, based our analysis, are

C1. The development of a drone operation system that can operate safely, securely and reliably beyond visual line of sight, while maintaining appropriate levels of privacy.

C2. The provision of suitably managed unsegregated urban airspace allowing for interaction with other airborne systems.

C3. The development of key elements of drone and drone systems technology, particularly with respect to automated systems that remove routine elements of human interaction, eventually moving to a fully autonomous system.

C4. Achieving a large scale service with interoperability between all emergency services and fully integrated into the processes and systems for a rapid response by the appropriate organisations.

C5. Being able to operate in low light, at night time and in adverse weather conditions, including high winds, rain, snow and poor visibility.

C6. Achieving high endurance for long dwell-times at an incident.

Recommendations

The following recommendations relate directly to the six challenges outlined above (referenced in brackets).

A. Regulatory change to enable routine drone operations at scale, beyond visual line sight and near people, buildings or vehicles. (C1 and C2)

B. The development of a new form of airspace management to enable safe automated drone operations at scale. (C1 and C2)

C. Electronic conspicuity devices fitted to all air traffic and integrated into a traffic management system, to improve safety, security, privacy and positive public perception. (C1 and C2)

D. Secure interfaces into other systems and infrastructure needs to be considered with the number of interfaces minimised and encrypted. (C1)

E. Development of technologies that can demonstrate safe operation through high levels of redundancy, including secondary and possibly tertiary systems for command and control, navigation, power and propulsion systems. (C1)

F. Development of counter drone systems to identify and manage unauthorised drone operations, either malicious or accidental. (C1)

G. Development of registration and enforcement systems, with appropriate resource to ensure operator accountability. Including a centralised database showing licensing of operator competency, the platform ID and airworthiness and the capability to provide real-time monitoring of the airspace. (C1, C2 and C3)

H. Requirement to develop tools and standards for the verification and validation of the drone components, platforms and systems, with traceability of the hardware and software supply chains. This should include development of simulation tools to ensure safe operation and validation of autonomous and machine learning systems. (C1 and C3)

I. Development of appropriate safety cases for the use case that could be published and used as standard scenarios to support the regulator and the growing UK industry. (C1 and C2)

J. Establishment of a clear, accountable ownership and sign-off of the various aspects of operation. This includes maintaining airworthiness, oversight of system upgrades, assurance of pre-flight checks, the flight, associated safety related flight data and appropriate legal accountability and insurances. (C1 and C2)

K. Integration and interoperability between airspace management systems. This will require both technology solutions as well as co-ordinated standards, legislation and process development. (C2)

L. Coordination with other aligned technology areas around common challenges which could include collaborations with the robotics and autonomous systems and connected and autonomous vehicle communities. (C3)

M. There is an opportunity to develop technologies along with the Emergency Services Network being developed by the Home Office. (C4)

N. Development of technologies and regulatory frameworks to allow the systems to scale safely and in line with growing market demand. (C4)

O. Development and integration of processes and standards to alert all the relevant organisations that need to respond to a fire. These processes should then be able to scale to incorporate all emergency Services. (C4)

P. Development of capabilities to ensure safe flight during poor weather conditions and during darkness. (C5)

Q. Development of high endurance platform technology to ensure extended coverage and support during a major incident. This should include the development of systems that seamlessly handover from one drone to another. (C6)

R. Development of tests that prove out the capability of the platform and system in representative environments. Leading to trials with growing complexity, moving from controlled environments to full public demonstrations. (C1-C6)

Key assumptions in the economic feasibility studies

This section outlines the core assumptions made as part of our modelling approach. Model sensitivity to these assumptions changing and the implications for scalability are explored later in this economic feasibility study.

General assumptions

Dates and pricing

It is assumed that the in-year value of an outcome is constant across all years, such that the in-year value of an outcome in Y1 is the same as the in-year value of an outcome delivered in Y7 or Y10. This means that the values allocated to each outcome (e.g. increased health outcomes or reductions in the number of injuries) are in constant prices. This reflects the fact that whilst individuals may place a lower value on outcomes further along the time horizon, the benefits delivered are in-year values, where the valuation is assumed to be constant.

Prices in this EFS are reported in 2019 figures, with an assumption that this would be the first year of the use case. As such, unless otherwise stated Y1 is assumed to be 2019. Although there are use cases which are likely to commence later due to technological or regulatory constraints, we calculate this EFS as if the program were to be launched in 2019. Where we make explicit assumptions about changes in price or valuation over time (e.g. drone technology becoming cheaper after five years) this is explicitly noted in the use case assumptions.

In order to create a robust economic feasibility framework, all figures drawn from historical sources have been uprated to their predicted 2019 figures. This has been conducted using the latest OBR CPI inflation figures[96] to uprate all figures to 2019 prices. This allows for values to be constant and comparable and provides an extra degree of confidence and robustness to our modelling.

Depreciation

Depreciation would normally be applied to assets to account for their declining value over time. We expect the value of the drone technology as an asset to rapidly decrease, with

96 This has been done by averaging quarterly figures and compounding from the date of figures we have taken up until 2019. http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

the cost of a new drone halving every five years.[97] The use cases also assume that the technology will be used for ten or more years. This would mean that even before adjusting for the fact that the drone was second hand, it would be expected to be valued at only 25 per cent of the original purchase price.

