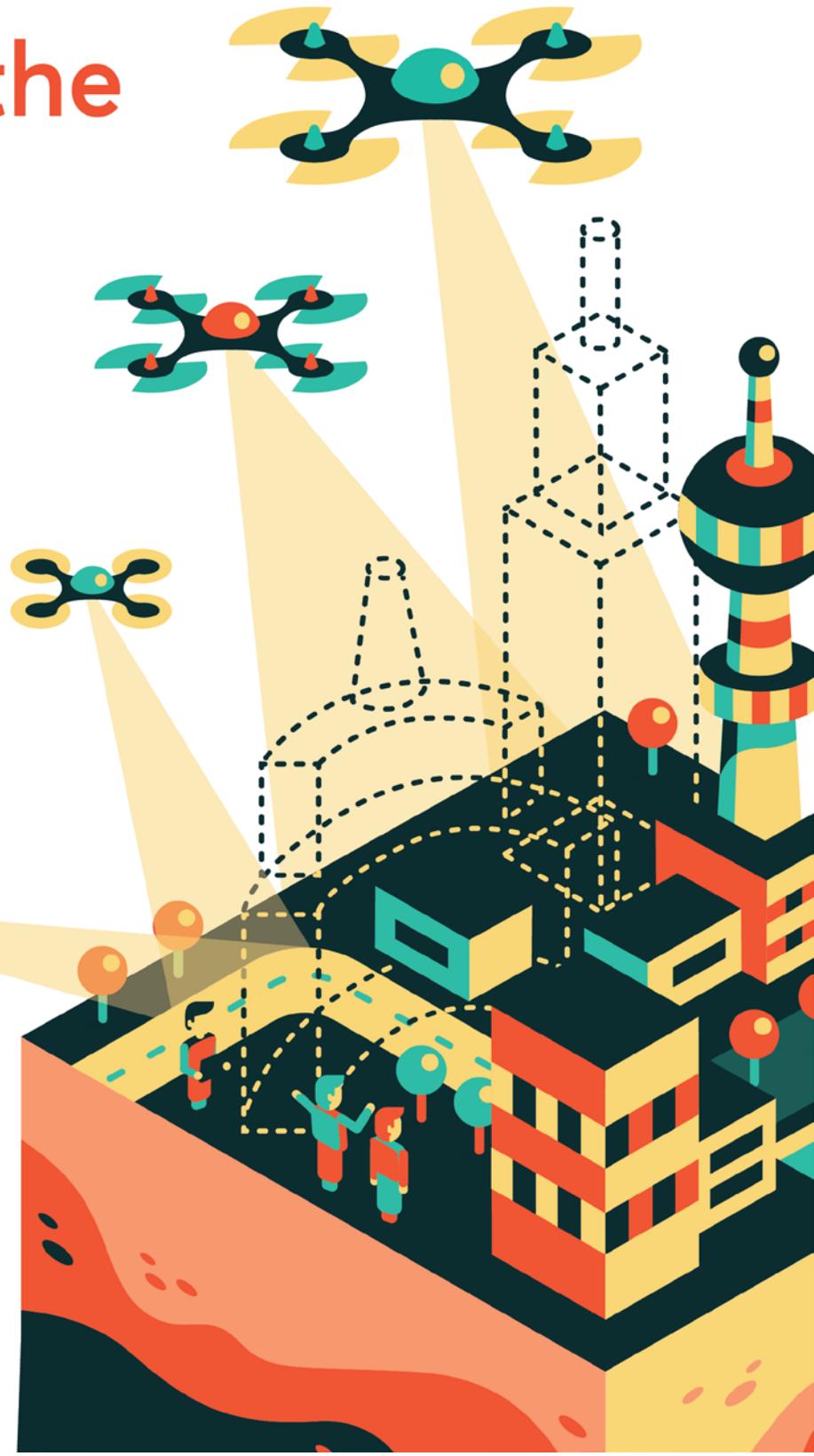
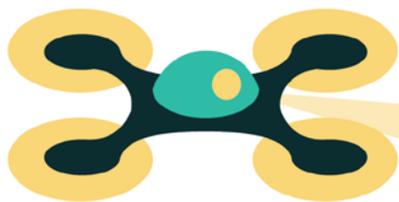


fly:ng high

Shaping the
future of
drones in
UK cities

Full report

July 2018



INDUSTRIAL
STRATEGY

UK Research
and Innovation



Flying High: shaping the future of drones in UK cities

Full report

23 July 2018

The full text of this report, including high resolution images and an interactive map, is available at flyinghighchallenge.org

About Nesta

Nesta is a global innovation foundation. We back new ideas to tackle the big challenges of our time.

We use our knowledge, networks, funding and skills -working in partnership with others, including governments, businesses and charities. We are a UK charity but work all over the world, supported by a financial endowment.

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Foreword

We have a golden opportunity to shape the future of drones in the UK

There is a moment in time where a new technology is in its infancy, where the opportunity exists to shape how it evolves and impacts our lives. A moment when we can choose for it to be largely beneficial and driven by the needs of those it will affect.

This is also a moment where a country can position itself to take the lead in its development and reap the associated economic benefits.

For drones that moment in time is now.

There are competing views of the future of drones in UK cities, and the country at large. Utopian visions of smart cities, congestion solved, services streamlined. Dystopian visions of surveillance, nuisance and noise. And for many, not much vision at all: an uncertain future, seldom thought of in any depth.

The Flying High project intends to shine some light on this future. To better understand what drones' place in our lives might be, to find out what challenges lie in store, to assess the benefits to cities and the people who live in them, and to start a much-needed conversation to build a shared view of this future.

This report is a summary of some of the key things we've done and the key facts we've learned as part of this process of engaging with five UK cities, as well as national stakeholders and experts.

The most important legacy of Flying High, though, is not in the pages you are reading now, but in the coalition that has been built, the shared objectives that have been developed and the future action that will follow.

Tris Dyson

Executive Director, Challenge Prize Centre

Nesta



This report demonstrates the potential of drone technology

The Flying High project will help accelerate drone technology for real-world complex city environments, says UK Research and Innovation's Andrew Tyrer

The five city projects under the Flying High project are all excellent examples of the potential for drone technology to make a real difference to our everyday lives.

This important report clearly sets out the challenges involved in delivering the vision for drone utilisation in city landscapes, and also points out the huge potential for UK companies and organisations to seize these exciting opportunities.

This is why UK Research and Innovation were pleased to sponsor this first stage of the Flying High project, because it complements the aims of the Industrial Strategy Robots for a Safer World Challenge.

When we made the case to Government for Industrial Strategy Challenge Fund investment in robotics and artificial intelligence, one of the prime candidate areas was extreme and hazardous environments. Not only is it one of the places cutting-edge robotic technologies are being developed, it's a place where the UK already plays well, where there is a defined need and where the opportunity to grow and dominate international markets exists.

The Flying High project's goal will be to help accelerate the use of cutting edge robotic drone technologies into real-world, complex city environments. Its findings will be important for the whole robotics and AI sector.

Andrew Tyrer

Challenge Director, Robots for a Safer World Challenge

UK Research and Innovation



Executive summary

We can take control of the future by solving the key technical and societal hurdles for drones

- Cities are enthusiastic about the potential for drones to deliver societal benefit
- Public confidence, technical progress and space to experiment are all needed if we are to move forward
- Challenge prizes could help unlock the opportunity

Through an engagement with five UK cities, national-level institutions and policy and technology experts, the Flying High project has explored the current state and future possibilities of the use of unmanned aerial vehicles, commonly known as drones, in urban environments in the UK. The project has looked at drones from several contrasting and complementary perspectives - not just technology, but also policy, economics and societal impact. The project has included:

- City engagement with five partner cities.
- Technical feasibility studies into five applications of drones.
- Economic and social feasibility studies of these five applications.
- Key stakeholder engagement with national bodies such as regulators.
- Industry and research mapping to understand the opportunity for the UK.
- Systems research to understand how drones could work at scale in cities.
- Public impact analysis to assess the likelihood of future initiatives having the desired outcomes.

This is what we have found.

Drones bring benefits to UK cities: they are worth promoting

Cities see an opportunity for drones to support public services

Our work on the place-based aspects of drones has been driven through our engagement with cities, and in particular informed by the five cities (Bradford, London, Preston, Southampton and the West Midlands) with which we partnered. We find a considerable appetite for the use of drones in these cities, and for public service applications in particular.

This is reflected in the five urban drone uses we explore in greater depth. In general there are commonalities in the cities' visions for the future of drones, particularly in the applications seen as most beneficial, and in concerns around safety, security and privacy. However, we also find significant variation between cities in the particulars of how drones

can help them to achieve their goals and fit into their local contexts, as well as the extent to which they have given serious thought to the future of drones up until now.

These city findings are outlined in the city visions published in this report.

Public confidence is key

The public needs to be on side if drones are to be used more widely

The conversation has barely started on what drones should and should not do. Through the Flying High project, cities are starting to think about this, but so far the general public has played only a small role in the discussions. From what we know to date, there is widespread public support for the use of drones for cases of clear social benefit, such as supporting the emergency services, but some suspicion of more speculative uses such as parcel delivery. In the first instance, the focus on drone deployment in cities should be on the uses with the clearest social value. Findings on social value and public confidence emerge throughout this report.

There are technical and regulatory challenges to scale

Among a number of challenges, solving flight beyond the operator's visual line of sight is key

We have examined the wide array of tasks to which drones can be put. In partnership with five cities, we have selected five socially beneficial use cases in order to explore their technical, social and economic aspects.

These are:

- Medical delivery in London.
- Traffic incident response in the West Midlands.
- Southampton-Isle of Wight medical delivery.
- Construction and regeneration in Preston.
- Supporting the fire and rescue service in Bradford.

Each of these use cases are technically possible to demonstrate in a limited sense today, but to realise them as everyday, routine services in complex environments requires several key challenges to be overcome. Most of these use cases utilise the capability of drones to cover a lot of ground rapidly and with a degree of automation. That means having drones fly beyond the visual line of sight of an operator. Doing so safely at scale in a busy environment is still a major technical and regulatory challenge. There are also challenges around integrating, validating and regulating autonomy; and developing new infrastructure

to safely manage large numbers of low altitude aerial vehicles. These technical and infrastructural challenges are outlined in the five use cases examined in this report.

While there is demand for all of the use cases we investigated, the economics of each application varies: some bring clear cost savings; others bring more in terms of social benefits. Some would be economically feasible even at small scale, while others only become viable when operating at high frequency or volume. The economics of each use case is outlined in the use cases section of the report.

Alongside technological development, regulation needs to evolve to allow these use cases to operate, as outlined in the five use cases as well as the chapter on Exploring urban drone integration.

A vision for the future

Policymakers, technologists and businesses need to align their agenda

There is growing alignment between the key stakeholders - government, industry, regulators - on what the future of drones should look like in the UK. There is considerable evidence that the economic opportunity for the UK is substantial. But this is still a work in progress. Prior to the Flying High project beginning, there was surprisingly little coordination between key players, and cities were largely absent from the discussion.

We need to keep up the momentum - and we urgently need to bring the public into discussions about the future of drones.

Drones are an opportunity for the UK

Get this right, and the UK stands to benefit

Through our industry mapping, engagement with national stakeholders and our work with the five partner cities, we have seen clear evidence that drones are an opportunity for the UK. There is already uptake of drone services in urban areas in the UK and a rapidly growing drone economy.

We have found a thriving drone ecosystem in the UK today, taking in companies that develop drones or drone technologies, provide drone services, and services to the drone industry such as training. The UK also has world-leading drone research and development. These are outlined in an interactive map published alongside this report.

Public opinion also provides an opportunity: views are still forming, but polling shows that socially beneficial uses of drones do have meaningful public support.

Alongside this opportunity, we have also seen a threat: UK policy responses to drones are behind those of leading countries. The US, EU and Singapore in particular have taken bigger steps towards reforming regulations, creating testbeds and supporting businesses with innovative ideas.

These findings are outlined in the chapter of this report on the opportunity for the UK.

So what needs to happen?

A programme of challenge prizes would accelerate solutions to complex and interconnected issues

The proposed next phase of the Flying Project is a series of major challenge prizes built around creating real-world trials to demonstrate the use cases that we have investigated. This process would drive innovation to address the key technical barriers to drone development, while forming the core of a continued programme of public and wider stakeholder engagement. Brought together, this can unlock the opportunity for the UK.

In addition to the challenge prizes, we recommend that regulation be updated to reflect advances in drone technology, particularly around management of urban airspace; and investment in the infrastructure that drones will need if they are ever to operate at large scale.

The need for Flying High

Introducing cars into cities brought chaos. With this new transport technology, we must do better

- Drone technology is already here - we have a choice to actively shape it for the better, or be passive and risk negative outcomes
- We must avoid making the same mistakes with drones that we did with cars in the 20th century
- Cities and citizens need to be at the heart of decision-making
- The UK has a narrow window of opportunity to be at the forefront of the global drone industry, and must act now

A lesson from history

There are strong parallels between the introduction of cars and the introduction of drones - for good and for ill

In the first few years of the 20th century, cars became mainstream.

In 1908, the Model T Ford came on the market. As a car, it was nothing special: slow, underpowered, inelegant. But, mass-produced and built from cheap parts, it radically changed the affordability of motoring.

Suddenly, motor vehicles became an economically feasible way to move people and goods. Their numbers exploded.

The first Model Ts to come off the production line needed little more than a smooth surface to drive on.

Fast forward 110 years, and the basic setup of a car has changed remarkably little - peel away the streamlined exterior and the sophisticated electronics of a modern car, and you still have four wheels, two rows of seats, an internal combustion engine and some gears.

But the environment has changed beyond recognition. Just like crowds are something more than a collection of individuals, traffic is qualitatively as well as quantitatively different from the cars that make it up.

And so, a huge array of physical and virtual mechanisms have been developed to help our cities cope with the massive uptake of automobiles.

- Laws: around speeding, alcohol, driver licensing, vehicle inspections, emissions standards, parking restrictions.

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- Physical infrastructure: crash barriers, motorways, traffic lights, roundabouts - even the bitumen surface of roads that replaced granite setts in the 20th century.
- New businesses: dealerships, petrol stations, garages, motorway service stations, but also minicab firms, car hire companies, car clubs.
- And then there's the way that our cities have been reshaped around them: suburbanisation, blight on main roads, creation of rat runs, erosion or destruction of public transport, impacts of air and noise pollutions on residents.

The environment that cars operate in today is the result of countless decisions taken over the past century. But the decisions were rarely deliberate, and rarely strategic.

Cars shaped our cities.

As drone technology matures, we must ensure that it's cities that shape the future of drones.

Planning for what comes next

Cities must shape the future of drones: drones must not shape the future of cities

Drones are both an opportunity and a threat; a strength for the UK economy but a potential unwelcome addition to our cities. The decisions we make in the next few years will shape what path we follow. We need to consider what we want the future of drone applications to look like in the UK, and thinking this through in urban areas allows us to tackle the most complex and challenging issues head on.

The Flying High project is a step in this direction - and this report a summary of some of its key findings.

Over much of the past year, Nesta has been leading a unique collaborative research and engagement programme to better understand what kind of demand there is for the use of drones in UK cities, and what these services should look like.

Working in partnership with five UK cities, as well as regulators and researchers, we have concluded that there is a demand, that drones can fulfil socially beneficial goals, but that there are challenges that need to be solved.

Some are technical challenges of drone technology - in particular around control beyond the vision line of sight of the operator, precision flight and autonomy. But most are not.

Just as the challenges of integrating cars into cities were largely around the infrastructure, laws and management of vehicles, so it is with drones.

- Creating the regulatory environment to allow autonomous flight, or piloted flight beyond the operator's line of sight, that makes deployment of drones over long distances or in large numbers feasible.
- Creating the air traffic control systems that allow drones to operate at scale without interfering with each other or with traditional aircraft.

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- Creating shared visions of what is acceptable or not - noise and other pollution, safety, economic gain - that involve the public and public authorities rather than sidelining them.

These are the issues we believe need to be solved sooner rather than later in order to unlock the full potential of the drone market in the UK.

There are hundreds of UK companies working in this space. Make the right decisions and they can prosper.

Make the wrong ones and we could blow a golden opportunity to lead the world.

The opportunity for the UK

Business is ready for the drone economy: if we seize the opportunity, Britain can prosper, but only if we take the public with us

- The UK already has a drone economy, with companies operating in every part of the country
- The industry has shown extraordinary growth since 2010
- But the UK is falling behind other leading countries around the world
- Public knowledge remains low, but public opinion is open to seeing the benefits of drones

Mapping the UK drone sector

Strong foundations exist in the UK

The drone sector is growing fast. By 2030, PwC estimates that drones will have contributed to a £42bn increase in UK GDP, £16bn in annual cost savings to the UK economy. There will be over 600,000 jobs in the drone economy.¹

The opportunity of the drone sector goes far beyond just technology. Drones have already created a diverse ecosystem of products and services that spans a diverse set of sectors, including media, construction, real-estate, agriculture, search and rescue and more.

Services have also emerged that support the professional drone industry, such as insurance, training, maintenance and drone strategy consulting. In terms of technology, the opportunity is not just the drone platforms themselves but supporting technology such as data analytics, data management, sensors and subsystems. There is also technology to support integration, including flight planning and management, as well as counter drone systems.

Drones are already touching sectors of the economy far beyond aerospace and engineering. PwC estimates that seven sectors will see positive impacts of over 1% in sector GDP from drones - ranging from agriculture to retail.

Drones are still an emerging technology and much of their promise lies in the future, but there is already a significant drone economy in the UK today.

Analysis carried out as part of the Flying High Challenge by Nesta, PwC and Glass² has identified over 650 firms in the UK drone industry, including both technology and service

¹ <https://www.pwc.co.uk/dronesreport>

² <http://www.glass.ai/>

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firms operating in a range of sectors. We have also identified over 400 public grants that have been awarded by Innovate UK, the Research Councils and Horizon 2020 to develop drone or drone-related technologies.

Since 2010, when there were only five operators licensed in the UK, the number of CAA approved drone operators has increased exponentially to 4,411 licensed operators as of 3 July 2018.^{3,4}

Geographic data on this full dataset is not publicly available and hence not mapped here.

However it includes the organisations listed and mapped in our dataset as well as companies and sole traders who do not advertise their services (and hence are not mapped), for instance because they provide an in-house service to a company or work directly with a small number of clients.

The research data in this map is based on identifying and analysing the websites of UK companies advertising drone products and services. We are particularly grateful to Glass for use of their proprietary technology which reads and classifies data from the web, and whose data forms the core of this map; and to PwC for providing a secondee to support in the analysis of this data.