Given this drastic rate of depreciation and the fact that specialised platforms may not be easy to sell, we have chosen not to treat the drone technology or supporting infrastructure as an asset, therefore to essentially apply a de facto depreciation rate of 100 per cent in Y1.

The net effect of this assumption makes our economic feasibility studies extremely conservative compared to an approach that would apply depreciation to make the initial cost of the drone appear to be spread over time. This is intended to provide a clearer view of the immediate costs and benefits of deploying this technology, rather than a view of the overall balance sheet.

Ownership and rent

The model that drones could be deployed through could either be the city owning and operating its own infrastructure or putting it out to competitive tender and paying a fee in return for the service. These studies take no position on this question; assuming that either the city pays up-front, that the responsibility is taken on by a provider who then charges out services at an appropriate fee, or that a combined approach is used.

As a consequence, the feasibility studies instead assess the expected costs and benefits of drone deployment regardless of the ownership and operation model selected. This means that the findings can be applied to a range of different commercial and procurement options, although it also means that they make no clear recommendations on how different financial or contractual structures would affect economic feasibility.

Insurance

Other costs, including salaries, maintenance and training are accounted for. Insurance is not accounted for separately for three key reasons:

- The use cases make the assumption that the regulatory environment has evolved enough that the level of risk, herefore the cost of insurance for drones is not prohibitively expensive;
- In the majority of cases large corporate operators will already have wide ranging insurance policies that, given their scale, the use of drones would make only a marginal difference to.

97 Advances in digital electronics have been linked with 'Moore's law', which tracks the advances in microprocessor capacity and suggested that this would double every two years (thereby halving prices). We have taken a modified version of this to estimate the increasing affordability of new technology.

- To some extent the cost of insurance could be accounted for through the assumptions made about the costs to maintain drone operations.

As such we have made no separate assumptions about additional insurance costs, though in future iterations it would be possible to if necessary.

Drone failure and deployment in adverse weather

The specifications for the drones in each use case have been balanced between functionality and cost. However, there are some extreme weather conditions that may prevent operations, especially as drones are more susceptible to the weather compared to helicopters due to their size and weight.

To account for the minority of circumstances where drones are unable to operate, it is assumed that for 3 per cent of the year they are unable to fly, a figure that roughly mirrors restrictions on aircraft.[98] This is equivalent to approximately 11 days per year. It is also assumed that this accounts for cases of drone failure, where mechanical issues mean that the drone cannot fly or complete its missions that day.

Given technological advances, the need to pass regulatory checks and the requirement to approve flight plans, the assumption has been made that drone failure is extremely rare and that any issues are contained prior to any risk of injury or damage occurring to the drone or other devices. Consequently, the feasibility studies do not explicitly put a price on drone failure as part of the expected in-year evaluation.

Use case specific assumptions

London economic assumptions

Number of samples

We estimate the annual number of blood samples delivered from the renal clinic to St. Thomas' laboratories for kidney transplant patients as approximately 13,000. This assumption was drawn from discussions with clinical staff who indicated the approximate weekly number of samples per week transported between the two hospitals was 250, suggesting an average of 35.7 samples per day, coming from both inpatients and outpatients.

Number of drones

As a general assumption, our estimate is that two drones are required. Although only one drone would be in operation at a time, the second drone would allow for operations and

98 In practice drones are likely to have higher vulnerability to adverse weather due to their size and battery life. However, they would have more flexibility to deploy earlier or later compared to scheduled flights and the limits placed on them are unclear until the drone has been created and tested. As such we assume 3 per cent is a reasonable benchmark to apply in this case.

the network's effectiveness to be maintained whilst one drone is either committed, charging, or requiring maintenance.

Depending on the number of the hospitals in the network (i.e. the inclusion of King's), this would lead to an assumption of either two or three drones. For this specific use case we have assumed **two drones** operating between St. Guy's and St. Thomas's.

Number of deliveries

Given the small size of samples, we have estimated that a maximum of **ten samples** can be included in each delivery. The drone has a reported flight time of under five minutes and the functionality to operate 24h per day. Accounting for loading, unloading, extra time and recharging, we have assumed that each drone would be able to make on average one delivery per hour, meaning that they would make an average of **24** deliveries per day, meaning a total possible capacity of 240 samples per day, per drone. Therefore, in this particular use case we have incorporated a conservative assumption that the drone would be operating significantly below full capacity.Additional pathology test samples (e.g. biochemistry tests) could be included in this same set of drone deliveries but have been exempted from this analysis

Cost of drone

The approximate cost of a drone of this specification at current market rates is £25,000. Given the novelty of this technology and the lack of current regulations surrounding drone usage in London airspace, this specific use case will presumably be unlikely to be implemented in 2019. As a conservative estimate, we have assumed that drone implementation will occur in five years. Given the rapidly expanding market and constant innovation in drone technology, it is likely that this price is going to decrease substantially between now and its first day of operation, which is why we have assumed a medium cost of £10,000 per drone, with lower and higher assumptions of £7,500 and £12,500 respectively.

Cost of wider supporting infrastructure

We have assumed a networked approach to this form of drone deployment, meaning that each drone does not require an individual pilot, but rather that one full-time staff member has responsibility for supervising a number of drones on pre-determined delivery pathways.

As a consequence, the infrastructure cost comes primarily from fitting landing spots to existing buildings, we have estimated the minor cost of this at **£5,000.** We assume that after ten drones further landing spots would be needed, therefore this cost would increase again. We also assume a maintenance cost of **5 per cent** of the drone's total cost annually, representing the cost of new or replacement parts for the drone or the infrastructure.

In terms of personnel, we estimate that three members of staff would be required to provide round-the-clock services, at a cost of **£35,638** each for salary, plus a training cost of **£1,345** – a figure drawn from consultation with the industry. We also assume that on average staff move on after approximately three years, necessitating further training.

Cost of delivery

Under the current approach, the twice daily deliveries between the two hospitals for post kidney transplant blood samples cost approximately £15 per day. Given the number of samples, this means that for each courier delivery the approximate cost is £0.42. In theory, were they combined into batches of 10 and charged proportionately, this would mean a single delivery would cost £4.20.

We estimate the marginal cost of using the drone, after accounting for salary and infrastructure, as being primarily drawn from the cost of charging and electricity. Given the low cost of charging such appliances, we have assumed a medium assumption of £0.02 per sample, meaning a variable cost of £0.20 per delivery. This means that per sample delivered, we estimate that there is a cost saving of approximately £0.40 in our medium scenario.

Social benefits

External benefits would be those which did not directly come as part of the changed delivery mechanism, but are nonetheless caused by its deployment. These could accrue to the hospital (e.g. by increasing discharge rates), to the laboratory (e.g. better utilisation of resources when receiving samples distributed over the day), to patients (e.g. by getting treatment earlier due to quicker diagnosis), or to society as a whole (for example, by reducing congestion on city roads).

We have defined these benefits for this use case in two ways. First, the health benefits per sample are estimated to be worth £0.00. The reason for this is that after discussions with clinical staff, it became clear that whilst it would be optimal to receive sample results back sooner, the delay in changes to medication and the fact that 95 per cent of results were delivered on the same day meant that there was no obvious health benefits that would accrue, partially because the system had already been heavily optimised to still be able to produce test results despite the large variance in delivery times.

The second set of external benefits come from the increased network efficiency that is made possible by drones delivering directly to labs. Conversations with clinical staff indicated that intra-hospital transfers of samples were as big of an issue as inter-hospital transfers, with samples often waiting several hours to be delivered to the right place within a hospital. However, due to the direct (A to B) nature of the existing courier service for post-kidney transplant blood samples and the small scale of the sample deliveries, we assumed a 0 per cent increase in efficiency for this use case, though at a different scale, or for samples which do not have that direct courier service, the increase may be significant.

With appropriate scale, there could be wider societal benefits from a reduction in congestion, both on public health grounds and in terms of time saved for motorists and users of public transport. However, given the scale of the use case (2-3 drones) this is unlikely to be realised in this specific use case, as such we have assumed a 0 per cent decrease in congestion.

West Midlands economic assumptions

This section details the core assumptions made under our modelling of the specific use case of drone deployment to assist with traffic management and emergency responses in the West Midlands. These are the core assumptions made for the main findings. In a later section scalability and the sensitivity of these results to changes in key assumptions are explored.

Drone Cost

As described above, the two drones would differ only in regards to their payload. The slightly slower drone with more expensive payload would cost £25,000 and the fast response drone costs £20,000.

These costs are subject to a cost curve where the cost of technology halves every five years. However, as a static number of drones to cover the area is assumed this has no effect on the longer-term cost.

Number of drones

Two drones would be deployed in the initial phase of this use case. This reflects the need to have an appropriate level of backup in the case of required maintenance and/or the ability to deploy them for two incidents at once. The technical analyses have indicated that there would be options to swap battery packs to enable a quick turnaround and charging time, meaning that more would not be needed to provide coverage during charging periods.

Number of incidents

Data on the number of traffic incidents in the area is drawn from internal data, filtered geographically to exclude anything outside of the area covered by the drone. This illustrated that in the last year there were **10 fatal incidents, 215 serious incidents and 1,223 slight incidents**. Estimates were applied for population growth (0.74 per cent annual increase)[99] to increase these figures over time and minor reductions in the incident rate to reflect improved road safety (-1.96 per cent annual decrease in collisions)[100].

99 This figure is the average population growth in the West Midlands over the past 4 years taken from https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland

100 This figure is the average change in collisions nationally over the past 6 years taken from https://www.gov.uk/government/statistical-data-sets/ras40-reported-accidents-vehicles-and-casualties#excel-data-tables-for-ras40

Supporting infrastructure and staff

It is assumed that 3 FTE members of staff would be required in order to run the network the drone is operating on for 24 hours and estimate a salary of approximately **£35,638**[101] for each one. Additionally, following from discussions with industry partners an initial training cost of **£1,345**[102] per member of staff is estimated. A member of staff serves for approximately three years in the model, after which training is required for a new member.

Fixed infrastructure in the form of network integration and the costs of integrating drone functionality are estimated at **£50,000** and maintenance and replacement parts are estimated as having a cost of approximately **5 per cent of the drone cost** per year. In addition, the cost of deployment per flight is estimated as approximately **£0.50.** These estimates were developed to be relative to the estimated drone cost, but due to the lack of precedent could not be compared or checked against current industry uses.