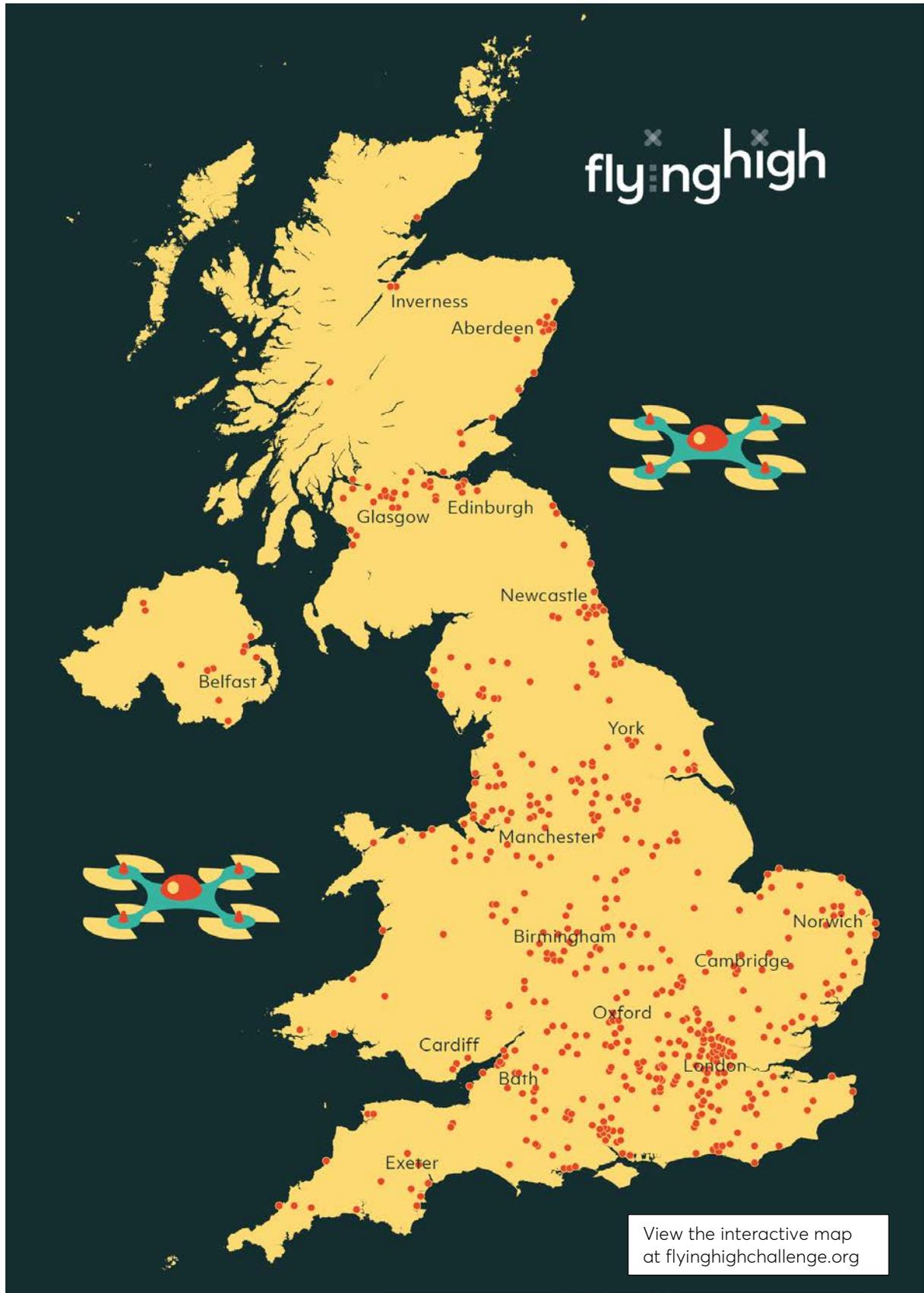


GLASS

Glass has invented AI technology that can understand text at scale. With this innovation they are building a product that wants to revolutionise how professionals can research the internet. With deep roots in machine learning and computational linguistics, Glass are digitally mapping the global economy, tracking any topic of interest across hundreds of millions of web pages, watching over millions of organisations.

3 <http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-479>

4 <http://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=7078>



The drone economy: international comparisons

The UK has fallen behind in drone integration internationally, and must act now to catch up

Drones are recognised as an important emerging technology around the world. Recent initiatives in the US, EU, Switzerland, China and Singapore show those countries are pulling ahead. The UK does not have comparable initiatives.

Initiatives around the world include:

- In the United States, a focus on testing drones in real environments. This includes FAA approved test sites, the ASSURE programme⁵ and the UAS Integration Pilot Program;⁶ the Low Altitude Authorization and Notification Capability⁷ project on integrating drone and aviation airspace; there is also significant public funding for drone programmes (\$25m in both 2018 and 2019).
- The European Union has pushed forward on airspace management and unlocking new drone operations in complex environments through SESAR's U-Space programme.⁸ EASA is part way through introducing new drone regulations that will facilitate new types of operation while maintaining a focus on minimising risk.⁹
- In Switzerland, an emphasis on a collaborative ecosystem, including drone-friendly regulations and a nationwide UTM.¹⁰
- China has a head-start in manufacturing (through companies like eHang and DJI), alongside trials in drone-based delivery by JD.com and Alibaba. Three cities (Shenzhen, Hiangxi and Sanya) are carrying out UTM tests.¹¹
- Singapore is carrying out five trials (including by Airbus);¹² Nanyang Technical University has developed a UTM and four out of the country's six major universities are conducting drone research.

The UK has the technical expertise to join this list, but it needs to take action.

5 <http://www.assureuas.org/>

6 https://www.faa.gov/uas/programs_partnerships/uas_integration_pilot_program/

7 https://www.faa.gov/uas/programs_partnerships/uas_data_exchange/

8 <https://www.sesarju.eu/U-Space>

9 <https://www.easa.europa.eu/easa-and-you/civil-drones-rpas/drones-regulatory-framework-background>

10 <https://www.skyguide.ch/en/events-media-board/news/#p16238>

11 <https://www.unmannedairspace.info/uncategorized/eu-china-app-drone-workshop-highlights-utm-progress-china/>

12 <https://www.channelnewsasia.com/news/singapore/airbus-unit-caas-to-trial-using-drones-for-parcel-delivery-8187184>

Public involvement

We need to meaningfully engage the public in the emergence of this technology

The path to public acceptance for new technologies has not always been smooth. Civilian nuclear power has been mired in controversy around its environmental and safety risks, as well as its link to nuclear weapons, since it emerged in the 1950s. Testing and introduction of genetically modified crops in the 1990s and 2000s brought serious public disquiet. Around the same time, the MMR vaccine hit the headlines with public opposition.

For a technology to be widely accepted by the public, it is not enough for it to do good or for the benefits to be advertised - the public needs to be meaningfully involved and they need to make their own minds up. So where does public opinion lie today?

Studies of public opinion on drones have included:

- A UK Department for Transport (DfT) public dialogue consultation run in early 2016, involving three workshops in each of five locations across the UK (Aberystwyth, Manchester, Newry, Salisbury and Stirling).¹³
- A Royal Aeronautical Society poll of 2,043 British adults conducted in 2016.¹⁴
- A 2016 UPS survey of 1,465 adults from all over the US about public perception of drone delivery.¹⁵
- A three country survey conducted by customer intelligence software company Vision Critical in 2014 in the UK, US, and Canada.¹⁶
- Our own Nesta-commissioned poll of 2000 UK adults, conducted by OnePoll in December 2017.¹⁷

At present, self-reported awareness and understanding of drones is low. Nesta's poll found that only around 30% of respondents felt that they had a good understanding of drones and their uses. However both UPS and DfT's research show that familiarity is correlated with more positive perceptions.

Moreover, perceptions of drones are not monolithic: public tolerance depends on what use they are put to. These studies consistently show that public service and government uses of drones are far more supported (typically by 80-90% of respondents) than recreational and commercial uses (hobbyists, air-taxis and deliveries are typically supported by fewer than 40% in these polls).

13 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/579550/drones-uk-public-dialogue.pdf

14 http://www.comresglobal.com/wp-content/uploads/2016/06/160513_Royal-Aeronautical-Society_DronesPolling_Tables.pdf

15 https://www.uspsaig.gov/sites/default/files/document-library-files/2016/RARC_WP-17-001.pdf

16 http://odesi1.scholarsportal.info/documentation/drones-survey/2014/Drone_Awareness_and_Perceptions.pdf

17 <http://www.nesta.org.uk/news/drones-our-cities-2020-predict-quarter-people-rising-half-2024>

This suggests that, at least in the first instance, the types of public service uses outlined in this report are the most likely to meet with public support.

As the drone economy develops, we must never lose sight of public opinion. We should always see public engagement as an opportunity to listen and learn - never as a barrier to be overcome, a problem to be unlocked or an audience that needs to be lectured.

Regulation

An opportunity to rethink regulations so they enable technological development

Drone use in the UK is governed by the Air Navigation Order (ANO) 2016¹⁸ (most recently updated in May 2018) and managed by the CAA, who have produced extensive guidance on the operation of unmanned aircraft systems.¹⁹ The ANO 2016 contains default restrictions on many types of drone operation, summarised in the Drone Code.²⁰ These restrictions limits drone use to within the visual line of sight of the operator, within 500 metres horizontally and below 400 feet in height. They also prohibit operation within 1 kilometre of the boundary of an airport or airfield, within 50 metres of other people or their property, or within 150 metres of crowds or built up areas.

To gain exemption from these restrictions from the CAA, it is necessary to produce a safety case outlining how the proposed drone deployment will be conducted to minimise risk to people and infrastructure on the ground and to other airspace users.

This works at present, but as drone use continues to grow, there is an opportunity to take a more flexible, anticipatory approach to regulating drones; based on enabling, rather than simply curtailing certain uses.

The Regulators' Pioneer Fund²¹ set up in the 2017 Autumn Budget may be one opportunity to take this forward.

18 http://www.legislation.gov.uk/uksi/2016/765/pdfs/uksi_20160765_en.pdf

19 <https://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=415>

20 <http://dronesafe.uk/drone-code/>

21 <https://www.gov.uk/government/publications/autumn-budget-2017-documents/autumn-budget-2017>

What drones can do in UK cities

Cities have identified many potential benefits - and risks

- Cities see the opportunities for drones
- There is a shared view of the benefits of drones
- But there are significant downsides that need to be addressed at the same time

Future city trends

Cities see opportunities for drones - but they need to respond to citizens' needs

Drones can carry out useful tasks in cities. They can serve as eyes in the sky to look at things and report back to people on the ground, telling us quickly if a bridge is crumbling, a fire is spreading or a person needs help. They can supplement our transport systems by moving things around or getting someone somewhere quickly. Drones can also be robots on wings, performing tasks like repairing that crumbling bridge or putting out that fire.

Our work with five cities in the UK to evaluate these opportunities comes at the intersection of several major urban trends. First, in the UK and in other places, cities are taking on more leadership and responsibility than ever since the rise of the nation state. Second, cities have access to an array of technologies that help them make smarter decisions and serve the public more efficiently.

But cities are pragmatic. Every day, they are faced with making choices about how to spend (limited) money, how to best serve citizens' needs and how to solve mundane but important problems while making plans for the future.

The Flying High project reflects these trends. Cities are excited about the possibilities that drones can bring. But cities are wary of tech-led buzz that can gloss over concerns of privacy and safety and nuisance. Cities want to seize the opportunity presented by drones but do it in a way that responds to what their citizens need and want.

The Flying High partner cities saw many of the same benefits

Saving money, improving health and safety, protecting the environment, delivering growth

The benefits outlined through the engagement with the five Flying High partner cities can be grouped into the following four high-level categories:

Flying High: shaping the future of drones in UK cities

1. **Cost and time savings** to public bodies such as local government, emergency services and health service providers, through faster access to locations, more efficient service provision and the automation of certain processes, as well as by collecting information and generating relevant data to support more timely, transparent, and effective decision-making.
2. **Health and safety benefits** to workers who are taken out of hazardous and challenging environments such as working at height or in confined, compromised or unstable places; also to citizens that benefit from efficiencies that could be generated by emergency and health services.
3. **Environmental benefits** from use of drones to maintain urban spaces, monitor and ensure compliance with air pollution regulation, and track changes in the environment, to reducing road traffic by replacing road vehicles with airborne drones for some types of delivery.
4. **Economic growth** through efficiency gains to businesses and workers, and the creation and delivery of new skills, jobs, products and services.

As the technology, regulation and use of drones evolves it is possible that further benefits will be realised as new and previously unforeseen drone-based products and services are created.

The Flying High partner cities also had many of the same concerns

Safety, privacy and security are among the crucial things we must get right

The Flying High partner cities raised similar concerns with regards to the use of drones in their region; these included:

1. **Safety** of the drones flying above or around people and buildings, as well as drones landing in and taking off from populated environments, especially if operating autonomously and/or beyond visual line of sight.
2. **Privacy** of any personal data being collected and processed by the drones, ownership of the data, how and where it's going to be used and for what purpose.
3. **Security** of the drones both in terms of software and hardware to prevent hacking or malfunctions.
4. **Noise and visual pollution** as a result of drone operations scaling up or carrying out tasks across cities.
5. **Transparency** over what the drone is doing and who it belongs to.

6. **Impact on existing jobs** and the extent to which drones are actually providing value; how will drones affect employment, public services budgets and the way current jobs are being performed.

The Flying High project represents an opportunity for drone developers, operators, regulators, cities and their representatives to address these concerns early on and design drone systems that are in line with city priorities and principles.

What tasks could drones carry out?

Proposed uses for drones fall into five broad categories

A range of drone use cases have been identified by city stakeholders as having the potential to bring these benefits to UK cities in the next 20 years. These are grouped below according to the main functionality of the drones.

Monitoring

Continuous scanning or assessment of defined areas looking for live changes

Using drones to monitor air or water pollution in a more consistent way, mapping fires and floods, monitoring traffic flows on roads or shipping lanes, monitoring crowds at events, and supporting search and rescue missions were frequently mentioned by city stakeholders. The added value of drones in these situations is that they can offer new and timely data that can support decision-making and lead to more effective policies or interventions. Some of these use cases such as mapping fires or monitoring crowds at events are in operation today, but in discrete locations. Their potential is much greater.

For example, in cases of emergency, drones could become an integral part of emergency service operations. They could support a better coordination by collecting data and sharing it across the police, emergency, and fire services. Speaking optimistically, in the future drones will be able to not only respond in emergencies, but could also predict or even prevent them, such as in the case of fires. Similarly, in the case of monitoring traffic flows, data from drones could be used to predict peak times and better manage traffic.

Inspection

Assessing discrete objects, areas or systems to evaluate their current state

The inspection of assets – whether discrete objects such as bridges, houses, construction sites, tall buildings, or confined and compromised structures, or linear systems such as railway tracks, pipes, roads, power lines or sewers – were common desired applications mentioned by city stakeholders. The advantages of using drones in these situations include

time and cost reductions of carrying out the assessment, as well as risk reduction for personnel working in hazardous environments (e.g. at height or in compromised spaces).

Drones would also offer the opportunity to inspect confined or otherwise inaccessible areas. Similar to monitoring, the value of using drones in inspections lies in their ability to detect potentially dangerous faults and enable their timely, and more affordable, reparation. Drones used for monitoring and inspection could also play a key role in city development and planning; they can provide more complex and comprehensive data to inform development plans, as well as make it easier to share progress with residents. This would lead to better informed and much more transparent public services.

Delivery of goods

Collecting, transporting, and delivering goods from origin to destination

A lot of public attention has focused on the drone delivery of commercial goods – collecting, transporting and delivering goods from retailers to homes or between intermediary hubs. The city stakeholders consulted for the Flying High project mainly expressed an interest in situations where drones would be used to perform regular and/or unpredictable deliveries of critical items. This included urgent deliveries of medical samples or drugs between hospitals, or deliveries between a hub and variable emergency locations – for example, sending a defibrillator to the site of an accident or essential supplies to flood victims. If used to complement emergency services, drones could enable a faster and more targeted delivery of emergency supplies and more consistent services.

Beyond emergency services, delivery drones were seen as a way of improving the accessibility of different services and enabling the development of more inclusive communities. For example, drones could be used to deliver medical prescriptions or local produce to vulnerable people or to those in remote locations. The development of a drone delivery infrastructure could lead to reduced road traffic congestion and pollution in city centres, and faster and more consistent services for remote users.

Transport of people

Transporting passengers from one location to another

Some people and companies have discussed the use of drones to carry people, for instance in an urban taxi service. This was raised by city stakeholders, but as a longer-term possibility rather than a priority use case. Use for emergency services, for instance as air ambulances, is more likely to be a nearer-term goal. Ambitions of using people-carrying drones on a large scale to decongest road traffic and reduce strain on existing public transport is a much longer-term aspiration, and one that would require much stronger public and political support than is currently evident.

Intervention

Interact with objects or persons in an attempt to improve or support their current state

In addition to collecting data, delivering goods and transporting people, several other drone applications were flagged up by city stakeholders. These included drones that could pick up litter, spray weeds, repair roads, street lamps or faults in hard-to-reach structures such as bridges, they could boost mobile networks at events or in emergencies or could rescue people in danger. This versatility of these applications supports a vision where drones would seamlessly integrate into the day-to-day operations of a city and its emergency services. They would enable an extension and improvement of existing services and capabilities, as well as allow for a greater flexibility of carrying out tasks in confined or dangerous locations.

Grouping drone use cases into categories based on their functionality can be a helpful way to consider the common technical and infrastructure requirements needed to enable their effective operation in an urban setting.

In reality, it is most likely that drones will carry out multiple and diverse tasks as part of an end-to-end service. In the engagement with city stakeholders, an emerging expectation was that drones would be used across multiple services, they will likely be modular, and could perform a range of complementary tasks.

For example, emergency drones will likely be used across the emergency services, and will support a range of capabilities including monitoring, inspection, sharing important and timely data, delivery of critical equipment and even transport of people in need of immediate attention. Another emerging feature was that drone operations will likely become increasingly proactive and focus on prediction and prevention, not just rapid response. Using drones to identify and prioritise maintenance operations in a city or to build better models of how people and vehicles move in a city can support the development of more proactive, effective and transparent public services in urban settings.

Shaping drone use in London

Why we are talking about the future of drones in London

London is a diverse, rapidly growing city

London is growing. It attracts attention, visitors and new residents from all over the world drawn by its heritage, culture, diversity, economy and progressive approach. But like any world city, London must solve big, strategic challenges, such as congestion and air quality, if it is to protect and enhance the quality of life of its residents and visitors.

The Mayor's Transport Strategy (MTS) estimates that London's population will grow from nine million people today to 10.8 million by 2041. The MTS acknowledges that without further intervention "rising traffic and falling road capacity for private vehicles means that congestion will rise for essential traffic" while "industry trends and economic growth will lead to more freight traffic, especially vans".²²

Analysis by Inrix²³ shows that London has the seventh-worst rate of traffic congestion in the world; further, London has been listed as one of the European capitals with the worst air pollution.²⁴ Road transport is responsible for half of the main air pollutants, with cars contributing 14 percent of nitrogen oxides and 56 percent of particulate matter less than 2.5 microns in diameter.²⁵ The MTS commits TfL to several significant measures that will help tackle these challenges including the Elizabeth Line, Crossrail 2, new cycling infrastructure, funding for electric vehicle infrastructure and the Ultra Low Emission Zone. However the world is changing and these measures alone may not be enough to meet the needs of a changing city.

London is a major financial services centre, tech industry hub, and global draw for culture and tourism. The Global Financial Centres Index ranks London as the number one financial centre in the world based on scores relating to business environment, financial sector development, infrastructure, human capital and reputational factors.²⁶ Further, the UK is Europe's leading country for global tech investors, with "British tech firms attracting more venture capital funding than any other European country in 2017. London's tech sector continues to fuel the growth of the UK's digital economy, with the capital's tech firms raising

22 <https://www.london.gov.uk/what-we-do/transport/our-vision-transport/mayors-transport-strategy-2018>

23 <http://inrix.com/wp-content/uploads/2017/09/INRIX-London-Congestion-Trends-May16.pdf>

24 <https://www.theguardian.com/uk-news/2018/may/22/london-one-of-worst-capital-cities-in-europe-for-clean-safe-transport-study-shows>

25 <https://www.london.gov.uk/what-we-do/transport/our-vision-transport/mayors-transport-strategy-2018>

26 <http://uk.businessinsider.com/most-powerful-financial-centres-gfci-index-for-2017-2017-9>

a record £2.45 billion and accounting for around 80 per cent of all UK venture capital tech funding in 2017” – according to a study by Pitchbook commissioned by London & Partners.²⁷

London’s government has a progressive policy framework delivered through a strong public sector including a respected transport authority recognised for integration and innovation. London was the first city in the UK to directly elect a mayor, its transport system was the first in the world to embrace contactless payment systems and it was the first city in the UK and one of the first and largest cities in the world to introduce congestion pricing.

The Mayor’s Transport Strategy

The Mayor’s Transport Strategy²⁸ (MTS), published by Mayor Sadiq Khan in March 2018, states the Mayor’s policies and proposals to reshape transport in London, with a time horizon of 2041. The MTS is based on the healthy streets approach²⁹ and prioritises human health and experience. The three key themes of the strategy are:

- 1) Healthy streets and healthy people (creating a street experience that encourages walking, cycling and public transport over car dependency),
- 2) a good public transport experience (shifting from private car to public transport use) and
- 3) New homes and jobs (planning the future city around walking, cycling and public transport use to unlock growth in new areas and create opportunities for ‘good growth’ that benefits everyone).

London’s approach to drones should be underpinned by the principles of the MTS to create Healthy Streets, a better public transport experience and ‘good growth’.