Drone deployment

The assumption in the model is that drones can respond to **10 cases per day**, or approximately one case every 144 minutes, with no constraints on time of day that responses will occur. The model further assumes that the proportion of these incidents will scale with current patterns, therefore that 1 per cent of responses will be to fatal incidents, 15 per cent to serious incidents and 84 per cent to slight incidents.

Slight incidents are estimated to require significantly less than two hours of drone time and therefore that this estimate of coverage is fairly conservative. The goal of having two or more drones ready for deployment is also intended to provide different strategic options for response, such as a fast-moving drone for initial response and/or a slower drone with a longer flight time for monitoring.

Savings per incident

Two steps were taken to calculate savings per incident. First, assumptions were made regarding what the typical level of response for each incident type would be for fatal incidents, serious incidents and slight incidents. Drawing from information from the National Audit Office and The West Midlands Police, it was estimated that the presence of a police

101 The baseline 2018 salary of £35,000 was provided by in-depth discussions with industry partners/ experts; this was uprated to 2019 prices using recent OBR CPI estimates found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

102 The original baseline 2018 cost was provided by in-depth discussions with industry partners/ experts; this was uprated to 2019 prices using recent OBR CPI estimates found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

vehicle with 2 officers per hour is £64.70[103] and an hour of ambulance time is £206.03[104]. Furthermore, assumptions were made regarding the likely response to each incident with the assistance of a drone.

To assess this, "low", "medium" and "high" scenarios were incorporated, which measure the uptake and the measurable impact that the drone has on incident response operations. For example, the "low" scenario would refer to a limited adoption of the drone technology and therefore modest cost savings, whereas the "high" scenario refers to a significantly larger measurable impact where, for example, police time at the scene of the incident is significantly reduced due to the immediate provision of photographic evidence and therefore a more significant cost saving and reduction of traffic disruption. These are displayed below:

incident Severity	Response Scenario			
	Baseline	Low	Medium	High
Fatal	· 2 ambulance hours · 4 police officers (6 hours) · 1 fire response unit (1 hour) £1,622.87	· 2 ambulance hours · 4 police officers (4 hours) · 1 fire response unit (1 hour) £1,364.07	· 2 ambulance hours · 4 policemen (3 hours) · 1 fire response unit (45 minutes) £1,163.73	· 2 ambulance hours · 4 policemen (2.5 hours) · 1 fire response unit (30 minutes) £1,028.10
Serious	· 3 ambulance hours · 4 police officers (3 hours) · 1 fire response unit (1 hour)	· 3 ambulance hours · 4 police officers (2 hours) · 1 fire response unit (1 hour)	· 3 ambulance hours · 4 police officers (1.5 hours) · 1 fire response unit (45 minutes)	· 3 ambulance hours · 4 police officers (1 hours) · 1 fire response unit (30 minutes)

103 The average hourly salary of a police officer in 2014 was around £17. With vehicle cost and fuel etc, this was estimated to be around £30 an hour: http://foi.west-midlands.police.uk/wp-content/uploads/2014/05/Police-Officer-Salary-Scales.pdf. Uprated to 2019 values, this becomes £32.35. This has been done by averaging quarterly figures and compounding from the date of figures taken up until 2019. http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

104 https://www.nao.org.uk/wp-content/uploads/2017/01/NHS-Ambulance-Services-Summary.pdf, £1.78billion total cost of responding to casualties, 6.6million casualties responded to (2016 figures)

	£1,516.00	£1,386.62	£1,250.98	£1,115.35
Slight	· 0 ambulance hours · 2 police officers (1 hour) · 0 fire response units £64.70	· 0 ambulance hours · 2 police officers (1 hour) · 0 fire response units £64.70	· 0 ambulance hours · 2 police officers (45 minutes) · 0 fire response units £48.36	· 0 ambulance hours · 1 police officer (30 minutes) · 0 fire response units £16.18

Following from these assumptions, a wider estimate was then made about how effective the drones were – represented by the amount of times that these savings were delivered. In the medium assumption it was estimated that in 20 per cent of cases these benefits were delivered, that this increased by 10 per cent in each following year as the services became more effective at using and responding to the information that the drones provide.

Health benefits per incident

To account for the estimated health benefits from an improved emergency response, data on average values of prevention of road casualties[105] and incidents[106] was used. These provide estimates of the overall social costs imposed from incidents and casualties, including lost output, medical costs and human costs. Using these figures and adjusting for inflation and uncertainty[107], a medium social cost of **£1.25m** is estimated for a fatal incident, **£174,186** for a serious incident and **£12,751** for a slight incident.

Given that the available data is for confirmed incidents, the probability that these occur under the baseline cost without a drone is assumed to be 100 per cent. An estimated reduction in that probability as a result of better coordinated responses from the emergency services is then applied. Given that most injuries are likely to be sustained during

105 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/254720/rrcgb-valuation-methodology.pdf

106 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/254720/rrcgb-valuation-methodology.pdf

107 In this case we adjust for the low assumptions by taking 80 per cent of the medium assumption and the high value by taking 120 per cent of the medium assumption.

the initial collision an extremely small estimate of the effect is taken, assuming that the likelihood of injury is reduced by **0.1 per cent.**

Reduced congestion and lane clearance

To determine the value added from faster lane clearance and reduced congestion following a traffic incident, internal traffic data was used to determine the proportion of incidents which occurred on main roads and motorways in 2017, as well as the traffic flow, determined by the time of the incident [108]. Data from Highways England[109] on the estimated cost to the economy of lane closures on main roads was then used in order to create an estimated total cost of the time taken to clear these roads, depending on the severity of the incident. This provided the baseline for our analysis.

The data indicates that even marginal reductions in the time taken to clear one lane on a main road can reduce the impact and cost to the economy of an incident significantly. It was assumed that the impact of drone technology and their ability to speed up the evidence collection process and provide situational intelligence to the emergency services in order for them to respond effectively and efficiently, would be small but significant. Therefore the medium assumption was made that the cost would be reduced by **10 per cent** as a consequence of the deployment of drones at the site. Lower and higher assumptions of **5 per cent** and **15 per cent** provide the ability to test the sensitivity of findings to this assumption.

Southampton economic assumptions

Appendix: Key assumptions in the economic feasibility study

Dates and pricing

It is assumed that the in-year value of an outcome is constant across all years, such that the in-year value of an outcome in Y1 is the same as the in-year value of an outcome delivered in Y7 or Y10. This means that the values allocated to each outcome (e.g. increased health outcomes or reductions in the number of injuries) are in constant prices. This reflects the fact that whilst individuals may place a lower value on outcomes further along the time horizon, the benefits delivered are in-year values, where the valuation is assumed to be constant.

Prices in this EFS are reported in 2019 figures, with an assumption that this would be the first year of the use case. As such, unless otherwise stated Y1 is assumed to be 2019. Although there are use cases which are likely to commence later due to technological or regulatory constraints, we calculate this EFS as if the program were to be launched in 2019. Where we make explicit assumptions about changes in price or valuation over time (e.g.

108 To determine this time of day was used as a proxy as a proxy, assuming different flow rates depending on rough peak times. 80 per cent flow is estimated to apply from 6am-1-am and 4pm-8pm, 60 per cent flow from 10am-4pm and 8pm-10pm and 40 per cent flow from 10pm-6am.

109 Highways England, CLEAR – Collision, Lead, Evaluate, Act, Reopen – Briefing, 2016

drone technology becoming cheaper after five years) this is explicitly noted in the use case assumptions.

In order to create a robust economic feasibility framework, all figures drawn from historical sources have been uprated to their predicted 2019 figures. This has been conducted using the latest OBR CPI inflation figures[110] to uprate all figures to 2019 prices. This allows for values to be constant and comparable and provides an extra degree of confidence and robustness to our modelling.

Depreciation

Depreciation would normally be applied to assets to account for their declining value over time. We expect the value of the drone technology as an asset to rapidly decrease, with the cost of a new drone halving every five years.[111] The use cases also assume that the technology will be used for ten or more years. This would mean that even before adjusting for the fact that the drone was second hand, it would be expected to be valued at only 25 per cent of the original purchase price.

Given this drastic rate of depreciation and the fact that specialised platforms may not be easy to sell, we have chosen not to treat the drone technology or supporting infrastructure as an asset and therefore to essentially apply a de facto depreciation rate of 100 per cent in Y1.

The net effect of this assumption makes our economic feasibility studies extremely conservative compared to an approach that would apply depreciation to make the initial cost of the drone appear to be spread over time. This is intended to provide a clearer view of the immediate costs and benefits of deploying this technology, rather than a view of the overall balance sheet.

Ownership and rent

The model that drones could be deployed through could either be the city owning and operating its own infrastructure, or putting it out to competitive tender and paying a fee in return for the service. These studies take no position on this question; assuming that either the city pays up-front, that the responsibility is taken on by a provider who then charges out services at an appropriate fee, or that a combined approach is used.

As a consequence, the feasibility studies instead assess the expected costs and benefits of drone deployment regardless of the ownership and operation model selected. This means that the findings can be applied to a range of different commercial and procurement options, although it also means that they make no clear recommendations on how different financial or contractual structures would affect economic feasibility.

---

110 This has been done by averaging quarterly figures and compounding from the date of figures we have taken up until 2019. http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

111 Advances in digital electronics have been linked with 'Moore's law', which tracks the advances in microprocessor capacity and suggested that this would double every two years (thereby halving prices). We have taken a modified version of this to estimate the increasing affordability of new technology.

Insurance

Other costs, including salaries, maintenance and training are accounted for. Insurance is not accounted for separately for three key reasons:

- The use cases make the assumption that the regulatory environment has evolved enough that the level of risk and therefore the cost of insurance for drones, is not prohibitively expensive;
- In the majority of cases large corporate operators will already have wide ranging insurance policies that, given their scale, the use of drones would make only a marginal difference to; and
- To some extent the cost of insurance could be accounted for through the assumptions made about the costs to maintain drone operations.

As such we have made no separate assumptions about additional insurance costs, though in future iterations it would be possible to if necessary.

Drone failure and deployment in adverse weather

The specifications for the drones in each use case have been balanced between functionality and cost. However, there are some extreme weather conditions that may prevent operations, especially as drones are more susceptible to the weather compared to helicopters due to their size and weight.

To account for the minority of circumstances where drones are unable to operate, it is assumed that for 3 per cent of the year they are unable to fly, a figure that roughly mirrors restrictions on aircraft.[112] This is equivalent to approximately 11 days per year. It is also assumed that this accounts for cases of drone failure, where mechanical issues mean that the drone cannot fly or complete its missions that day.