The UK’s most complex airspace offers an important test case for urban drone use

Airports, restricted areas and a dense urban core make London a unique environment for drones

London’s airspace is one of the most complex places to introduce innovations. London has the largest collective airport system in the world and its airspace is the most congested in the world, handling more than 170 million passenger journeys in 2017; 30 million more than the next busiest city, New York.³⁰ Heathrow is the busiest airport in Europe and the seventh-

²⁷ <http://www.itpro.co.uk/digital-transformation/30234/uk-tech-industry-saw-record-investment-in-2017-despite-brex>

²⁸ <https://www.london.gov.uk/what-we-do/transport/our-vision-transport/mayors-transport-strategy-2018?intcmp=46686>

²⁹ <https://www.london.gov.uk/what-we-do/health/transport-and-health/healthy-streets-london>

³⁰ <http://www.aci.aero/News/Releases/Most-Recent/2018/04/09/ACI-World-releases-preliminary-2017-world-airport-traffic-rankings--Passenger-traffic-Indian-and-Chinese-airports-major-contributors-to-growth---Air-cargo-Volumes-surge-at-major-hubs-as-trade-wars-threaten->

busiest in the world. Over the next 20 years, the industry estimates a doubling of the world's aircraft fleet, according to Chris Grayling, the transport secretary.³¹

London's urban airspace is equally complicated. London has some of the highest population densities and largest numbers of tall buildings in the UK. This combined with numerous no fly zones and a complex patchwork of land ownership means that flying drones in London is more challenging than any other UK city.

Today, airspace is regulated and managed to enable traditional forms of commercial, military and recreational aviation to operate safely. The focus is on traditional airports and long-range routes, operating (in general) high above London's urban area. Outside of airports, the interaction of aviation with the city is via a limited number of small aircraft operating at lower altitudes (eg helicopters) as well as the environmental impacts of both smaller and larger aircraft, such as carbon emissions and noise.

Drones could unlock new ways to use the city's low-altitude airspace if that airspace is made available to them. This urban airspace has direct relationships with the city through multiple landing points and direct adjacencies with buildings and infrastructure and existing manned aircraft such as helicopters. Unlocking this airspace is high-risk and could have a significant effect on the city beneath and around it, directly affecting many more Londoners than traditional aviation. The approach to its use must be risk-based and meet the legitimate needs of those on the ground, while protecting existing aviation.

London is a thought leader on urban transport and can be the same for the urban integration of drones

London is a respected convener and can help shape the national discussion about drone use

London's diverse geographic, cultural and business landscapes create opportunities for testing and deploying a wide range of innovative and socially beneficial drone applications. London has a unique urban fabric that combines diverse buildings, infrastructure and natural assets. This mix means that tourist destinations and world heritage sites, hyper-dense hubs and towering skyscrapers, metropolitan centres and residential neighbourhoods are all embedded within a network of green spaces.

This context creates a mix of opportunities and constraints for the drone industry to tackle, but a considered approach will be essential. Innovative deployment of drones could impact the quality of life of millions; for this impact to be positive, careful thought is required to understand what constitutes appropriate use. This will require diverse stakeholders to work together in new ways that challenge the status quo.

London is a respected convener and has the opportunity to bring together diverse partners, including respected service providers like the NHS, private enterprise and the R&D

³¹ <https://www.gov.uk/government/speeches/modernising-the-uks-airspace>

community along with national regulators to shape urban drone use. National and international policymakers look to London as a trendsetter for policy around transport, urban development and economic growth. How it approaches the technological, regulatory, policy and practical challenges that sit around urban drone operations can help to position the UK as a world leader in urban deployment of drone technologies.

This influence brings the responsibility to define a pragmatic and safety-first approach that is in the interests of the public. While the complexity of London should not make it the first place to test disruptive, high-risk technologies, innovators should be able to look to London to set the opportunities, challenges and parameters of what will ultimately be acceptable. In line with the Smarter London Together³² strategy, released in June 2018, which compels London to improve its ability to adapt, scale and amplify the best innovations, so too should any future policy around drones be flexible, adaptable and scalable.

If it continues the momentum of the Flying High project, London can define how drones should be used in London to benefit Londoners and influence drone deployment in cities all over the world. To do this, it must set the parameters for the drone industry to meet and the challenges it must solve.

What should guide drone policy development in London?

The strategy for London's urban airspace should be risk-based, city-led, adaptive and focused on the long term

The unique nature of urban airspace and the differences from traditional airspace should be recognised in the way that it is regulated and managed. Unlocking airspace in London presents opportunities and risks for all Londoners. Decisions on the use, management and operation of London's urban airspace should be made by the city government in close collaboration with central government and the regulators, on behalf of Londoners. A steering group should be created and made up of those affected by the opportunities and risks of drone use. This may be through the continuation of the task force convened for London's participation in the Flying High project, paired with a senior level board. The city must also engage the drone industry to fully understand the capabilities and trajectory of drone technologies.

Decisions London makes now will affect unknown opportunities in the future. An adaptive governance approach focused on safety and learning should be applied, setting the principles and considering the appropriateness of new technologies. This should include those not yet mature, recognising that decisions made today will define how London's airspace will be used and who uses it, for generations.

Lessons should be learned from traditional aviation and mature uses such as inspection drones. Flexible policies should be put in place to guide more long-term and speculative

³² <https://www.london.gov.uk/what-we-do/business-and-economy/supporting-londons-sectors/smart-london/smarter-london-together>

uses and create the conditions that support the shaping and development of appropriate applications in the future. Further, lessons learned and knowledge shared by other cities in the UK and globally should inform the path that London chooses to take.

London should collaborate with local and national stakeholders to develop its own principles and approach to urban drone use and policy. A set of guiding principles, such as those recommended below, should be developed as a foundation for any future public decision-making or policy development governing drone use in London. These foundational concepts can form the basis for how London chooses to approach drone use. Some can be applied directly by London government, others will require lobbying to other national and international regulators.

Guiding principles for policy development in London

1. Place safety and security first

Any approach to drone usage in London must place the safety and security of Londoners above all else.

2. Recognise and define the uniqueness of urban airspace

Urban airspace is different from the space traditionally occupied by commercial aviation. What happens in London's low-altitude urban airspace should directly support what happens in London's streets, buildings and public spaces. This should be true regardless of whether it is manned or unmanned, manually controlled or autonomous. London's approach should be led by the city, considering the opportunities as well as the impacts including noise, privacy, security and environmental impact.

3. Assess the public viewpoint and align with existing policy objectives

Public engagement should be a key part of future drone policy development and Londoners should be invited to explore, understand and collaborate with decision-makers to shape the future of drone use. Future policy should support the healthy streets approach, align with the principles of good growth as articulated in the MTS, address London's strategic challenges (in line with the London Plan) and unlock airspace value for Londoners.

4. Prioritise publicly beneficial and critical uses

Drone uses that offer true public benefit should be prioritised. Drone use by the emergency services and public sector should take precedence over commercial activity. Recreational drone use should, in general, be deemed unsuitable.

5. Work with the drone industry, investors and academia to identify and utilise the unique capabilities of drones and minimise any negative impact

Drone use should be limited to applications that best utilise the unique capabilities of drone technology (eg for critical, time-sensitive operations or activities that can be done by

drones more quickly, accurately and safely than by humans). London should leverage its ability to convene experts and assemble resources to work closely with the drone industry to develop these capabilities for London; however, research, trials and deployment should involve collaboration and learning with other cities to foster co-learning and advance shared national goals.

6. Employ an adaptive governance model

An adaptive approach should be taken to allow city services to evolve and capitalise on the opportunities that the urban airspace presents and limit possible problems. Early decisions should therefore be made with an open, flexible approach to emerging technologies that creates capacity to evolve policy as the technology matures.

London's role in trialling and demonstrating urban use cases

London should set the aspirations and parameters to demonstrate mature technologies in complex urban environments

London's ability to convene industry leaders, attract capital investment and access world leading universities give it a clear role to play in the research and development process. This opportunity should support UK-wide R&D opportunities in drone technologies and put the UK drone industry on the world stage. However, due to its complexity and density, London should not be the first place to trial or pilot disruptive, high-risk technologies and applications. Rather, London should set the challenges and parameters to which the scaled deployment of an application should adhere, followed by mature trials and demonstrations once they have been proven in more controlled environments. Such trials are likely to focus on testing the response of drone systems in urban environments. Demonstrations would be focused on generating feedback from public and other stakeholders.

London has potential to create demonstration sites and urban testbeds for drone development once this maturity has been reached. Policy 4.10 of the London Plan (New and Emerging Economic Sectors) calls on the Mayor, boroughs and other relevant agencies and stakeholders to "support innovation and research, including strong promotion of London as a research location and encourage the application of the products of research in the capital's economic development". For drones, these opportunities should focus on relatively mature technologies for demonstrations of new applications, identifying the public viewpoint and creating place-specific pilots.

London should explore locations where open spaces, ownership, diversity of uses and landscapes are suitable for demonstrating drone applications and testing certain capabilities in an urban setting. Opportunities for synergies with existing test sites should also be sought. For example the Smart Mobility Living Lab: London³³ has been established to provide a real-world urban testbed in a complex public environment, with a mission

³³ <http://www.smartmobility.london/>

focused on connected and autonomous vehicles and mobility services. The current SMLL:L test bed covers the Queen Elizabeth Olympic Park and parts of Greenwich. London could build on the existing smart mobility trials in these locations to develop test beds for drone technologies and applications.

What could drones do in London?

Support emergency services and infrastructure - without losing sight of innovative new uses

The high number of people on the ground and intensity of activity in London is likely to create much higher demand for the use of the airspace and the need to make decisions about what uses to prioritise, so London's urban airspace should be seen as a valuable asset with limited capacity. Careful thought should be given to its use.

To get the most benefit from the airspace, drone use in London should be focused on high-need uses that bring societal benefit, based on public need rather than commercial opportunity. Decision-making should be guided with respect to safety, privacy, security, need, transparency, openness and accountability along with the above principles. Our initial work suggests that the following applications may be appropriate for London.

Saving lives with the fire, ambulance and police services

The emergency services' use of drones should be supported

By far the greatest public benefit of drones is the way that they can support the emergency services. In the short-term drones can help with search and rescue, surveying incident and crime scenes and supporting the Fire Brigade in investigating burning buildings. These uses can ultimately save people's lives and London's emergency services are already trialling such use cases. This work should continue and be supported at a strategic and local level. Regulation and airspace management should continue to support and enable these use cases.

Support London's growth and the safe management of its built environment

London's built environment is changing: drones can help it happen safely

London's population is forecast to grow from nine million people today to 10.8 million by 2041. This means an additional 1.8 million people will need places to live and work and the infrastructure to get around. London's built environment and transport network is already being developed, redeveloped and intensified to adapt to meet these demands. This growth must be underpinned by the principles of good growth and the healthy streets approach. Its construction and management must be safe, cost-effective and reduce its

environmental impact. The pace of change in London, at a city and local level, requires dynamic governance models and policies that can support effective, efficient and safe construction and maintenance of homes, workplaces and infrastructure.

Drones are uniquely able to perform difficult and dangerous tasks accurately and safely in rapidly changing environments. These include inspection and monitoring of buildings and construction sites, infrastructure and transport networks, supporting planning and development processes and even performing building-related tasks. These uses are already in practice, but they can be better routinised and proactively delivered in an intentional way to support London's growth and regeneration in safer, more cost-effective and more time-efficient ways, thereby offering public benefits and improving local quality of life. The technology for these uses is already mature and can be deployed at scale today, but requires public sector intervention to set policy and ensure safety, privacy and security.

Drones can bring innovation and efficiency to public services in the capital

Services are facing challenges; drones could help us meet them

With an increasing population, London's essential services will need to work harder, faster and reduce costs. This should be achieved in a way that supports the healthy streets approach and reduces environmental impact despite high levels of congestion throughout London. London needs innovative solutions to transport challenges to create greater efficiencies in transport, reduce emissions, improve the urban experience on the ground, and support good growth, including healthy, inclusive, resilient development.

In the long term, drone technology could enable new modes of zero-emission mobility with enhanced reliability and reduced travel times for critical journeys. Focused on London's essential services, the technology could reduce costs, save lives and enhance the quality of service. Given London's limited airspace capacity, these mobility opportunities should be focused on 'missions' that provide direct public benefit and only once they are fully proven to be safe. The earliest opportunities are likely to be focused on carrying time-critical items between hospitals for the NHS (further details on these possibilities and their implications are discussed in the Flying High use case analysis). Future possibilities are less certain.

London's public sector should take steps to prepare for the most positive applications of these technologies, for example exploring how the airspace can be 'safeguarded' for the most publicly beneficial uses, even if the technologies are not yet ready for deployment in London.

Shape transformative new uses as they evolve

London should stay at the forefront of sensible innovation

The recent growth in the drone industry has created significant hype and excitement. Many promoters of new applications and products will look to London to endorse and embrace their proposals. This could result in pressure to use London's airspace for applications less

aligned with London's objectives and with less publicly beneficial outcomes. Many of these applications may be hailed as transformational, with the potential to change the way that Londoners perceive the benefits of the technology and London's policy approach.

In a location where the stakes of safety and security are so high, it will be essential that London sees through this hype and recognises the many technological, regulatory and public acceptance hurdles to be addressed if the applications are to be realised. London should therefore focus on the priority applications outlined above, but also seek to shape certain technologies and business models that may initially seem less aligned with current policy. It should also use its past experience to offer guidance on business models and technologies, highlighting how services can be made more or less workable and appropriate in a dense megacity like London. Policy 23 in the MTS, which directs the Mayor and TfL "to explore, influence and manage new transport services in London so that they support the Healthy Streets Approach," is an excellent starting point for this process, and will enable London to stay at the forefront of sensible innovation and appropriate urban drone use.

Recommended next steps for London

Keep the momentum up: develop policy, engage the public and work with industry

Over the coming year, London and its strategic partners should identify and assemble resources to further investigate and address the opportunities outlined in this vision, using the following outline of near-term actions as a roadmap:

- **Appoint a steering group**, including TfL, GLA, boroughs and national stakeholders, focused on shaping London's approach to drones, including drone policy and regulations, in the interest of Londoners.
- **Explore opportunities to engage the public** and identify what is acceptable and supported by Londoners.
- **Develop and define principles for the use of London's urban airspace** and how it should be managed, and take steps to develop policy and lobby national, European and international bodies to enable this approach.
- **Explore** drone applications that provide safety, societal and other public benefits and consider how these can be brought forward appropriately.
- **Engage** industry and facilitate opportunities for the development and deployment of drone technologies to support delivery of London's strategic objectives.

Shaping drone use in the West Midlands

Why we are talking about the future of drones in the West Midlands?

The West Midlands region has long been one of the UK's leading economic centres

One of the main economic powerhouses in the UK, the West Midlands is home to 2.8 million residents, international corporations and an expanding community of small-and-medium sized enterprises. It is the largest urban area outside London and is geographically diverse, with Birmingham city centre at its heart and the cities of Coventry and Wolverhampton well placed to build upon the region's significant potential. In the 18th century, the Black Country districts of Dudley, Sandwell, Walsall and Wolverhampton supplied the coal which fuelled Victorian factories, and in the next few years Coventry will house the nation's new battery research facility.³⁴

The West Midlands has built upon its proud heritage as the historic birthplace of the Industrial Revolution, and has retained its strengths in advanced manufacturing and engineering.³⁵ The region continues to be recognised as 'the UK's automotive heartland', thanks to its concentration of research and development assets in that sector, and is set to become a world-leading testbed for connected and autonomous vehicles (CAVs).³⁶

A recent report by the World Economic Forum identified a fourth, contemporary industrial revolution. It highlighted drones, alongside autonomous vehicles, as a distinctive and vital technology of this shift.³⁷ Given the region's heritage, geographic advantage and economic strength, the West Midlands is well positioned to be at the forefront of this, shaping drone usage and building the drone development ecosystem in the UK.

34 <https://www.gov.uk/government/publications/automotive-sector-deal>

35 <https://www.ft.com/content/908ba3d0-75da-11e6-b60a-de4532d5ea35>

36 <https://www.gov.uk/government/publications/automotive-sector-deal>

37 http://www3.weforum.org/docs/WEF_Harnessing_the_4IR_for_Sustainable_Emerging_Cities.pdf

Transport innovation lies at the heart of the region's strategy

New infrastructure and advanced technology are key

A culture of innovation continues to be a key driver for future progress in the West Midlands, demonstrated by the West Midlands Combined Authority (WMCA)'s recognition of smart mobility as the glue behind its transport strategy.³⁸ Successes in this field include the region's recent launch of the UK's first 'Mobility as a Service' package, and the successful bid to build a £25 million real-road CAV test environment.³⁹ The region's eagerness to identify and test new forms of transport technology to drive regional growth speaks to the viability of exploring drones in its urban centres.

Alongside these proof-of-concept trials, major infrastructure projects promise to transform the skyline and offering of the West Midlands. The largest infrastructure project in Europe, High Speed Two, is coming soon and will connect Birmingham to London, Manchester and Leeds by rail. Other connectivity projects within the West Midlands, from metro expansion to a network resilience programme, will also help in linking people to employment and boosting economic growth. This combination of innovation, investment and transformation presents unique opportunities to explore transformative technologies.

The establishment of the West Midlands Combined Authority brings new leadership to the region

The region now has the institutions it needs

The West Midlands was a pioneering region in the launch of the UK's metro mayor concept and move towards devolution of power from Westminster to the local level. The region can seize this opportunity to develop local leadership around issues of regional importance – including the future of urban drone operations.

Established in 2016, the WMCA consists of the seven existing metropolitan councils and three local enterprise partnerships which make up the region. The organisation was created to secure and manage investment and set the direction for regional strategy. Headed by the elected metro mayor, Andy Street, the WMCA has responsibility for regional economic growth, transport, housing, skills and jobs. At its heart, the organisation aims to use the devolved powers to deliver a stronger West Midlands, accelerating regional productivity and improving the quality of life for those living or working in the region.⁴⁰

In addition to these formal governance structures, regional development is led by the West Midlands' ethos of collaboration and enterprise. Not only do local authorities work in

38 <https://www.wmca.org.uk/media/1682/west-midlands-sia-final-for-publication-21617.pdf>

39 <https://www.tfwm.org.uk/news/travelling-on-a-whim-revolutionary-app-is-launched-in-west-midlands>

40 <https://www.wmca.org.uk/what-we-do/strategy>

partnership with each other, but a positive approach to public sector reform has seen councils work with charities, universities, hospitals and the emergency services. Likewise, engagement with business spans beyond the WMCA's connections to local enterprise partnerships. The contribution that the private sector makes to the region is valued, with some commercial partners directly involved with WMCA projects and others working independently on initiatives which enhance the West Midlands.

What should guide the usage of drones in the West Midlands?

Excitement must be balanced with care

Drones are a disruptive technology with the potential to bring significant change as well as benefit to the West Midlands. While this is exciting, it needs a considered approach to guide future deployment of drones in order to ensure that opportunities are exploited and potential issues avoided. Initial engagement with public services, business, academia and elected members has captured early views on which principles should characterise the region's approach to drones. These ideas will be further supported by a policy-led approach to ensure that trials and initiatives align with regional ambitions.

A set of guiding principles should be developed as a foundation for any future public decision-making or policy development governing drone use in the West Midlands. Within the stakeholder engagement process for the Flying High project, the following themes emerged to form the basis of these as important guiding principles for a future drone policy.

Recommended principles to guide future drone development in the West Midlands

1. Create a growth environment

Continue to act as an enabler of innovation, looking for opportunities where drones could support regional priorities and boost key sectors such as advanced manufacturing, but also creating an environment in which enterprise can flourish.

2. Encourage interoperability

Encourage the ambitious development of interoperable and modular drone systems, which can offer multiple uses and be shared among users and sectors.

3. Add value

Prioritise drone applications which truly add value to the West Midlands, creating alignment between community and commercial interests. This principle was the most important to elected members, and will be central to future public engagement efforts.

West Midlands' framework for disruptive technologies

The West Midlands already have a framework for innovative transport technologies - the introduction of drones should follow it

Transport for West Midlands (TfWM), as part of the WMCA, works to identify whether new and emerging mobility solutions could help meet the rising and evolving demands placed on the region's networks. Often, these solutions come in the form of disruptive technologies, such as smart ticketing, on-demand services and mobility apps, such as Whim.⁴¹ Many of these initiatives are collaborative, where TfWM enables a range of partners to launch or trial new services. This requires the organisation to simultaneously empower projects and guide them so that they meet the region's best interests. Drones, along with other autonomous systems, fall firmly within this category.

To achieve the balance between innovation and added value, TfWM has developed a set of core regional policies which new initiatives in disruptive technologies must look to improve, or not adversely affect. These policies reflect the strategic priorities for the region, from social wellbeing to sustainable growth. For example, the traffic incident response use case analysis set out in this publication has the potential to benefit policies 2, 3 and 12, which focus on using and maintaining existing transport capacity more effectively to provide greater resilience and greater reliability for the movement of people and goods, and reducing road traffic casualty numbers and severity.

Development and uptake of drones could also stimulate economic growth more broadly, consistent with the framework's policies to support economic growth and economic inclusion, whereas the environmental impact of increased drone use would need to be understood and monitored, consistent with policies 9 and 10. Overall, these policies act as a light touch framework to quickly assess and then guide trials of disruptive technologies without stifling innovation. Alongside principles identified by stakeholders, these policies will shape the development of drone initiatives in the West Midlands.

What could drones do in the West Midlands?

The West Midlands vision for drones focuses on public benefit: infrastructure and development, transport and logistics and emergency services

A wide network of expert and local stakeholders from the public, commercial and academic sectors were asked what they think drones could or should be able to do in the West Midlands. Through the engagement process, the following functions for drones emerged as regional priorities for the future:

⁴¹ <https://whimapp.com/uk/>

Infrastructure and development

- Asset monitoring and maintenance
- Surveying
- Land use monitoring
- Supporting construction projects

Transport and logistics

- Monitoring transport conditions
- Managing congestion and mobility
- Last mile delivery
- Product movement

Emergency services

- Traffic incident response
- Emergency response: Police, Fire, Ambulance
- Policing: crowd monitoring, missing people, crime
- Medical transport

The West Midlands is poised to utilise urban drone operations to boost regional economic growth in three ways: application-based economic growth, broader industry involvement and testbed opportunities.

Application-based economic growth

Continue to work as an enabler in the region, through creating an environment which encourages the uptake of drones to perform specific services which could add value to the West Midlands

Pursuing ways to enable the wider adoption of drones for infrastructure and development would support the West Midlands in its ambition to bring forward new land for housing, jobs and economic development. Some commercial companies already use drones within these sectors, from monitoring rail lines to surveying construction sites, and demand for these applications is growing. Within an urban environment, drones can be used to enable more effective and sustainable construction, bringing efficiency to processes and providing a greater level of real-time high-accuracy data on which to make decisions. Therefore unlocking more urban sites for the use of this technology could therefore have a tangible impact on the shape of the West Midlands.

Transport and logistics is another major sector in which drones could deliver economic benefit in the region at pace. Creating conditions which enable the integration of drones into freight and logistics operations could work to boost regional productivity, as

warehouses become more efficient and products manufactured in the West Midlands are brought to market more quickly. Meanwhile, within a future transport system, drones could respond to traffic incidents, intelligently manage congestion, or even inform cars about road conditions. Other, perhaps more contentious, possibilities for drone use include transporting people and delivering goods. Whilst it remains to be seen if these ideas will become practical from a technological and economic standpoint in the region, they demonstrate the potential for drones to reimagine our networks.

Other applications could benefit the region's communities more directly, such as the potential 'blue light' uses for drones within the emergency services. For instance, in their ongoing trial of the technology, West Midlands Police have deployed drones to prevent automobile theft and quickly locate missing people, as well as working alongside West Midlands Fire Service to provide an eye in the sky for localised flooding events. These 'drones for good' uses can both complement existing services and save public money, and are typically well supported by the public and elected representatives.

Broader industry development

Strategically intervene to support existing and emerging industries related to drone technology to flourish in the West Midlands, and beyond

The West Midlands has fostered a rich culture of innovation built upon growth industries and inter-sector collaboration. Through identifying and taking advantage of opportunities to test new technologies, the region can foster the necessary collaborations among industry players to deliver drone trials, projects and services. Much of this work will be focusing on creating the opportunities for existing and emerging industries to take off within the West Midlands. Initial steps towards this have been taken within the stakeholder engagement conducted by WMCA as part of the Flying High project.

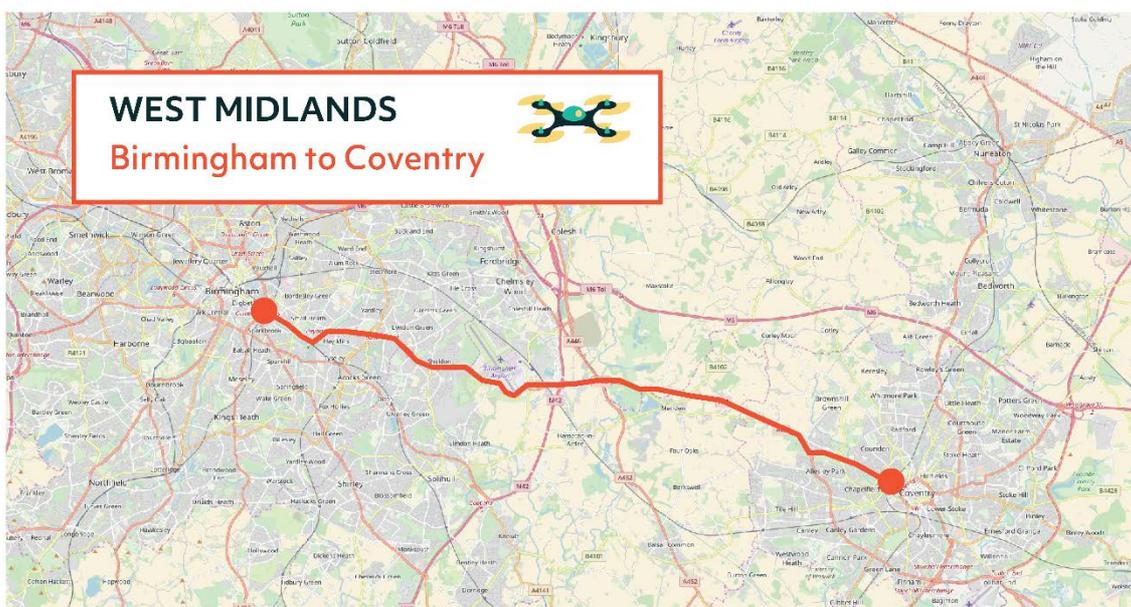
However, a much broader supporting ecosystem is needed to enable the drone industry to mature, and the West Midlands' young population and diverse economy - the region has the highest proportion of people aged 24 and under in England⁴² - offers scope to support its development. To explain, the drone ecosystem expands beyond the aviation sector to include experts in data security, communications and digital media. Regional policies, such as planned investment into skills or initiatives to retain local talent, can ensure the sustainable development of the drone sector. Public and political support for drones is another vital aspect of the ecosystem, and perhaps more challenging to secure.

⁴² <https://www.wmca.org.uk/media/1382/full-sep-document.pdf>

Demonstration and testbed opportunities

The West Midlands should leverage its position as a future testbed for mobility technologies to explore the potential for drones in UK cities

The opening of Midlands Future Mobility in 2020/21 will establish the West Midlands as a world-leading test environment for future technologies.⁴³ The multi-million pound government investment, matched by private sector funding, will deliver a testbed for CAVs across more than 50 kilometres of open public roads. The route spans the strategic A45 route which connects Coventry and Birmingham cities, passing Birmingham International Airport at Solihull. It will reach into city centre routes and, going forward, may take advantage of the high speed routes or M40 / M42 smart motorway junction which were covered by the UK CITE connected vehicle project. The diversity of the test environments roads will be matched in its versatile offer for trialling technologies. Although designed with CAVs in mind, Midlands Future Mobility looks to explore the wider transport ecosystem, including road side units, communications infrastructure and, potentially, drones.



The A45 route between Birmingham and Coventry. Credit: ©OpenStreetMap contributors

Midlands Future Mobility will provide the best-of-both in offering a controlled yet real-world test environment for disruptive technologies.⁴⁴ The facility will be able to bridge the gap between simulation and service deployment, granting autonomous technologies the scope in which to build their safety cases. For drones, this could enable multiple proof-of-concept trials to be conducted in closer proximity to highways than would otherwise be permitted.

43 https://warwick.ac.uk/newsandevents/pressreleases/midlands_roads_to/

44 <https://meridianmobility.tech/>

The strong 4G coverage across Midlands Future Mobility, as well as the potential for 5G capability in selected areas, will further guarantee the low latency communications needed for drone technology to securely advance. This is particularly noteworthy as the testbed's strategic route also aligns with the area researched for the Flying High study of the traffic incident response use case. Finally, as a future melting pot for advanced manufacturers, communications specialists and enterprise, Midlands Future Mobility could offer drone systems a nurturing, as well as technologically-equipped, space in which to develop.⁴⁵

Recommended next steps for the West Midlands

Be proactive, explore opportunities for collaboration and have a meaningful conversation with the public

Over the coming year, the coalition of partners coordinated by the WMCA to address the future of drones in the region should explore opportunities in these three areas:

- **Enable new initiatives which have the potential to contribute to regional ambitions.** Although the future of national drone policy and regulation remains ambiguous, it is clear that the region stands to benefit from a proactive approach to drones. Referring to core regional policies as a framework to shape future drone activity will help realise the necessary balance between enabling innovation and ensuring added benefit.
- **Explore opportunities for collaboration among commercial, public sector and academic partners.** Expertise in drone technology sits with commercial and academic partners, and it is probable that many urban drone operations will not be owned or run by local authorities. This means that early cross-sector engagement and collaboration will be vital to securing stakeholder buy-in to a community-first regional policy. Such partnership is also essential in unlocking investment opportunities.
- **Seek to better assess the public viewpoint.** Ensuring public and political engagement will be a priority going forward. Meaningful, two-way conversations are needed, in which policy makers solicit the views of their communities and work to develop a shared, accurate understanding of what drones mean to the West Midlands.

⁴⁵ <https://www.cwlep.com/news/midlands-future-mobility-driving-seat-connected-and-autonomous-vehicles>

Shaping drone use in Southampton

Why we are talking about the future of drones in Southampton

Southampton is a leader in aerospace and a coastal transport hub

A city with a population of a quarter of a million residents, Southampton anchors the larger coastal region including Portsmouth and the Isle of Wight.⁴⁶ The Southampton economy alone represents a GVA of £6.15 billion,⁴⁷ with the wider Solent economy valued at £27.8 billion GVA.⁴⁸ Southampton's economy relies on strong clusters in maritime, aerospace and business and financial services.⁴⁹ Its geographic position offers strategic importance as a gateway economy, providing connectivity for the UK to global markets.

Southampton is the UK's south coastal travel hub; nearly two million passengers passed through the airport in 2016,⁵⁰ while the Port of Southampton received the largest number of passenger vessels in the UK in 2016,⁵¹ is the UK's second-largest container terminal and is one of the top exporting ports for vehicles.^{52,53} The port handles 14 million tonnes of cargo each year, supports 15,000 jobs and contributes around £1 billion to the UK economy.⁵⁴

Southampton aims to position itself as an important hub of the UK drone industry

The Hampshire aerospace cluster is key for the local economy

In the coming decades, drone technology could play an important part in transport systems in Southampton and an even bigger role in the growth of Southampton's economy. With the support of a coalition built by the Southampton City Council, the University of Southampton and other academic, public sector and industry partners, Southampton is positioned to grow as an important hub in the UK drone industry.

46 <https://www.southampton.gov.uk/council-democracy/council-data/statistics/>

47 <https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/regionalgrossvalueaddedincomeapproach>

48 <https://solentlep.org.uk/the-solent/economic-outlook/>

49 https://solentlep.org.uk/media/1332/solent_strategic_economic_plan.pdf

50 <https://www.southamptonairport.com/about-us/facts-figures/>

51 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/646188/port-freight-statistics-2016-revised.pdf

52 http://www.abports.co.uk/Our_Locations/Southampton/More_About_Southampton/

53 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/646188/port-freight-statistics-2016-revised.pdf

54 http://www.abports.co.uk/Our_Locations/Southampton/More_About_Southampton/

Flying High: shaping the future of drones in UK cities

Southampton contributes to the larger Hampshire aerospace and defence cluster which supports over 18,000 jobs in the local economy.⁵⁵ In the Solent region, which includes Southampton, seven of the world's ten largest aerospace companies are based. Increased R&D investment in the drone sector and related enabling technologies could further grow this cluster and position Southampton as a primary hub of the UK drone industry.

Southampton seeks to increase the number of business start-ups, create more high-paying jobs, grow the technology sector and increase opportunities for STEM employment locally. By drawing on its existing industrial strengths and research institutions, the city intends to carve out a niche in the drone sector, create training opportunities, retain the skills and knowledge developed in the robotics, AI and aviation industries, and grow the regional economy, with a focus on the R&D opportunities around the knowledge, design and production of high-value parts.

The University of Southampton has over 500 staff across five departments conducting aerospace research.⁵⁶ It was the first university to offer a postgraduate course in the design of unmanned autonomous vehicles;⁵⁷ its unmanned aerial vehicles (UAV) research team has been involved in pioneering projects such as developing the first 3D printed UAV and the first low-cost maritime surveillance UAV.⁵⁸ The university is also the lead researcher behind CASCADE (Complex Autonomous aircraft Systems Configuration, Analysis and Design Exploratory),⁵⁹ a five-year project bringing together business, government and academic partners, funded by the Engineering and Physical Sciences Research Council. CASCADE launched this year to research and address current constraints on UAV operations.

Both the University of Southampton and the University of Portsmouth have close working links with top global aerospace companies including Airbus, Rolls-Royce, and Boeing. The University of Southampton is the sole UK partner to help operate the US National Centre of Excellence for Unmanned Aircraft Systems, which will work towards addressing challenges and opportunities in drone technology.⁶⁰

Southampton is also home to several testbeds for autonomous technologies. In 2017, the Solent Local Enterprise Partnership (LEP) and partner organisations invested £1.5 million in the design and development of the UK's first dedicated marine and maritime autonomy testbed.⁶¹ Its aim is to enable the testing, teaching and development of specialist autonomous systems such as unmanned boats, air vehicles and autonomous sensors in a safe, controlled, and realistic environment in the Solent. The ambition of the project is to attract further international investment, build innovation skills, support world class research

55 <http://www.investinhampshire.co.uk/eng/aerospace-defence>

56 <http://investinhampshire.co.uk/aerospace-and-defence>

57 https://www.southampton.ac.uk/engineering/postgraduate/taught_courses/uav/designing_your_career_in_unmanned_autonomous_vehicles.page

58 <https://www.sotonuav.uk/>

59 <http://gtr.ukri.org/projects?ref=EP%2FR009953%2F1>

60 <https://www.southampton.ac.uk/news/2015/06/04-assure-project.page>

61 <https://www.baesystems.com/en/article/bae-systems-awarded--457-000-to-launch-uk-s-first-maritime-autonomous-systems-testing-service>

on autonomy, and generate new jobs in the region as the Solent becomes a centre for maritime autonomy.⁶²

Southampton City Council is also exploring smart cities and the application of technology to reduce transport delays and promote a more efficient, better connected city. One of three long-term goals contained in the draft local transport plan is 'Successful Southampton,' which states, "New disruptive technologies have the potential to completely change how people travel," and that "drones and new innovations could help reduce the cost of maintaining and operating the road network and improve efficiency of busy traffic junctions."⁶³

Southampton should take the lead in airspace management

Southampton aims to become the first city in the UK to host a complex unmanned traffic management system to enable complex drone usage

Southampton is a hub of autonomous systems R&D, across land, air and sea. This includes one of the world's leading autonomous systems research groups at the University of Southampton,⁶⁴ the Marine Robotics Innovation Centre at the National Oceanography Centre⁶⁵ and a number of private sector companies based in the region. Southampton is also the location of the headquarters of NATS, the UK's main air navigation service provider. This local expertise makes the region well suited as a testbed for advancing unmanned and autonomous systems deployment. A key step in enabling this is the development of an unmanned traffic management (UTM) system. A UTM is generally conceived of as a system of systems or a set of interoperable, evolutionary services that enable high volume and complex autonomous operations. These systems can unlock applications of drones that can go beyond current restrictions relating to line of sight of the operator, autonomy and operations in congested areas or around airfields.

Basic UTM systems already exist for drones, generally in the form of flight logging and tracking systems, but this is limited, and a standardised, unified system across land, air and sea has not yet been tested in the real world. Southampton aims to be a national lead in trialling advanced UTM solutions in a complex urban environment, encompassing drones, autonomous maritime applications and connected and autonomous land vehicles. Southampton aspires to have the first mature UTM system in the UK operating across the wider region, including Southampton Airport, the Isle of Wight, Portsmouth and Bournemouth.

62 <https://solentlep.org.uk/media/1835/bae-marine-and-maritime-autonomy-test-bed.pdf>

63 <http://www.southampton.gov.uk/modernGov/ieListDocuments.aspx?CId=126&MId=3824&Ver=4>

64 <https://www.southampton.ac.uk/autonomous-systems/index.page>

65 <http://noc.ac.uk/business/marine-robotics-innovation-centre>

Local partners, including the University of Southampton and local drone industry leaders, envisage moving quickly to work with regulators and policymakers to pioneer a UK UTM system. Existing drone use experience at the port, the airport and in support of the Hampshire Constabulary provide the core competency platform upon which to build a case. A Southampton area UTM, under CAA approved management, would ensure safety and appropriate interfaces and seek to enable the roll-out of use cases that serve the collective public service ambitions as well as commercial activity.

What should guide drone policy development in Southampton?

Drones must add value and be introduced in a responsible way

A set of guiding principles, such as those recommended below, should be developed as a foundation for any future public decision-making or policy development governing drone use in Southampton.

Recommended principles to guide future drone development in Southampton

1. Focus on drone applications that add value, rather than duplicate services

Any policy or investment committed by Southampton around drone use should capitalise on the unique capabilities of drones to perform tasks that cannot otherwise be done as safely, efficiently or as cost-effectively. In particular, Southampton City Council, Hampshire Constabulary and other appropriate parties should collaborate to establish a joint understanding of the safety opportunities and public interest. Delivery, as an example, for last-mile distributions should be considered only if it is an effective alternative in terms of economic and societal benefit. In addition, Southampton will work to extend beneficial drone use within the confines of private commercial premises such as Associated British Ports dockside estate and Southampton Airport.

2. Protect the public realm

Drone support infrastructure should be designed in ways that complement high-quality urban design and planning principles. Southampton should assess the infrastructure opportunities and set parameters for where and how drones should fit in with the existing urban and suburban landscape, and where they should be prohibited. City planners should engage with the Southampton People's Panel to assess the public viewpoint and ensure any increased drone usage responds to the public's input.

3. Mitigate environmental impact

The port, airport and road network already bear environmental concern for Southampton residents. A 2014 survey of residents' views on air quality found that 36 percent felt that air

quality in the city was a “significant issue”, while only seven percent felt it was not an issue.⁶⁶ Future policy around drone use will need to ensure that drones do not exacerbate noise and air pollution concerns in the Southampton region. Flight routes need to be considered carefully to ensure that they do not impact negatively on residential areas. Technological innovations should prioritise extending battery life to minimise the risk of air pollution, as well as making more efficient and quieter propellers to minimise noise pollution.

4. Safeguard privacy and data

As the technology progresses, drone use will likely become more frequent and use cases will become more varied. Relevant policies and procedures must be established to protect the privacy and security of data. Operators should provide transparency as to what data drones are collecting, how the data is going to be processed and stored, who will have access to it and how it’s going to be used.

What could drones do in Southampton?

Drones are already in use by the Hampshire Constabulary to aid in emergencies, to monitor construction sites by companies such as Balfour Beatty, and by Southampton Airport for runway inspections and bird control. However, Southampton recognises there is an untapped opportunity to utilise drones to support public services more widely and create efficiencies in business operations.

Top priorities for drone applications in the region include:

Time-sensitive medical delivery

The city and the main medical institutions in the region seek to investigate the use of drones to transport urgent blood, plasma, medicines and other medical supplies, providing greater connectivity among Southampton General Hospital and others in the Solent regions and northwards towards Winchester. Preliminary analysis suggests there are both demand and evident cost savings from pursuing this course, as further detailed in the Flying High use case analysis.

Support the growth of the port

Southampton stakeholders see an opportunity in using drones to improve port operations in the near term by performing monitoring and inspecting tasks to assess infrastructure and manage traffic, monitor air and water quality, and provide security. More longer term aspirations include using drones to assist with piloting and mooring operations, support goods transport and provide vessel control. This represents a unique opportunity to both capitalise on drones’ specific attributes, and to link aerial robotics with connected and autonomous vehicle systems and autonomous maritime systems.