Given technological advances, the need to pass regulatory checks and the requirement to approve flight plans, the assumption has been made that drone failure is extremely rare and that any issues are contained prior to any risk of injury or damage occurring to the drone or other devices. Consequently, the feasibility studies do not explicitly put a price on drone failure as part of the expected in-year evaluation.

Preston economic assumptions

Project duration and cost

We estimated a project duration of **42 months** (3.5 years) and construction costs of approximately **£140m**. These reflected our conversations with the Project Directors and interviews with construction and engineering companies who outlined this timescale and

112 In practice drones are likely to have higher vulnerability to adverse weather due to their size and battery life. However, they would have more flexibility to deploy earlier or later compared to scheduled flights and the limits placed on them are unclear until the drone has been created and tested. As such we assume 3 per cent is a reasonable benchmark to apply in this case.

expected construction costs of between £130 and £140m and total capital costs of c. £160m. These assumptions were validated by representatives of the City, who agreed that they were an accurate reflection of current plans.

Estimated overruns

An initial scan of available research suggested that the average cost overrun of road-specific construction projects was approximately 20 per cent. However, after conversations with city representatives, we learnt that the figure had been significantly higher for their recent road construction projects. They expected that this was a consequence of overly optimistic initial assessments and that this had been rectified within use case projects, but cautioned that the estimates should exceed 20 per cent. As such, we chose to assume a cost overrun of **40 per cent**.

In our conversations it became clear that the cost overrun was primarily due to a longer construction period, rather than increasing costs per se. Therefore, we assumed that the project duration would also overrun by **40 per cent** and that this would drive the cost overrun, with the cost per month remaining the same, but more months being committed than the initial estimate of 42 months.

We have also carried out calculations assuming the more conservative figure of 20 per cent.

Number of drones

As a general assumption, we have assumed that **one drone** would be deployed to cover all three major projects.

Cost of drone

The approximate cost of a drone of this specification at current market rates is **£26,000**. We chose this as our medium assumption and assume that the drone would be purchased at the start of the project, meaning that the future cost curve of the drone technology is not relevant for this use case. In the event that another drone was purchased, we also assume that the business purchases the same model of drone for future projects, rather than upgrading specifications.

Cost of wider supporting infrastructure

As mentioned, no additional staff would be required to operate the drone. However, to ensure that site managers are sufficiently qualified and trained, we estimate a total training cost of £15k.

In addition, there would be large costs of managing and implementing the process changes required to integrate the drone's findings into the construction process. We estimate this as a one-off cost of **£1,000,000**, representing an up-front cost for a significant program of change management and implementation and assume that the cost is spread across the first three months of operation. Aside from that, we do not estimate any other significant implementation or infrastructure costs, as deployment is primarily limited to the construction site itself.

Productivity benefits

We assume that productivity and efficiency are in this case interchangeable. This is because whilst workers might be more productive, by producing more outputs in a shorter period of time, we do not model this as representing a reduction in workers. Instead, we assume it manifests itself in a more efficient process and therefore a faster construction process. Consequently, we assume that a 10 per cent increase in productivity would therefore translate to a reduction in construction time of 10 per cent.

Our basis for understanding the likely impacts of deploying drones in this case reflected our discussions with the project team and others involved in drone innovation. The likely uses of the drone technology would result in changes to the process that would bring construction approaches more in line with manufacturing approaches – including a constant ability to monitor outputs, automated checking of progress and the ability to identify causes of delay earlier and more efficiently. As such, we have made the assumption that drone deployment and integration would improve productivity, bringing construction productivity partially in line with the (higher) rates of manufacturing productivity[113].

To draw a direct comparison, we have used the same set of assumptions used in a previous WPI Economics Report, which estimated the differential productivity effects that would arise from a move to off-site construction, which has similar benefits in terms of the introduction of manufacturing techniques.[114] In this case our medium assumption was a productivity increase of 10 per cent.

In practice, the cost savings delivered by this assumed productivity increase reflect a number of different savings that could be delivered, including reduced wastage, better maintenance and more frequent inspections and monitoring. We evaluate these effects based on their aggregate impact, rather than any one individual set of benefits.

Social benefits

There are a number of different benefits that drones could provide, including health benefits, improved safety and reduced pollution and disruption. For the purposes of this EFS we have focused primarily on tangible external impacts of construction that happen regardless of the process taken and therefore are only reduced by length of project, the area we assume that drones have a significant impact on.

Almost 47 per cent of the UK's CO^2 emissions come from construction, with approximately 16 per cent of that coming from the manufacturing and construction process.[115] We assume that the deployment of drones in construction sites would have significant external effects, particularly in the case of reducing carbon dioxide and other greenhouse gas emissions,

113 https://policy.ciob.org/wp-content/uploads/2016/05/CIOB-Productivity-report-2016-v4_single.pdf page7 and

https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/labourproductivitybyindustrydivision

114 http://wpieconomics.com/publications/off-site-construction/

115 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/31737/10-1316-estimat ing-co2-emissions-supporting-low-carbon-igt-report.pdf

partially by reducing the time taken to engage in construction and therefore the output per site.

To calculate this impact data from BEIS and the Office for National Statistics was used to calculate the level of CO^2 pollution that could be connected with Preston's projects, given their scale,[116] a figure that we estimated at over **58,000 tonnes** per month. This provided the baseline CO^2 level for the project and was combined with the existing UK 'social cost of carbon', with the estimated cost of **£90 per tonne**, to provide a baseline. The reduction in project time indicated by the productivity improvements was then used to calculate the reduced level of carbon and therefore the social benefit generated in each month that the project was finished earlier than anticipated.

Other social benefits were also considered, including the significant impacts and costs that noise pollution can have on the economy, such as increasing stress levels, lowering sleep quality and reducing productivity. 2010 statistics from the Interdepartmental Group on Costs and Benefits Noise Subject Group estimates that the amenity/annoyance cost per household rises by £13.20 if decibel levels increase from 55 to 65 and the risk of heart attacks also rises significantly.

Although this is clearly a huge cost to households and the economy, this feasibility study does not take noise pollution in to consideration as the distance from the specific construction sites to any significantly built-up areas is at least 500m away. It is therefore impossible to estimate the noise level transmitted across this distance as it will be too small. However, in future use cases where the construction is taking place in built-up urban areas, the associated cost of noise pollution would be significantly higher and should likely be incorporated into social benefit calculations.

Bradford economic assumptions

Drone cost

This drone usage does not have an immediate precedent, but the drones themselves would be required to have substantial range and flight times in order to provide an appropriate coverage. The need for infrared or light detection and ranging (LIDAR) technology may swell these costs further.

As described above, the two drones would differ in regards to their payload and functionality with the "high spec" drone being estimated to cost £25,000, and the lower cost drone being estimated to cost £20,000.

These costs are subject to a cost curve where the cost of technology reduces at a rate that results in the price halving every five years. This means that if the number of drones scales over time then the marginal cost per additional drone decreases over time. This study

116 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/31737/10-1316-estimat ing-co2-emissions-supporting-low-carbon-igt-report.pdf and https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/680473/2016_Final_Emissions_statistics.pdf, page 6

assumes that the fire service do not upgrade the specifications of the drones, but rather purchase the same model they had previously.

Number of drones

We estimate that **two drones** would be deployed in the initial phase of this use case. This reflects the need to have an appropriate level of backup in the case of required maintenance, and/or the ability to deploy at two incidents at once. The technical analyses have indicated that there would be options to swap battery packs to enable a quick turnaround and charging time, meaning that more would not be needed to provide coverage during charging periods.

Number of fire incidents and false alarms

To determine the number of incidents we use fire data from 2017 to determine the scale of possible responses. We filtered this to remove incidents that would not be covered (e.g. special service calls), and then subdivided between fires and false alarms. This yielded figures of **3,029 fire incidents** over the past year, and **2,560 false alarms across Bradford.**

We apply an assumed rate of growth of fire incidents and false alarms in line with Bradford's annual population growth over the past 15 years. This means that annually we expect the amount of fires and false alarms to increase by **approximately 0.85 per cent**.

Number of cases per drone

We assume that drones would in theory be able to be deployed for nearly 24 hours per day, with fast recharging being enabled by switching batteries. In practice, deployments would be in response to calls or alarms, rather than continuous flights. We assume that having two or more drones provides some redundancy that allows the network to respond to all calls.

The time that a drone is deployed would vary depending on the case. The distribution of cases in the previous year was such that **54 per cent of relevant cases were fires, and 46 per cent were false alarms.** We assume therefore that the drones are roughly equally likely to be sent to a false alarm as to an actual fire.

For responses to false alarms, we assume that a total deployment would take a total of approximately one hour, including flight time and a brief period of deployment to verify that the call was a false alarm, and a period of refitting the battery. For fire incidents, we assume a similar travel time, though a substantially longer deployment to monitor the fire. As such we assume that the average fire incident would take approximately two hours for the drone to respond to. In both cases we expect that downtime would be minimised by swapping batteries, rather than fully recharging the drone.

In either of these cases some incidents may take significantly more or less time for the drone to respond to. However, on average this would mean that the drone would be capable of responding to 16 incidents per day, composed of eight responses to false alarms and eight responses to fires. This however relies on an extremely high level of efficiency, as well as alarms being perfectly spaced. As such we take the more conservative assumption that a drone could be deployed to **10 incidents or false alarms** per day.

Supporting infrastructure and staff

We assume that 3 FTE members of staff would be required in order to run the network the drone is operating on for 24 hours, and estimate a total staff cost[117] of £35,638[118] for each one. Additionally, following from discussions with industry partners we estimate an initial training cost of **£1,345**[119] per member of staff. We also assume that a member of staff serves for approximately three years, after which training is required for a new member.

Fixed infrastructure in the form of network integration and the costs of integrating drone functionality are estimated at **£100,000,** and maintenance and replacement parts for the drone and the network are estimated as having a cost of approximately **5 per cent of the drone cost** per year. In addition, we also estimate the cost of deployment in terms of fuel and electricity per flight as approximately **£5.00**. This is a conservative estimate and significantly higher than the other use cases presented in this study due to the high payload and longer flight time of the drone. However, we think this is likely to be a significant overestimate**.** These estimates were developed to be relative to the estimated drone cost, but due to the lack of precedent could not be compared or checked against current industry uses.