⁶⁶ <https://www.southampton.gov.uk/modernGov/documents/s31110/Appendix%201.pdf>

Traffic management

Congestion in Southampton has a detrimental impact on air quality, social mobility and the local economy. Southampton City Council expects a population increase of over 13 percent in the next 20 years, meaning traffic congestion will only worsen unless interventions are made. Drones offer a flexible and agile method of collecting data, and can also be used to track traffic flow real time responding to local conditions at the time. In the near term, drones can assist with monitoring conditions, collecting transport data to assist with real-time traffic management and longer term planning initiatives. In the future, drones could play a key role in an integrated traffic management system that encompasses aerial transport, connected and autonomous vehicles on the ground, autonomous freight systems and smart city infrastructure.

Emergency services

Drones can offer essential capabilities to create greater efficiencies in supporting emergency services, by using drones to monitor crowd dynamics, recover evidence, and deploy drones as initial eyes on the scene in advance of deploying emergency services for incident response. Drone technology may also be valuable in border and maritime security to augment and extend policing capabilities that might otherwise rely upon road vehicles or helicopters.

Solent connectivity

The Solent maritime geography presents particular connectivity problems. The city intends to explore how drone technology can provide services to locations such as the Isle of Wight (beyond the planned medical trials goal) and to the Fawley Waterside development in order to improve the level of connectedness of these locations with hubs in the region and to open up new services that will generate economic value for the region.

Demonstration and testbed opportunities

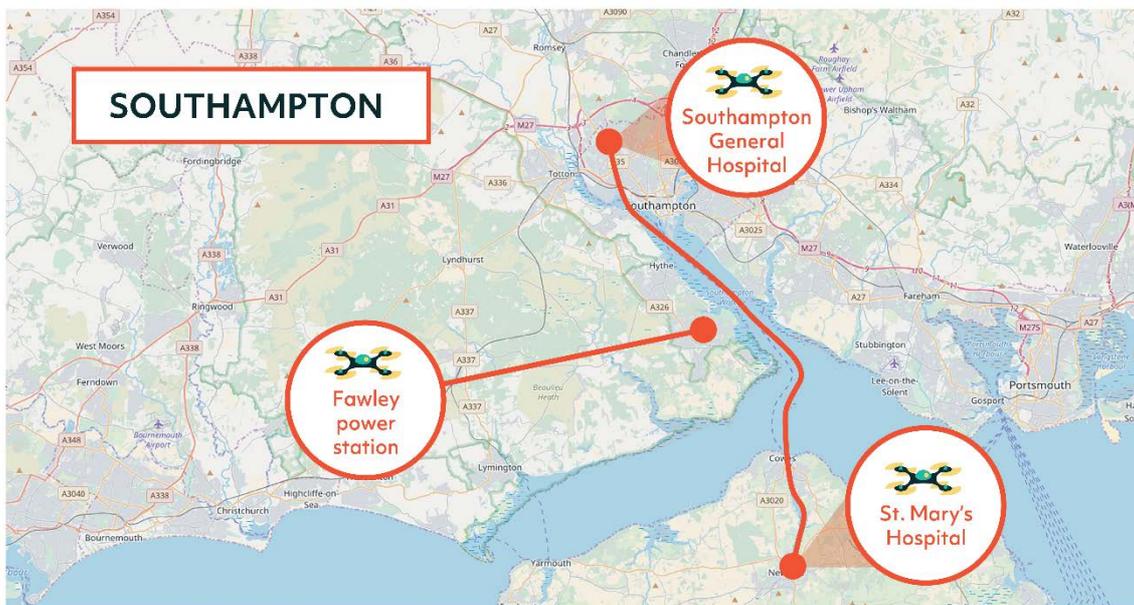
Where drone services could be tried out

The transportation of goods from Southampton to the Isle of Wight is currently made by scheduled ferry journeys. The use of drone technology to transport small, light goods frequently in emergency situations could offer an efficient and flexible alternative form of transport. Due to budget constraints, currently patients are transported to the mainland to receive non-urgent NHS services. Drone transportation could offer a cost-efficient courier service of medical supplies such as blood, medicine and medical equipment to these locations. The journey between the Isle of Wight and the mainland is challenging due to the transit over sea and withstanding varied weather conditions. With the future advancement of regulation and technology created to overcome these obstacles, the route could be used as a testbed to trial other forms of delivery (see the Flying High use case analysis for further details).

Beyond the applications envisaged under the Isle of Wight connectivity medical use case, there is potential to explore how drones can support rapid movement of goods within the

Flying High: shaping the future of drones in UK cities

Solent area. The Solent LEP has supported a BAE Systems-led autonomous systems test centre that serves both commercial and military uses and draws together a number of companies and academic institutions. Trials and tests could be conducted on systems such as air vehicles and autonomous sensors in a safe, controlled and realistic environment in the Solent. This is backed by a rigorous safety case analysis and access to secure communication systems and control centres. Additionally, the extensive research and development test and trials capabilities of the University of Southampton, the National Oceanographic Centre and of companies domiciled in the Solent area provide a viable environment in which to explore drone technology.



The route between Southampton and the Isle of Wight and the site of Fawley power station could be possible testbeds. Credit: ©OpenStreetMap contributors

Another ambitious project on the outskirts of Southampton aims to transform the site of the former Fawley power station - Hampshire's most extensive brownfield site - into Fawley Waterside, the first town-scale smart city in either Europe or America.⁶⁷ Bringing together a technical group representing private sector, education and public agencies the project will look to install new technologies to enable intelligent infrastructure to support communities and businesses. This could present an exciting and unique opportunity to share insights from the Flying High project and inform the design of a city where drones are integrated into day-to-day operations and management. Fawley Waterside could also become a demonstration site to test and assess different components of a drone system. Lessons learnt from developing Fawley Waterside could be shared with Southampton and other urban centres in the UK and adapted to the challenges of larger, highly populated environments.

⁶⁷ <https://www.southampton.ac.uk/wsi/news/2018/01/wsi-partners-fawley-waterside.page>

Recommended next steps

Drone development in the Southampton explore how drones can help the city and support the development of the local drone economy

Over the coming year, the coalition built by the Southampton City Council, the University of Southampton and other partners should identify and assemble resources to further investigate and address the opportunities outline in this vision, using the following set of near-term actions as a roadmap:

- **Define the parameters**, barriers and necessary interventions to lay the groundwork to develop a UTM system.
- **Investigate opportunities** to align with and inform national policies and regulations in line with local priorities regarding the smart cities agenda, including the role of drones.
- **Collaborate with public services** to identify how drones can support their services and provide greater efficiencies.
- **Evaluate the resources** needed to invest in the necessary drone support infrastructure, such as the communications systems or physical infrastructure.
- **Create a branding strategy** to position Southampton as a hub for drone research and development and to attract inward investment.
- **Support start-up businesses** interested in manufacturing, operating or using drones to develop commercial or public services and provide them with the relevant resources to scale-up (e.g. access to finance, skilled employees and infrastructure).
- **Extend dialogue with the public** via the Southampton People's Panel on the best way to roll out beneficial drone use.
- **Work with the Solent LEP** and the business community to grow the level of drone SME activity and to foster a vibrant industry community.
- **Build upon the research and skills capabilities** at the region's educational establishments to establish a 'go to' training, development and support network that can add to local economic activity and further build the Solent area's brand.

Shaping drone use in Preston

Why we are talking about drones in Preston

Lancashire is the heart of the UK's aerospace industry

Situated in the county of Lancashire in North West England, the City of Preston is home to over 141,000 residents.⁶⁸ The city's urban environment is surrounded by a mixture of landscapes - coastal plain, river valley and moorland. Preston is a regional transport hub and the location of the main campus of the University of Central Lancashire (UCLan). It is also in the middle of one of the most significant aerospace hubs in the UK. The city itself, however, has economic challenges that have accompanied deindustrialisation, the aftermath of the financial crisis of 2007 and large cuts to local government budgets. In response to this, the council has adopted an innovative approach to local economic development that focuses on retaining wealth locally and reducing inequality by fostering local supply chains and promoting cooperative models of ownership to deliver local services.

Preston and the wider region has strengths in aerospace and civic applications of drone technology

The city can use drones to build on its strengths

Central Lancashire is the home to the largest aerospace cluster in the UK and the fourth-largest in the world (after Seattle, Toulouse and Montreal),⁶⁹ with major multinational companies in the region including Airbus, BAE Systems, Magellan Aerospace and Rolls-Royce. This cluster contributes over £7 billion to the UK economy, employs over 12,700 people and accounts for one-quarter of UK aerospace production. The local industry includes a growing capability in unmanned aerial systems.

There is also considerable expertise in drones at the University of Central Lancashire (UCLan), which has facilities for developing and testing new drone technologies. In 2013 the Engineering Innovation Centre and Media Innovation Studio at the university set up the Civic Drone Centre⁷⁰ to explore and promote socially beneficial uses of drones, working with both SMEs and large firms locally and outside the region. The Civic Drone Centre has investigated the use of drones for search and rescue, journalism and media and

68 <https://www.nomisweb.co.uk/reports/lmp/la/1946157097/report.aspx#tabrespop>

69 <http://www.lancashirelep.co.uk/the-lancashire-offer/key-business-sectors/aerospace.aspx>

70 <http://civicdronecentre.org/>

humanitarian aid, as well as hosting drone hackathons and offering training to drone operators and contributing to drone policy globally.

In addition, the UCLan Engineering Department has looked at drones for supporting the local fire and rescue service and for toxic gas monitoring. It has also developed the world's first drone to incorporate a graphene-skinned wing.⁷¹ A new £32 million Engineering Innovation Centre facility in central Preston is due for completion in 2019,⁷² and will enable further expansion of the university's drone activities. With local industry knowledge and the research centre well established, drones could play a big part in Preston attracting start-up businesses and offering a wide range of high-skilled job opportunities to encourage students to remain in the city after graduation.

The city faces challenges around skills, jobs and disused properties

Drones could be part of the solution to these local problems

Despite the challenges of a post-industrial economy, Preston grew in population and in employment in the decades up to 2008,⁷³ but was hit hard by the global financial crisis where employment dropped significantly between 2008 and 2014⁷⁴ and there are still pockets of ingrained deprivation. An £800 million regeneration project for a new shopping centre collapsed in 2011, further increasing the number of vacant sites in need of redevelopment. Preston has relatively high employment,⁷⁵ performing above the North West and Great Britain averages, but relies on the public sector and business service industries. Preston's higher skilled workforce is slightly smaller than the North West and national average, so there is a need to diversify the workforce and ensure residents can access higher-paid and higher-skilled jobs. Preston is also a major transport hub for the region, but this has resulted in high levels of air pollution, presenting an environmental challenge. Emerging technologies, including drones, could help tackle some of these issues by increasing the efficiency of services and attracting inward investment and creating new high-skilled jobs.

The Preston model

Building community wealth

Responding to local challenges, in 2011 Preston City Council embarked on an innovative approach to economic development focusing on community wealth-building, which

71 <https://www.uclan.ac.uk/news/graphene-skinned-aircraft-farnborough-show.php>

72 <https://www.uclan.ac.uk/research/engage/eic/eic-project.php>

73 <http://www.lancashire.gov.uk/lancashire-insight/area-profiles/local-authority-profiles/preston-district/>

74 <http://www.lancashire.gov.uk/lancashire-insight/area-profiles/local-authority-profiles/preston-district/>

75 <https://www.nomisweb.co.uk/reports/lmp/la/1946157097/report.aspx#tabempunemp>

became known as the Preston model.⁷⁶ The Preston model aims to build local wealth by encouraging local procurement and the development of local value chains, so more money is spent and invested locally. This includes identifying gaps in the local value chain and supporting new businesses, particularly cooperatives, to fill these. Preston City Council has led this and partnered with a series of 'anchor institutions' (other public sector bodies and local organisations) to redirect procurement locally. Through this approach, the city council doubled its procurement spend on Preston-based companies from 14 percent in 2012-13 to 28 percent in 2014-15.⁷⁷ By 2016, an estimated £4 million had been directed back into the Preston economy.⁷⁸

The city is eager to explore how the use of drones can integrate into and enhance this community wealth building model. This could involve a community drone service, described below. It also implies a policy of procuring drone services locally. In the future, a drone delivery service could streamline local value chains, reducing delivery times and allowing for new operating models.

What should guide drone policy development in Preston?

Use drones to serve the public good

A set of guiding principles, such as those recommended below, should be developed as a foundation for any future public decision-making or policy development governing drone use in Preston.

Guiding principles for drone development in Preston

1. Foster opportunities to create and retain wealth locally, aligned with the Preston model

Preston intends to use its community wealth-building approach to explore new ways to bring together community and technology to create an economically vibrant future for Preston, by supporting innovation and service provision by local start-ups.

2. Reduce environmental impacts

As a transport hub for Lancashire, noise and air pollution is already a concern for the city centre. If regular drone usage becomes an everyday reality, it is important to consider noise and air standards and ensure that technology is developed to tackle this issue (e.g. renewable energy batteries for power instead of diesel and low noise drones). Preston, like

⁷⁶ <https://www.preston.gov.uk/thecouncil/the-preston-model/preston-model/>

⁷⁷ <https://www.theguardian.com/society/2017/feb/14/poverty-was-entrenched-in-preston-so-we-became-more-self-sufficient>

⁷⁸ <https://thenextsystem.org/the-preston-model>

any urban city, will also need to consider the times and locations at which drone operations can continue in urban residential areas.

3. Engage the public to shape drone use

The public has concerns about what drones will mean for personal privacy and security and should have a say in determining how they are used. Through public engagement efforts Preston should work with the community to understand the possibilities and implications of drone activities. Increased use of drones in Preston should adhere to standards around transparency and openness, governed by a clear code of conduct.

4. Consider the effects on public space

Drone use and associated infrastructure such as docking stations or charging points should be developed in a way that consider the public realm of city centres, respecting the integration of many modes of transport, liveability principles, principles of good urban design and historic preservation.

5. Support responsible public usage of drones

Preston would like to encourage the hobbyist drone community; however responsible use should be promoted and operators should be encouraged to use the Drone Code as guidance.

What could drones do in Preston?

Drones should improve Preston's environment, culture and housing

Through the Flying High project, Preston engaged a wide range of stakeholders to explore the most useful activities drones could perform for the city, in line with broader city goals. The below section describes those uses with the most resonance for Preston.

Aid in regeneration and housing development in the city

There is major regeneration work underway in Preston. There are 1,142 long-term empty properties in the city, particularly in the centre.⁷⁹ The Lancashire Core Strategy has outlined the need for 507 new homes to be built in Preston every year to 2026.⁸⁰ A £434 million of investment has been agreed as part of the Preston, South Ribble and Lancashire City Deal which is funding new construction and development projects.⁸¹ Drones can be usefully applied to support regeneration and construction in a number of ways, particularly through mapping and aerial surveying; the Flying High use case analysis offers further details on large scale activities such as the Preston Western Distributor road project that drones could support. Drones could identify areas for development, monitor the progress of construction projects and show the changing land use over time. They can also assist in the management

79 <https://www.preston.gov.uk/yourservices/planning/planning-policy/preston-local-plan/homes-for-all/>

80 <https://www.preston.gov.uk/yourservices/planning/planning-policy/preston-local-plan/homes-for-all/>

81 <http://www.lancashirelep.co.uk/city-deal.aspx>

of properties, including council assets, such as mapping energy use and identifying structural or other health and safety issues.

Innovative arts and culture offer a tool to promote the region

Preston aims to be a major cultural hub and destination in the North West and would like to explore new and creative ways to use digital technology in arts and media, including drones.⁸² Local cultural assets include the Media Innovation Studio at UCLan,⁸³ which has original and innovative projects around journalism, communication and digital technology, and is a partner in the Civic Drone Centre. The city is home to the Harris Museum and Art Gallery, which has a Makerspace that encourages new and innovative ways to showcase art, and the city has several outstanding live venues including the Preston Guild Hall and Charter Theatre. Drones could be used to create artworks, through aerial displays, being used as mobile projects or equipped with spray paint to create digitally-designed murals. Aerial platforms could help capture video and photography of arts events, enabling new views of art installations. Innovative uses of drones could help promote the region and be integrated directly with tourism services.

Support local sustainability and environmental goals

Improving sustainability and contributing to the battle against climate change is an important part of Preston's future vision, as outlined in the Preston Local Plan.⁸⁴ Drones fitted with thermal cameras can be used to understand the energy efficiency and insulation of particular buildings, identifying areas that are using more energy than needed. The Civic Drone Centre is already looking at how drones can be used to monitor for harmful and toxic gases, and this is something that could be useful for environmental protection. Drones could integrate into a raft of environmental measures, including river sampling and identifying illegal dumping.

Preston's community drone service to support communities and local businesses

In line with the localist and inclusive principles that underlie the Preston Model, the city could pioneer alternative and community-minded business models for drone use. The city is interested in a Preston-wide community drone service, whereby drones would be available for use by the community where there is a public benefit. This could be run by the Civic Drone Centre or a new organisation, which could be a cooperative or not-for-profit charity. Public sector services could benefit from being an end user of this service as and when required for instance when police or fire services monitor events or emergency situations or the local authority survey a construction site for health and safety assessment.

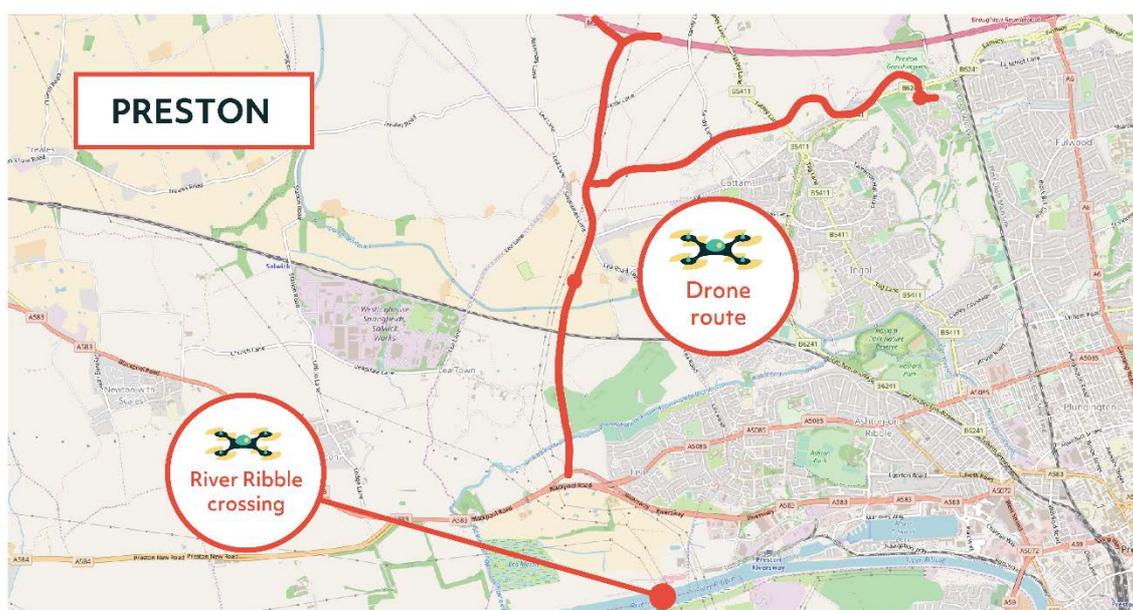
82 <https://www.preston.gov.uk/your-services/events/culture/>

83 <http://mediainnovationstudio.org/>

84 <https://www.preston.gov.uk/your-services/planning/planning-policy/preston-local-plan/preston-local-plan/>

Demonstration and testbed opportunities

Based on Preston's larger civic goals and the viability of the prioritised drone activities, Preston could explore developing demonstration and testbed facilities for drone technology around the Preston Western Distributor and development of a new crossing over the River Ribble, which has been proposed to improve links between Preston and South Ribble.



The Preston Western Distributor and new Ribble crossing: two possible sites. Credit: ©OpenStreetMap contributors

First, plans have been approved for a major new road - the Preston Western Distributor - linking Preston and southern Fylde to the M55 motorway. The Preston Western Distributor and associated link roads will support planned housing in North West Preston, improve access to the new enterprise zone in Warton, and provide an option to avoid peak hour congestion in the city centre. Second, Lancashire County Council is seeking funding to create a new crossing over the River Ribble to allow direct access to the western side of the city from Penwortham.⁸⁵ In keeping with Preston's goals around developing drone services to support city development efforts, potential trials of drone usage around these sites could be further explored.

⁸⁵ <http://www.blogpreston.co.uk/category/locations/penwortham-preston/>

Recommended next steps for Preston

Over the coming year, Preston should identify and assemble resources to further investigate and address the opportunities highlighted in this vision, using the following outline of near-term actions as a roadmap:

- **Preston's Flying High task force should continue to work together** to further explore public engagement opportunities to better assess the public viewpoint on drone usage, such as developing a programme to identify drone outreach and education events.
- **The task force should collaborate with the North West Aerospace Alliance** and the Lancashire Enterprise Partnership to create a coordinated strategy to strengthen the regional drone industry.
- In line with Preston's community wealth-building ethos, Preston should **assess the feasibility of bringing industry and local government services together** to develop a pilot community drone service.
- Preston City Council and Lancashire County Council have **an opportunity to work together with other partners to consider a smart cities strategy for the city** which should incorporate the region's goals with drone usage and the supporting ecosystem.
- UCLan's **Civic Drone Centre is well-situated to lead** further research and development into the use cases of how to deploy drones locally for a range of public benefit services.

Shaping drone use in Bradford

Why we are talking about the future of drones in Bradford

Bradford has pressing needs that drones can help fulfil

Bradford Metropolitan District is the fourth largest of its kind in the UK, and encompasses a range of landscapes that include dense urban areas as well as forest, farmland and moorland. It is home to a diverse population of over 500,000 people with roots all over the world.⁸⁶ Bradford was one of the hubs of the Industrial Revolution, and has an accompanying history of innovation and manufacturing. The legacy of this time is over 2,000 listed buildings and a UNESCO World Heritage Site in Saltaire.

Today the district faces a range of challenges and opportunities. Bradford is the youngest city in the UK, but is below the national average in terms of skills, employment and wages, an economic challenge resulting from the transition to a post-industrial economy.⁸⁷ A key goal for the city, as outlined in the District Plan 2016-2020⁸⁸, is to attract high-skilled jobs and inward investment and to improve educational attainment and job opportunities. The region is also growing in population, leading to an increased demand for good quality and affordable housing. At the same time, the district has a number of historic buildings lying empty in need of investment and redevelopment. The growing population, accompanied by demographic changes, has meant increased demand for social services, including health and social care. Improving health outcomes is thus an important priority for the region. This is occurring against a backdrop of financial constraints across all public services, requiring innovative approaches across the public sector.

A growing focus on the digital sector

Drones can align with the district's digital strategy

Bradford Council is about to launch a digital strategy, which sets out the use of digital technology for smart city management, economic growth and connected communities. It also discusses the need for building digital skills in the local workforce, convening different stakeholders and infrastructure development using digital technology. Drones can be a part of all of these objectives. Bradford has local digital sector strengths that can support the use of drones, including three internet of things (IoT) networks and a digital health enterprise zone. Further, the district aims to position itself as a testbed for emerging technologies, and Bradford Council and the University of Bradford are participating in the experimental

⁸⁶ <https://www.bradford.gov.uk/open-data/our-datasets/population/>

⁸⁷ <https://www.bradford.gov.uk/media/2312/bradford-district-plan-final.pdf>

⁸⁸ <https://www.bradford.gov.uk/media/2312/bradford-district-plan-final.pdf>

European Commission-funded Smart City and Open Data Re-use (SCORE)⁸⁹ programme. The development of testbeds for emerging technology can provide learnings for the local authority and enhance its growing reputation as a centre for innovation that can attract inwards investment and high skilled jobs.

There are a number of commercial drone operators locally. Yorkshire Water have a dedicated UAV team,⁹⁰ and drone trials have already begun within the local West Yorkshire Police⁹¹ and West Yorkshire Fire and Rescue Service,⁹² creating a growing foundation of expertise. Bradford also has a strong, globally networked drone hobbyist community. The region is highly connected with neighbouring Leeds, where the University of Leeds has advanced specialism in robotics, and hosts the Self Repairing Cities project that includes the use of autonomous drones for diagnosis and repair of city infrastructure.⁹³ Bradford is also a founding member of the Leeds-based Open Data Institute, an organisation set up to promote innovation at the city level based on the use of open data.

There is evidence of popular support for some uses of drones in the district. In a survey with Bradford Council's people's panel, 84 percent of respondents believed that drones would carry out a variety of important functions in the future and 63 percent supported Bradford being a testbed for drone applications (27 percent opposed and 10 percent undecided).

Drones can develop skills, support city development and improve the efficiency of public services

A vehicle for better skills and jobs, particularly through promoting STEM education, and attracting high-tech companies and inward investment

By pioneering drone applications through early adoption and testbeds, Bradford can attract more high-tech businesses to the region and create more high-skilled jobs. In addition to attracting high-skilled workers from outside, drones could inspire young people to pursue STEM subjects and improve skills in the district. This could be through a bespoke programme or one-off events in schools or community institutions such as the National Science and Media Museum.

89 <http://northsearegion.eu/score/>

90 <https://www.yorkshirewater.com/drones>

91 https://www.westyorkshire.police.uk/sites/default/files/files/disclosure-logs/foi_4395-16_wyp_uavs.pdf

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

93 <http://selfrepairingcities.com/>

Drones as a data source

Drone data could integrate with other digital technology (3D modelling, IoT, GIS, VR/AR, AI), to support initiatives within planning, surveying, regeneration and smart cities

As cities get smarter, drones can be used to provide better information to government, the blue light services, businesses and individuals. Combined with an array of sensors, drones can capture valuable data that would be prohibitively expensive or impossible to capture by other means. Bradford is interested in how this can contribute to understanding of the city, in both the near and long term, tying in with local digital initiatives such as SCORE⁹⁴ and Things Network Leeds-Bradford.⁹⁵

Drone data is even more valuable when combined with other digital technologies. For example drones can capture photos to be processed into 3D digital models that can then be used to support planning or even dynamically manage the city by feeding in sensor and IoT data, such as the five IoT sensors that have been installed to detect flooding in Bradford Beck.⁹⁶ Artificial intelligence tools such as machine learning can be applied to drone data, and the University of Bradford is currently investigating how this could be used to identify features in 3D models captured by drones. This could be applied to identify particular features of the city and changes over time, automatically assessing deterioration of infrastructure, progress in construction or long-term changes such as the impact of climate change on wildlife. Drones can also integrate with virtual reality to create fly throughs and interactive videos, which could provide a strong advert to developers for Bradford's many historic buildings, a lot of which are currently under-utilised.

Increased efficiency of public services

Drones could streamline crucial services such as surveying and inspection

Drones could streamline and reduce the cost of public services in Bradford. This could be through faster response to emergency incidents, more effective community safety and increased efficiency of local authority surveying and inspections. In the future these types of services are envisioned as being fully automated, saving time and money and removing people from physically demanding and dangerous work. Future uses could extend beyond data capture and include transporting time-critical goods such as medical or emergency supplies, linking hospitals in different parts of the city, or even to automating interventions such as repairs to urban infrastructure.

94 <http://northsearegion.eu/score/>

95 <https://www.thethingsnetwork.org/community/leeds-bradford/>

96 <https://flood.network/news/2017/2/22/city-of-bradford-joins-flood-network>

What should guide drone policy development in Bradford?

Public consent is key

Drones must only be rolled out with public consent - and consent is contingent on protecting the public. Future public decision-making or policy development governing drone use in Bradford should take these principles into account.

Recommended principles to guide future drone development in Bradford

1. Inclusivity

A core pillar of Bradford's digital strategy is that digital technology should be used to help tackle inequality and not exacerbate it. This includes making digital technologies widely accessible and facilitating open and free at point of delivery digital services. Some drone applications, particularly logistics and passenger transport, could widen inequalities, for example by being premium services that are only accessible to those who can afford them, or by replacing jobs (e.g. couriers). Bradford stakeholders believe the benefits of drone technology should be widely shared and that inclusivity should be a key factor in future drone integration policy.

2. Maintaining privacy and civil liberties

Clear guidance around privacy and drone use will be paramount. It should be easy to find out what type of information drones are collecting, and operators should follow GDPR guidelines. Citizens need to know how their data is going to be used, where it's going to be stored and for how long. Drones should only collect data that is relevant for their operation and if possible use privacy-by-design features so that inappropriate data cannot physically be collected.

3. Justification for use of drones

Bradford seeks to see a clear public benefit to justify the use of drones if they are to be deployed in the district at any significant scale. The social and economic impact of using drones for new and disruptive tasks should be understood, and it should be clear why a drone is the most effective solution as opposed to another approach, considering the benefits and disbenefits. This impact evaluation should consider time and cost savings, health and safety benefits, effect on jobs, and impact on the environment and local quality of life. Testbeds and trials would be one method to help understand some of this potential impact. Once a clear argument for novel or public-service use of drones has been established, it should be communicated effectively to the local community.

4. Public engagement

Bradford believes there should be a mechanism to inform citizens about drone use in the region and to enable the public to input into policy decisions around drone use. This should include relevant communication channels, clear information provided and mechanisms for people to provide feedback. This includes any drone operations conducted by or on behalf of the local authority as well as any drone trials in the district.

What could drones do in Bradford?

Priority Uses for Drones

Based on local stakeholders' review of Bradford's challenges, the activities that drones could perform, and the principles that should guide their usage, the following activities represent the greatest opportunities for Bradford:

Supporting the emergency services with incident response and prevention

In a recent survey conducted with Bradford Council's people's panel, 98 percent of respondents supported the use of drones by the fire and rescue service and 93 percent supported use by the police. Emergency services are also the most trusted to use drones responsibly (98 percent survey respondents trusted the fire and rescue service to use drones and 89 percent trusted the police). There is a clear public benefit that drones could provide in emergency scenarios. In risk prevention, drones can be used to capture data to understand the likelihood of, and plan a response to, disasters such as fires and floods. Drones could also be used in response to an incident to assess the situation in real time, understand dangers and locate missing persons (refer to the Flying High use case analysis of drones supporting the fire and rescue service for further detail). They could also be used in post-disaster management, helping to evaluate the extent of damage and provide intelligence to support reconstruction efforts. It is important, however, that civil liberties are protected and that drones do not become an invasion of citizens' privacy.

Improved city planning and management through surveying and mapping

Aerial imagery can be a very useful tool for understanding what is going on in a city, in both short and long term. Drone photography can support the council with planning decisions, either in the form of simple photography or 2D maps or more sophisticated methods such as 3D models that are updated in real time with sensor data in the district.

Streamlining government services to reduce costs of surveying, inspection and city maintenance

One of the council's functions is to manage and maintain local infrastructure, which involves a great deal of inspection work of assets such as roads, bridges, and sewers. Drones can provide a fast, safe and low-cost alternative to traditional means of inspection. Increasingly sophisticated data analytics can support this; for example, drones can automatically

identify the condition of infrastructure and assess structural integrity. One specific opportunity for this in Bradford is the mapping of the district's culverts and drains, which is difficult to carry out by traditional means. Looking further to the future, drones could be used to automatically detect and even repair damage to infrastructure, as is being investigated by the Self-Repairing Cities project at the University of Leeds.

City regeneration, such as supporting construction projects as well as using drones to film and advertise the city to tourists, companies and investors

Drones can be used to promote the Bradford district and support regeneration projects and planning. This could be directly through increasing the efficiency of construction, an area where drones are already being used but where there is scope for further adoption and new opportunities will arise as the technology evolves. Indirectly drones can be used to advertise the district. This could be through capturing aerial photography showcasing the district's attractions and landscape to visitors, or developing VR walk throughs and 360 degree videos so potential developers or residents can explore the district and its historic buildings.

Improving health outcomes through drones supporting medical logistics and response to medical emergencies

Bradford has six hospitals in the Bradford Teaching Hospitals NHS Foundation Trust. Many of these hospitals are some distance from each other and have complex logistics networks between each other and with other sites. Many shipments, such as pathology samples, are time critical. Drones for medical logistics could provide a substantial public health benefit as well as time and cost savings to the NHS, something Bradford views as a potential future opportunity to explore.

Demonstration and testbed sites

Bradford has identified concrete opportunities to trial and demonstrate drones in the district

360 degree video and VR tour of regeneration sites

Bradford has a large number of vacant properties that are lying empty and in need of development, many of which are historic listed buildings. Drones can support regeneration of these properties through capturing the inside and outside of these buildings. This imagery can be used to create 360 degree videos and virtual reality tours of the sites, showcasing the potential to developers and the public.

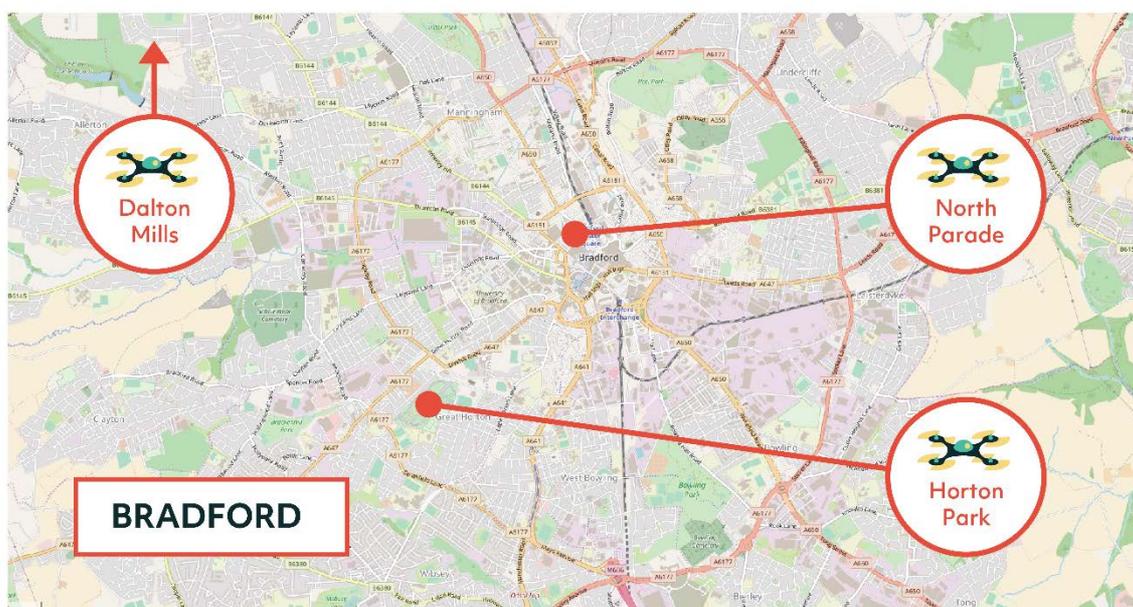
This could be trialled in several locations. Two examples are Dalton Mills and North Parade. Dalton Mills was built in 1869 and was once the largest textile mill in the region. It has been partially restored with significant work needed to bring the rest of the building back to life. Many heritage mill buildings in the district have been lost to fire, with drones providing an opportunity to encourage regeneration.

The area around North Parade in the city centre, known locally as the 'top of town', has a cluster of empty historic listed buildings that are ripe for redevelopment and would benefit from the more detailed digital showcasing that drones could offer.

Creating 3D maps for planning and smart-city applications

Drones can be used to create an interactive digital 3D model of the district, or part of it, where other datasets can be overlaid, including real-time data from IoT sensors. The model can then be used to see changes to the city as they happen, helping to get a better understanding of the city. This can be used to understand real-time trends such as air quality or flood water levels, or medium-term trends such as changes to the built environment. Updating the model periodically with aerial drone footage can help to understand much longer term changes, such as the impact of climate change or the spatial and landscape effects of particular investment or policy decisions.

One potential trial location for this application is Horton Park. A drone could capture imagery that could be processed into a photorealistic 3D model. IoT sensors to detect flood levels, air quality and other environmental factors could then be installed to give the local authority, and the community an understanding of the local environment and be able to observe both real-time and long term environmental changes.



The location of three possible sites in Bradford. Credit: ©OpenStreetMap contributors

Recommended next steps for Bradford

Over the coming year, Bradford should identify and assemble resources to further investigate and address the opportunities outlined in this vision, using the following near-term actions as a roadmap:

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- **Identify and consider allocating funding** for trials of drone services within the local authority of near term applications such as inspection, mapping and VR tours.
- **Engage the public around drone use**, disseminating examples of current use and supporting engagement around emerging uses by the police and fire and rescue service.
- **Create an online platform to publicise drone work** occurring in Bradford and benefits and learnings.
- **Promote current drone legislation**, including the drone code, to encourage safe use of drones.
- **Incorporate drone technology into future smart city and digital strategy work**, using drones as a data source and considering drone requirements for future digital infrastructure such as 5G.
- **Identify locations** for experimental drone applications.
- **Identify industry and research partners** that may be interested in working with the region to trial new drone applications that push the boundaries of what is currently possible.
- **Continue to follow drone industry and regulatory developments** and input to national policy debates around the future management of urban airspace.

Five use cases for drones in UK cities

We explore the feasibility of drone applications in cities through detailed case studies

In consultation with the five Flying High project cities, we selected five use cases for drones in order to further explore their feasibility. All use cases are closely related to each cities' visions for future drone use. We have aimed to explore a range of different use cases, each of which highlight different feasible applications for drones.

The five use cases are:

- Medical delivery in London.
- Traffic incident response in the West Midlands.
- Southampton-Isle of Wight medical delivery.
- Construction and regeneration in Preston.
- Supporting the fire and rescue service in Bradford.

These five operate in different sectors and relate to different geographical locations. Some are on fixed routes in dense urban cores, others free-flowing across an urban area, others go beyond the city and over extra-urban land or sea. They have different implications for technology, ranging from small multi-rotor drones to larger fixed-wing drones. They have different levels of requirements from infrastructure and regulation.

The different use cases we explore also vary in how close they are to being realised; in some, more ambition is applied to current uses of drones; others represent a totally new service.

General and specific

We explore the general implications of each use case, then dig deeper into a specific example of it

Our analysis is based on a combination of research and discussions with city and technical stakeholders to define the mission of these use cases. Wherever possible our analysis is based on real data or published documents. However, as with any attempt to specify a completely new service, we had to make a number of assumptions. These have been developed by the Flying High project's technical and economic teams in consultation with relevant stakeholders.

In each case we looked at the broad description and benefits of the use case, then dug deeper into a specific example of it. For instance, a pair of hospitals to connect, or a particular construction site to monitor.

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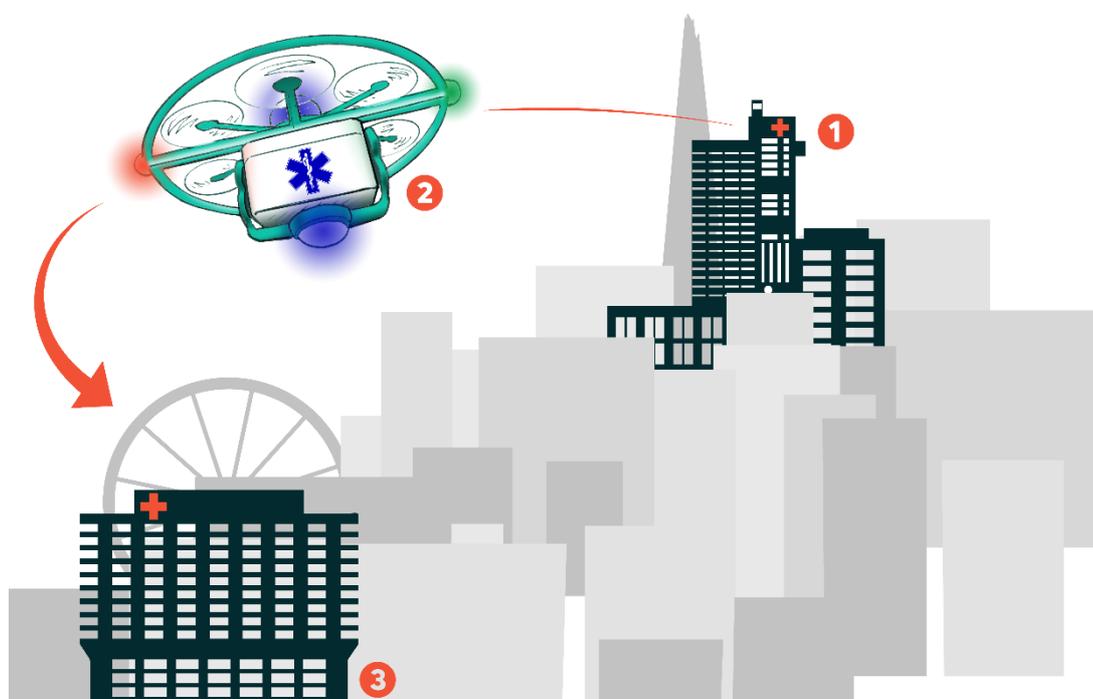
We used these specific examples to explore the feasibility of the use case, looking at what the key technical features of the drone were and what the requirements of each were. We then modelled their economic viability.