Cost savings for fires and false alarms

To calculate the approximate cost savings that would be delivered by this drone use, we first estimate the potential value that would be derived from not deploying an appliance to an incident. In the case of the false alarm, this would mean the drone being deployed quickly enough that whilst an appliance is sent out, the drone can identify the issue and allow the appliance to return quickly. In the case of a fire incident it might mean deploying fewer appliances once the drone has confirmed that they are not needed.

Both of these benefits will depend on the unique circumstances of the fire or false alarm, but as a proxy we have assumed a saving equivalent to the cost of deployment of one appliance for one hour, or **£284**[120].

This saving would only be realised in cases where the drone is clearly able to identify the level of risk and alter or reduce the response accordingly. This is the more uncertain element and depends on the extent to which the fire service is able to use the drone to generate, analyse, and make use of the data it records.

We make two assumptions here – first, we estimate the amount of cases where this saving would be delivered. For our medium assumptions we estimate that deployment of appliance in fire incidents would be reduced in **10 per cent of cases,** and for false alarms

117 This is taken as a total cost, including non-salary employment costs. In future iterations these costs could be split out into their constituent parts such as salary, pension contributions, national insurance contributions.

118 The baseline 2018 salary estimate was £35,000; this was uprated to 2019 prices using recent OBR CPI estimates found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

119 The original baseline 2018 cost was provided by in-depth discussions with industry partners/ experts; this was uprated to 2019 prices using recent OBR CPI estimates found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

120 The cost of one FRU appliance per hour, http://www.wyfs.co.uk/wp-content/uploads/2015/10/Special-Service-Charges.pdf, £265, uprated from original 2016 prices to 2019 values using OBR CPI forecasts found here: http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/

we estimate that this would be **20 per cent of cases.**[121] The full range of the low and medium assumptions is displayed below:

	Assumed reductions (Y1)		
	Low	Medium	High
Fire incidents	5 per cent	10 per cent	20 per cent
False alarms	10 per cent	20 per cent	30 per cent

Second, we assume that as the drones become integrated, the effectiveness of the fire services in using them to detect issues will increase over time. We expect that this effect will vary depending on how successful the service is at integrating drones initially, as lower levels of success will in turn reduce the amount of time and effort spent optimising responses. As such we estimate that the amount of cases will **increase by 10 per cent per year,** meaning that, for example, 22 per cent of false alarm cases in Y2 would have savings applied to them.

Improved safety outcomes

We categorised social benefits from improved safety outcomes in three ways; the reduced injury rate for victims of fires, the reduced death rate for victims of fires, and the reduced operator injury for victims of fires.

To determine this, we first took estimates about the prevalence of injuries from the most recently available fire data. These suggested that of all fire incidents in the previous year there was a victim fatality in **0.2 per cent of cases,** a victim injury in **3.2 per cent of cases**[122], and an operator injury in **1.5 per cent of cases**[123].

We then applied the estimated cost to each of these. Data on the cost of injuries from fires was drawn from a 2011 report from the Department for Communities and Local Government, which calculated a cost of £185,000 in 2008 prices; this has been uprated to produce an in-year estimate of **£235,442** for 2019.[124] This figure was applied to injuries for both victims and operators. For fatalities, the figure of £1,650,000 from 2008 was used. This was again uprated by inflation to produce a final figure of **£2,099,890**.

This provides a baseline for calculating current costs. Last, we applied assumptions as to the extent that this would reduce. Again, these are the most uncertain parts of the model,

121 Appliance are deployed extremely quickly after notification of a suspected fire, so appliances would continue to be deployed (but then stood down) in many cases where a drone identifies that a fire is a false alarm.

122 Evidence from Bradford fire data 2016. There were a reported 99 injuries and a reported 6 fatalities out of 3029 type 1 and type 2 fires responded to.

123https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/562334/fire-statistics-data-tables-fire0508.xlsx The number of operator injuries in 2016-17 was 2523, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/707406/fire-and-rescue-incident-dec17-hosb0818.pdf, there were 170,000 fires responded to in 2016-17, page 9

124http://webarchive.nationalarchives.gov.uk/20120919203945/http://www.communities.gov.uk/documents/corporate/pdf/1838338.pdf, page 30 and therefore form the contributing part of our sensitivity testing. Our medium assumptions are that there would be a reduction in each category of 10 per cent of the existing risk. Full assumptions for each scenario are provided below.

	Assumed reduction (all years)		
	Low	Medium	High
Victim injuries	5 per cent	10 per cent	15 per cent
Victim fatalities	5 per cent	10 per cent	15 per cent
Operator injuries	5 per cent	10 per cent	15 per cent

Network benefits

There are significant other benefits that could be leveraged from increased network efficiency, including better mental health levels for firefighters (due to better workload management and reduced professional risk), higher rates of recovery for properties affected by fires, higher levels of conservation, and better mapping of disaster areas and patterns. An understanding of the scale of these benefits is impossible to determine; depending both on quantifying a large amount of interrelated factors, and on avoiding double-counting.

Instead, we have attached a value associated with a 1 per cent efficiency increase in the operation of the network. Given that the budget of the West Yorkshire Fire and Rescue Service is approximately £81,912,000, of which the size of Bradford's district costs are approximately £21,297,000. We estimate an efficiency gain of 0.25 per cent of this budget, estimated at £52,000 . Our lower and medium assumptions are 0.1 per cent and 0.5 per cent of this figure respectively. We would anticipate that this efficiency impact would increase with the deployment of more drones and/or greater integration into operations.