Medical delivery in London

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

- 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 of a small-scale service would be challenging but could be compelling at larger scale

This use case focuses on a drone delivery network for carrying urgent medical products between NHS facilities, which would routinely carry products such as pathology samples, blood products and equipment over relatively short distances between hospitals in a network.



A (1) drone takes off from one hospital, (2) carries medical deliveries over a short route of up to a few miles, and (3) drops them off at another hospital.

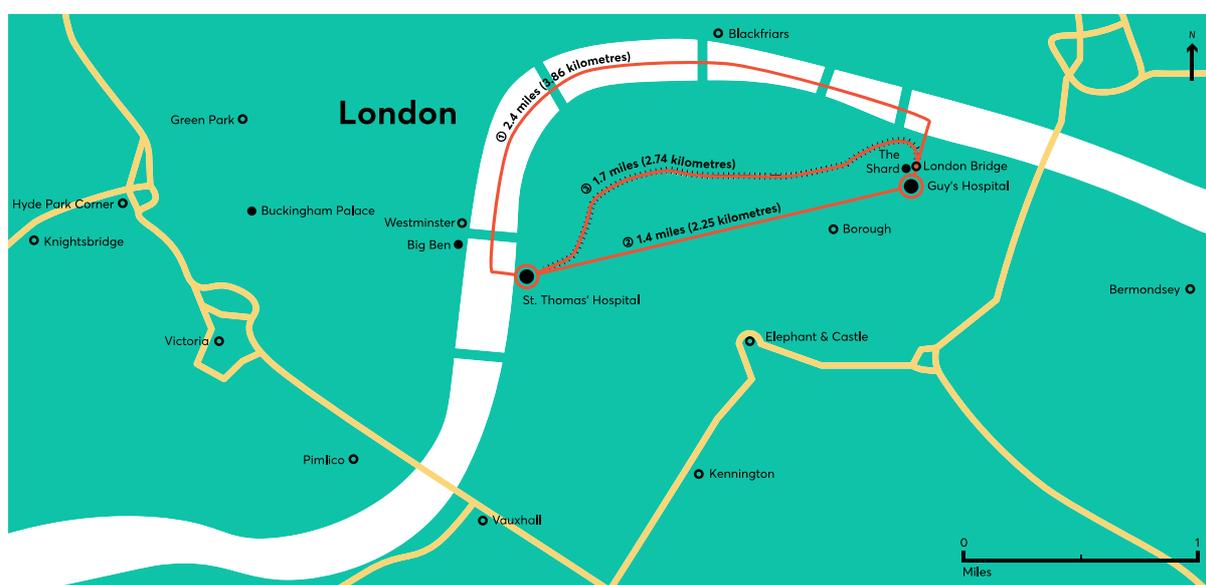
London has 34 hospitals in relatively close proximity. Deliveries between hospitals are frequent, and in many cases, time sensitive, but traffic and the lack of major roads restricts this.

The key benefits to drone medical deliveries in London would be:

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- Saving time by flying over the congested streets.
- Saving money (if the service operates at large scale).
- Making medical logistics more efficient by enabling deliveries which are not currently feasible.
- Providing quicker test results to patients.
- Reducing traffic on London's roads.

In order to better understand the feasibility of this use case, we have focused specifically on one possible connection in this network: the movement of pathology samples for post-kidney transplant monitoring between Guy's and St Thomas' hospitals in South London. This aligns with NHS plans to consolidate pathology testing into networks of multiple hospitals.



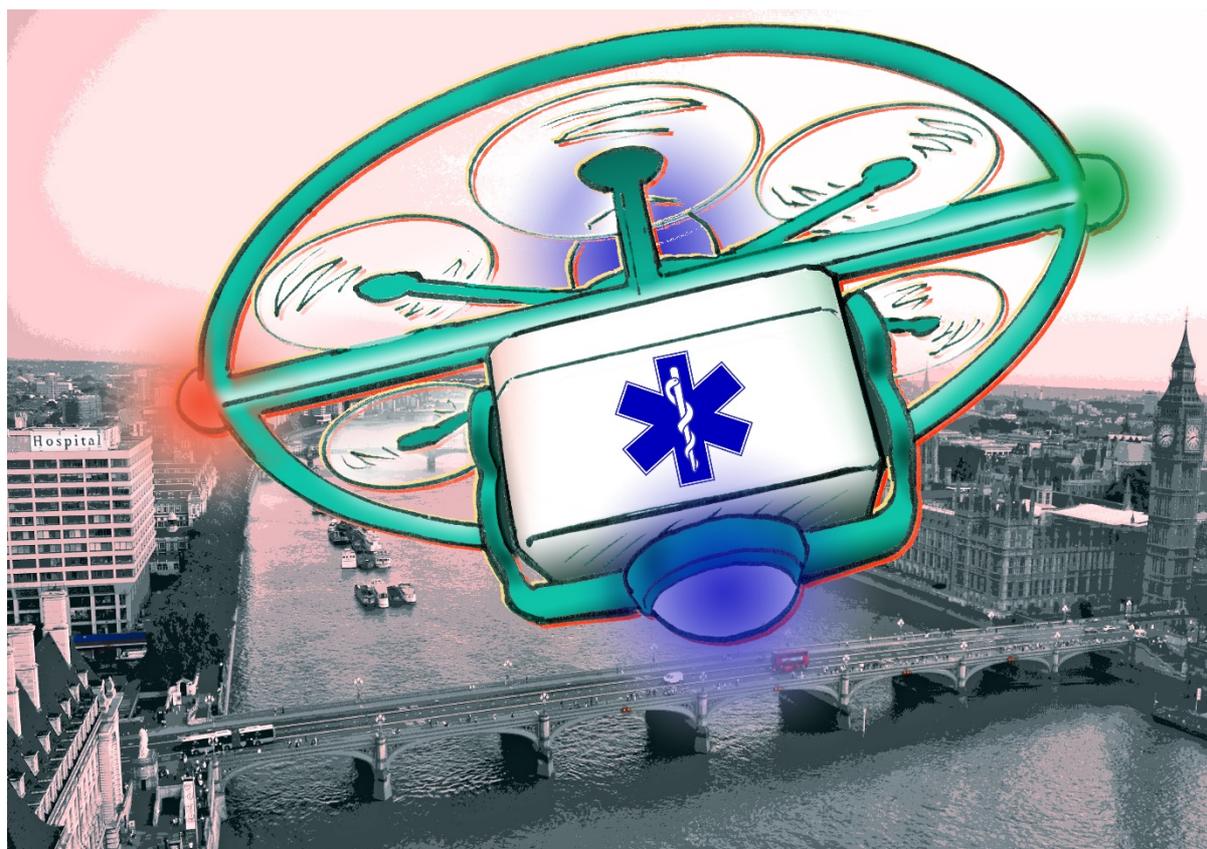
Possible flight routes between Guy's and St Thomas' hospitals

There are some technical challenges that need to be solved, owing to the complex environment. Safe operation in a heavily built-up area with complex and restricted airspace would require extensive testing. It would also require more sophisticated communications systems than are presently in place, along with ways of better managing shared airspace, in particular helicopters which operate along the Thames.

To be feasible, regulations around operation in built-up areas, under heli-routes and over the Thames would need to either be relaxed, or a specific exemption for these operations would need to be granted.

The drone connection between Guy's and St Thomas' should be seen as a pilot or proof of concept. The economic benefits of this use case would only manifest themselves as part of a broader network carrying a wide range of medical deliveries in a broader network of hospitals.

However there are no insurmountable barriers to this use case being feasible.



Artist's impression of a medical delivery drone at St Thomas' hospital. Credit: ILYA (Background image by Tom Arthur, CC-BY-SA)

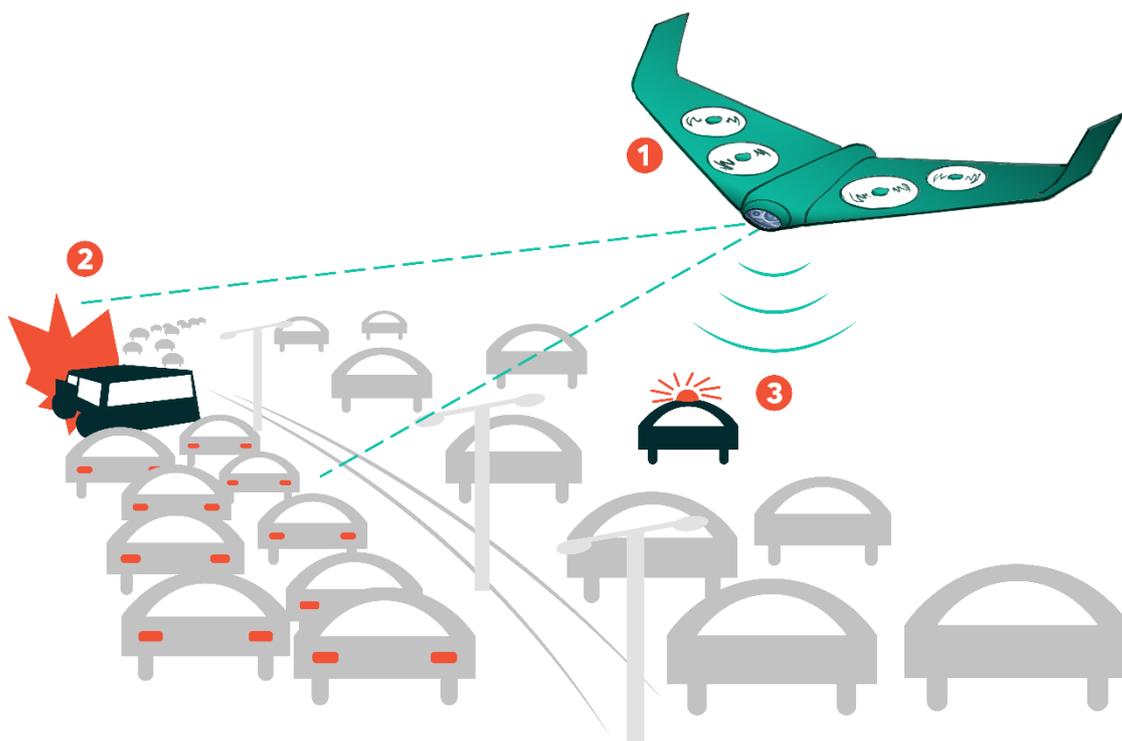
This is a summary of the full technical and economic analysis paper, which can be read in the appendices.

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 get 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

This use case is focused on responding to traffic incidents in the West Midlands, to support the emergency services.



The drone (1) gets eyes on the scene within minutes of the accident (2) and streams live information including video to the emergency services (3) as they are on their way.

The key benefits would be:

- Situational awareness for emergency services prior to their arrival and while they are on-site, allowing them to allocate the right resources and respond more effectively.
- Time saving for emergency services in reopening roads, saving money.

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- Reduced congestion.

In order to better understand the feasibility of this use case, we have focused specifically on response within a 7-mile radius of Birmingham International Airport, an area which covers several major roads including the M6, M42 and M40, parts of both the Birmingham and Coventry urban areas, all of Solihull, and rural areas in between.

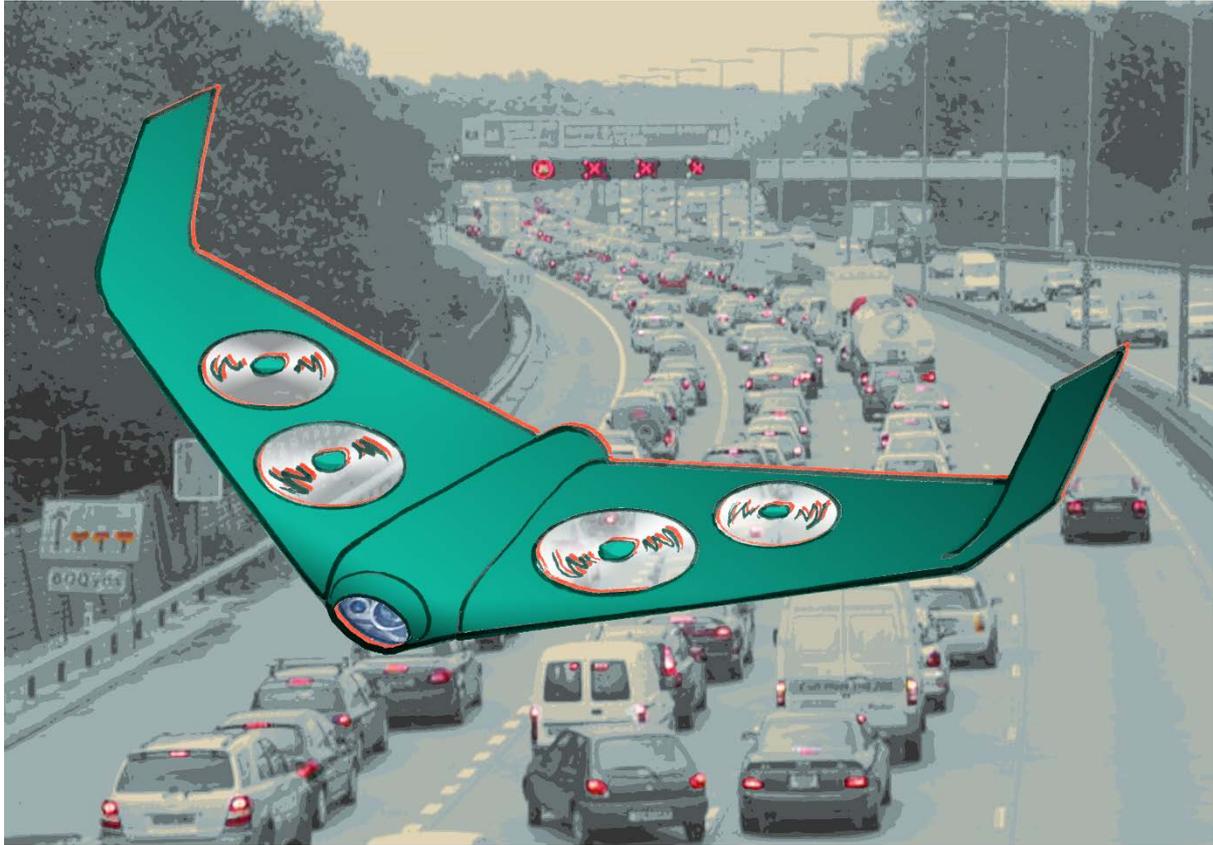


We have modelled a service which would use two fast hybrid VTOL fixed-wing drones: an initial response drone with a high-powered zoom lens to get the quickest possible images of the site; followed by a drone carrying high-resolution video and Lidar.

There are some technical challenges that need to be solved, primarily around safe operation and endurance. The location of Birmingham International Airport is in the middle of this zone, which also covers built-up areas. The drones would not be restricted to fixed routes, so they would need to be able to operate safely throughout the area, with as few restrictions as possible. This would require sophisticated and reliable communications networks and a sophisticated airspace management system to safely combine drone traffic and its other air users, particularly around the airport. The long duration of incidents would require good endurance.

Operating in restricted airspace around the airport and a number of other sensitive sites would require either an exemption from current rules, special permission or a change in regulation.

Our economic analysis suggests that this use case would bring significant benefits, with reductions in traffic disruption being the main contributor: even the small-scale pilot outlined here would bring around £2.4m in social benefit over 12 years.



Artist's impression of a fixed wing VTOL drone responding to a traffic incident in the West Midlands. Credit: ILYA (Background image by Ben Gamble, CC-BY-SA)

This is a summary of the full technical and economic analysis paper, which can be read in the appendices.

Southampton–Isle of Wight medical delivery

A fast connection across the Solent 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

Linking Southampton across the Solent to the Isle of Wight using a delivery drone.



The drone (1) takes off vertically from the mainland, having picked up a cargo of medical deliveries (2), flies over the Solent to a medical facility on the Isle of Wight (3). The flight would take place beyond visual line of sight and broadcast its position to a UTM (4).

The Isle of Wight is the UK's second most populous area (after Northern Ireland) not to have a fixed link to mainland Great Britain. The Solent is a barrier to people and goods, with relatively slow and expensive ferries providing the main connectivity. Similar drones could also serve other isolated centres of population such as the Scottish islands.

Drones could carry light payloads of up to a few kilos over distances of 10–20 miles, with medical deliveries of products being a key benefit.

The key benefits to drones for carrying medical products to the Isle of Wight would be:

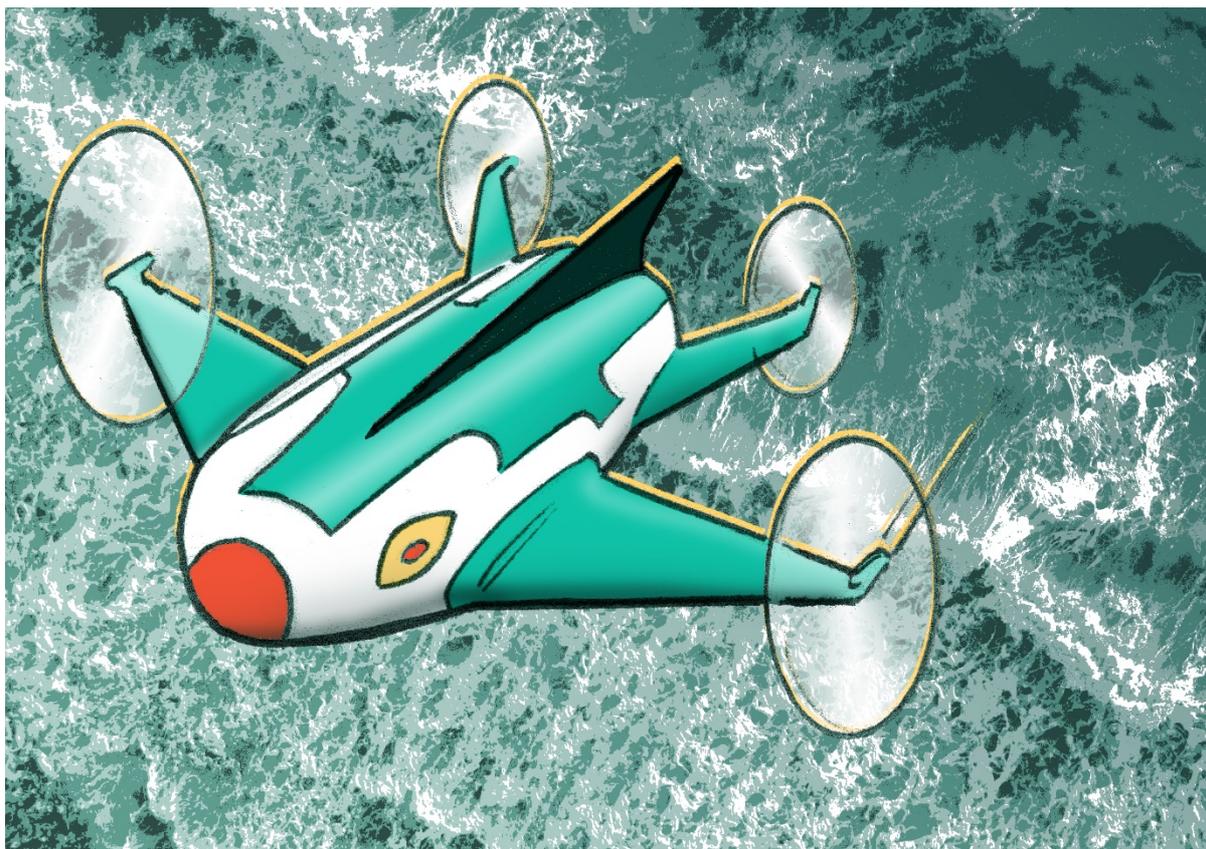
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- Saving time by avoiding the slow ferry service and roads.
- Saving money.
- Making medical logistics more efficient by enabling deliveries which are not currently feasible.
- Providing medical products and tests to patients more quickly.

In order to better understand the feasibility of this use case, we have focused on carrying blood products from NHS Blood and Transplant in Southampton to St Mary's Hospital on the Isle of Wight, as well as Portsmouth and Bournemouth, for ad-hoc short notice deliveries and occasional emergency shipments. A fixed-wing VTOL drone would carry blood in batches of up to 10 units between the two hospitals.



Drones already exist which can carry payloads of this size over comparable distances, but there are challenges around the drone flying beyond the operator's line of sight, and around allocation of airspace in restricted areas such as around Southampton Airport. A system to manage airspace and share it between drones and other air traffic would be required for this to operate safely, as would robust communications infrastructure.



Artist's impression of a drone crossing the Solent. Credit: ILYA

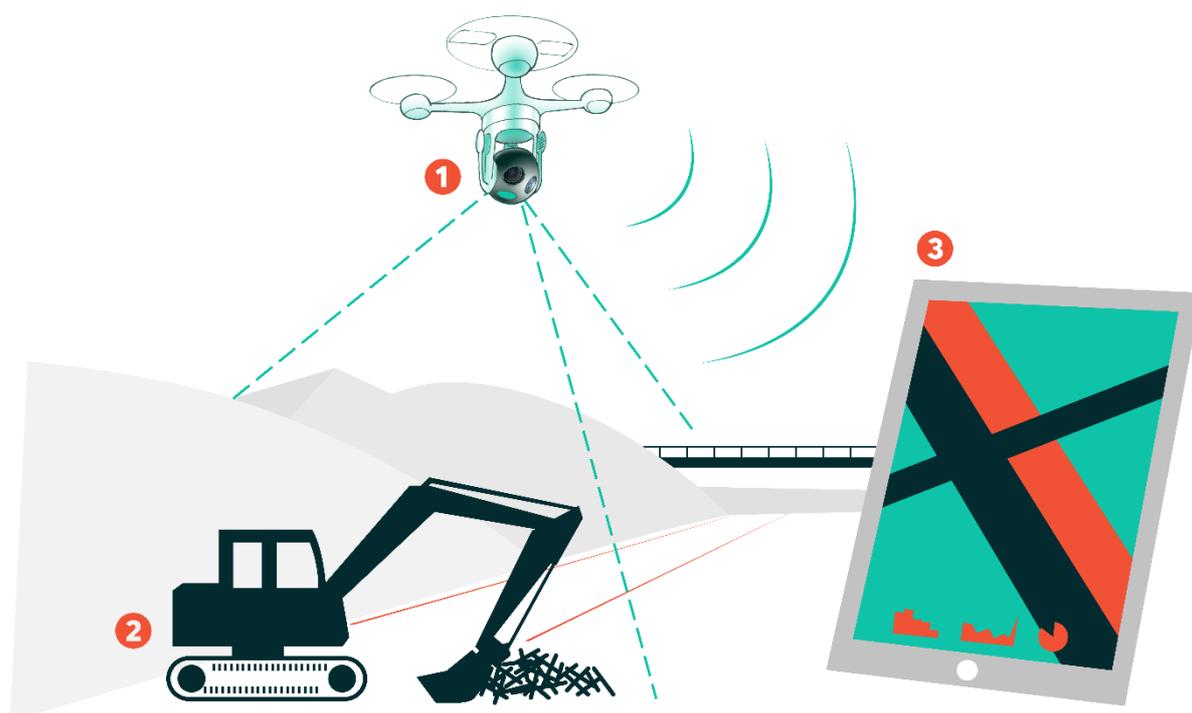
This is a summary of the full technical and economic analysis paper, which can be read in the appendices.

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 possible

This use case focuses on drone services supporting construction work for urban projects in Preston. This would involve routine use of drones prior to and during construction, in order to survey sites and gather real-time information on the progress of works.



The drone (1) flies over the building site gathering high-resolution data on the ongoing construction work (2). This is fed back in real time to a building information management system for use by managers on site (3).

The key benefits to drones for construction and urban regeneration in Preston would be:

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- Increased efficiency in construction site management.
- Reduced waste.
- Speedier recovery from incidents.
- Reduced risk of injury for workers.
- Better environmental management.

In order to better understand the feasibility of this use case, we have focused specifically on a major forthcoming construction project in Preston that could be a test case for this use of drones. This is the M55 link road project, where a major new road will be built starting in 2019.



We have explored the use of a drone with cameras, thermal imaging and Lidar to support the construction work there. A drone launched from the construction site would fly in a regular pattern over the construction site in order to gather information on important topics such as the progress of work, location of materials and staff and any safety issues that might be arising.

Of the use cases we have looked into, this is the closest to being realised already: drones are already widely used in building projects. However to be used routinely and as regularly and intensively as we anticipate, the technology needs advances in communications, airspace management and, most of all, autonomous flight - and restricted airspace thanks to a nuclear fuel facility near the site would currently be very challenging to operate in.

Our economic analysis concludes that the use of drones in a construction project such as the M55 link road is highly economically beneficial: we model productivity gains of £15.7m over the 42 months of the project.

Use of drones for this purpose is therefore already feasible, with technological advances enabling wider and more efficient use in future.



Artist's impression of a construction drone in Preston. Credit: ILYA

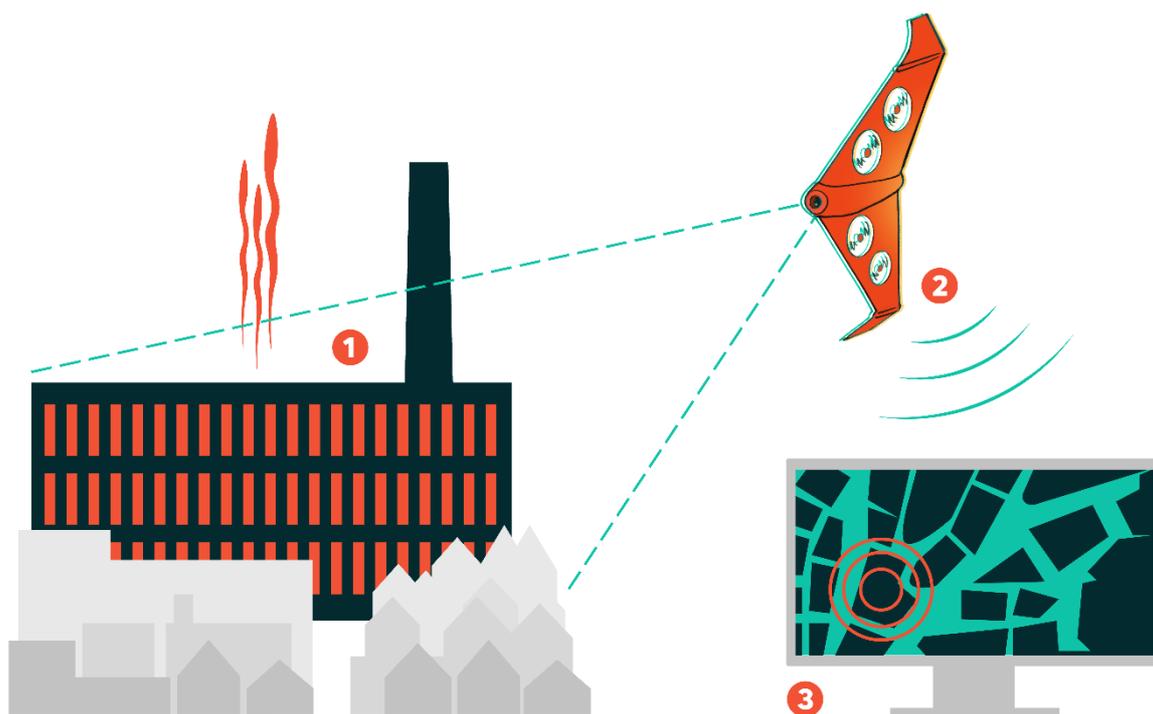
This is a summary of the full technical and economic analysis paper, which can be read in the appendices.

Supporting the fire and rescue service in Bradford

Using drones as a rapid response 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

This use case focuses on emergency response drones for West Yorkshire Fire and Rescue service. Drones would provide high-quality information to support mission planners and controllers to direct resources when the alarm has been raised, arriving on the scene faster than is currently possible and helping staff plan an appropriate response for the seriousness of the incident.



A fire is detected (1) and the drone (2) rapidly gets eyes on the scene. It feeds back live information such as video and thermal imaging (3) to incident controllers and firefighters.

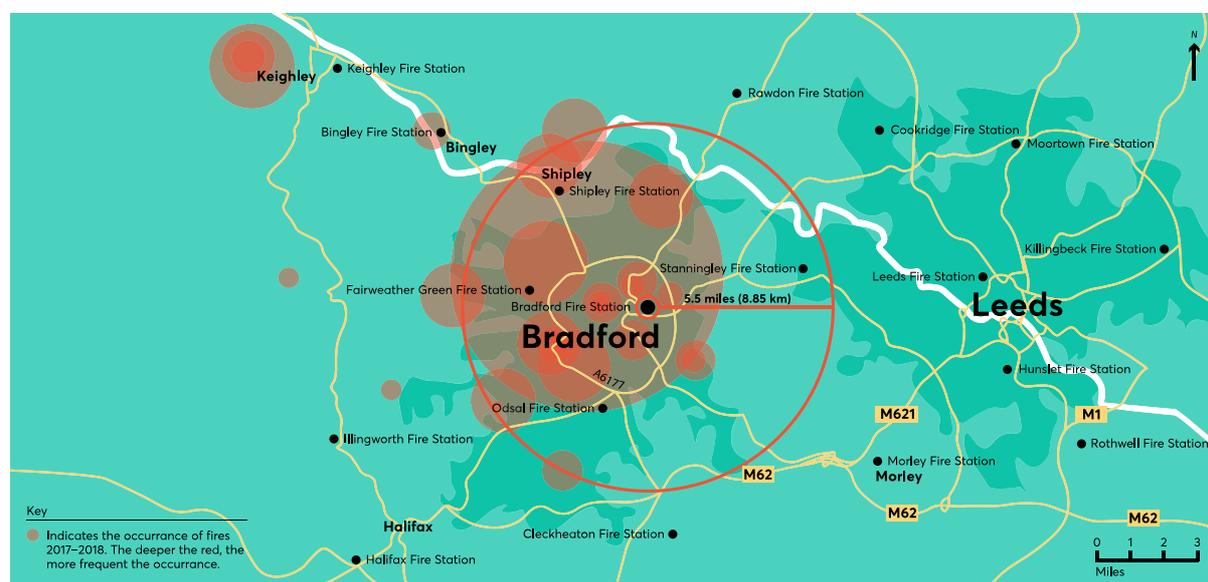
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Drones would provide real-time information to firefighters working at the site of an incident, giving early warning of structural problems, identifying hotspots or individuals in need of help. They could also help map out high-risk sites.

The key benefits to drones for fire and rescue in Bradford would be:

- Time savings, in particular around avoiding staff time being spent on false alarms.
- Cost savings, by avoiding the need for helicopters and by reducing resources spent unnecessarily on false alarms or small fires.
- Improved safety for firefighters and for members of the public caught up in fires.

In order to better understand the feasibility of this use case, we have focused on how a drone service centred on Bradford Fire Station. As with the West Midlands, we've looked into a two-drone service that gets rapid eyes on the scene, followed by high-resolution imagery.

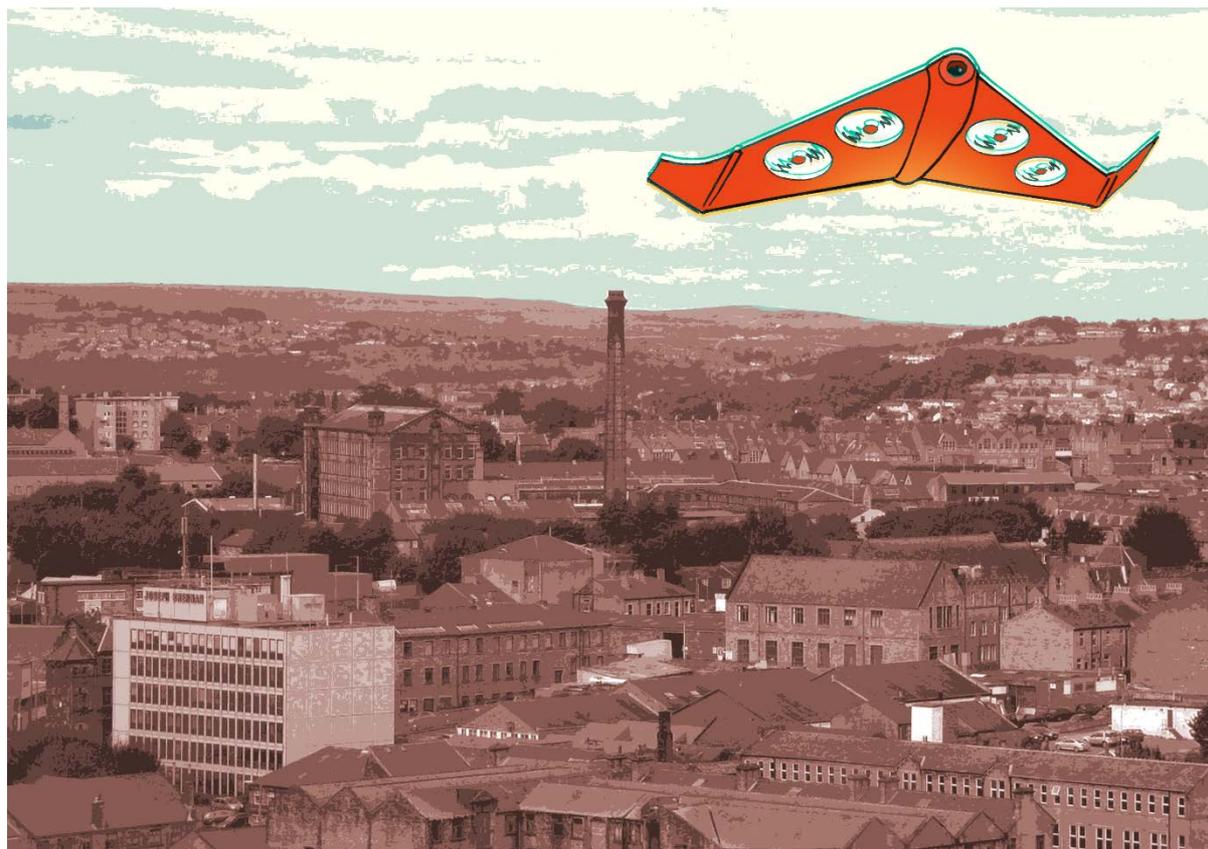


The technology required for this use case is very similar to our proposed traffic incident response service in the West Midlands, and hence the challenges are similar. Safe operation across a whole city is critical and needs communications and traffic management infrastructure that is not currently in place; particularly if operating in the half of the city which is within Leeds-Bradford Airport's controlled airspace.

To be feasible, regulations around operation in built-up areas would need to either be relaxed, or a specific exemption for these operations would need to be granted.

Our economic analysis suggests that such a service would be highly feasible: the cost savings it brings about for the fire and rescue service would pay for themselves within four years and deliver a net cost saving thereafter.

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Artist's impression of a fire service drone over Bradford. Credit: ILYA (Background image by Tim Green, CC-BY-SA)

This is a summary of the full technical and economic analysis paper, which can be read in the appendices.

Exploring urban drone integration

Planning for a future in which drones benefit our cities

- Increased use of drones entails greater use of low altitude airspace in cities, creating issues around how this airspace is managed.
- Their operation will directly affect the city below. The city should have a say in how this airspace is managed, or even be responsible for managing it.
- Large-scale operation of drones will require investment in infrastructure and could result in built environment changes at the points where drones interface with the city itself.
- New policies are needed around drone traffic management systems, streamlining access to urban airspace and increasing operational possibilities. The developing EASA framework is a good example of this.

Introduction

Complex city environments need complex systems

This section outlines some of the high-level systemic requirements and challenges for long-term integration of drones into UK cities, in line with the findings of the Flying High project. The purpose of this document is to consolidate existing research and proposals for urban drone systems with learnings from the city engagement and the feasibility research conducted by Nesta. This document can be used to support strategic roadmapping, identify challenges and opportunities and inform policy for a national vision for drones.

Urban areas present particular challenges for aviation. Dense populations and infrastructure and a high rise environment increases the safety and environmental risk, as well as the impact of noise, light pollution and visual blight. For these reasons flights in cities at very low altitude are generally prohibited. With some exceptions, the Rules of the Air require aircraft in a city to fly at least 1000 feet above the tallest building within 600 metres.⁹⁷ Small unmanned aircraft (drones) have a very different set of rules to other forms of aviation, but also have particular restrictions in cities.

Drones are operated in urban areas today, but in general this is either recreationally in wide open spaces like parks, or use by commercial operators with special permissions and exemptions from the Civil Aviation Authority (CAA). These exemptions are granted on a case by case basis. Drone use is governed by the Air Navigation Order (ANO) 2016. Unless an exemption is obtained from the CAA, drones fitted with cameras are not permitted to be flown within 150 metres of a congested or built up area (which includes all urban areas with exception of some wide open spaces) and all drones must be operated within visual

⁹⁷ http://publicapps.caa.co.uk/docs/33/CAA6395_Skyway_Code_AW_150817_SCREEN.pdf

line of sight of the operator, within 500 metres horizontally and below 400 feet in height, the latter becoming law in a May 2018 update to the ANO.

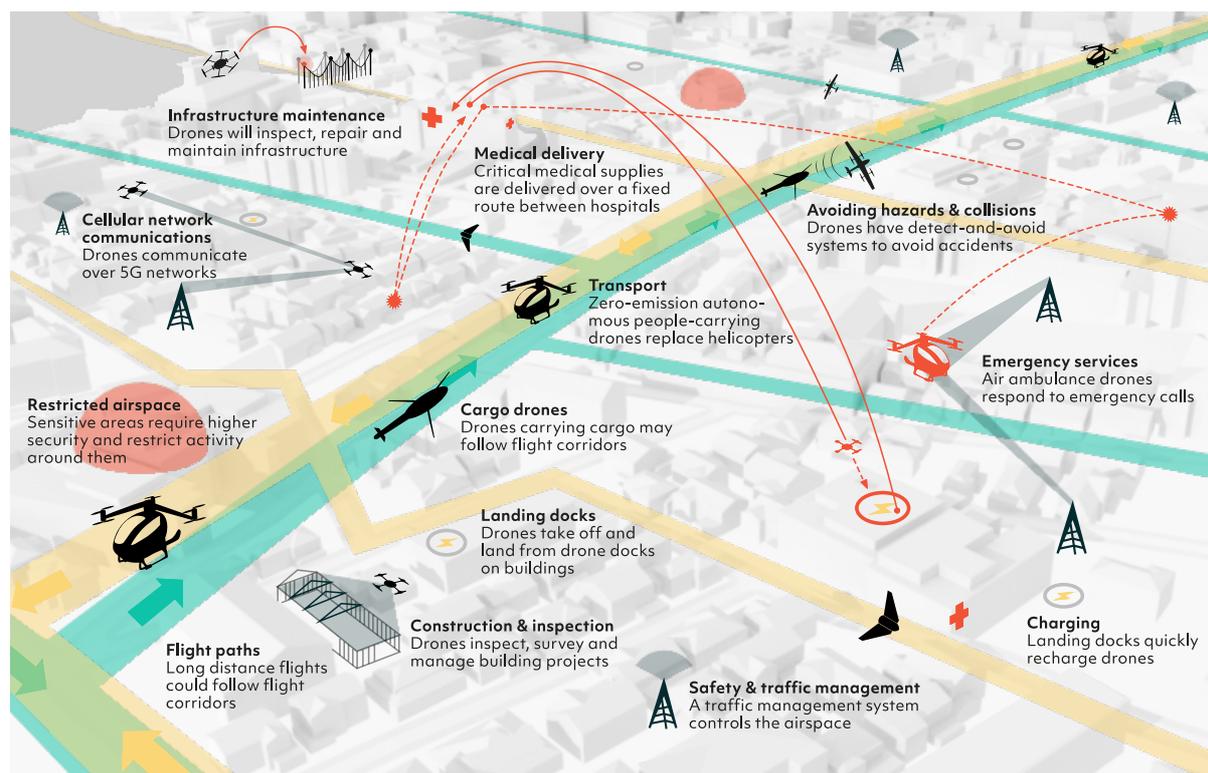
To gain exemption from these restrictions from the CAA it is necessary to produce a safety case outlining how the proposed drone deployment will be conducted safely. This safety case is contingent on the technology being used, the operator of this technology and the requirements of the mission such as location, duration and time of day.

The engagement with five UK cities conducted through the Flying High project has identified a wide range of application-specific and wider benefits that drones could bring to cities, summarised in the 'What drones can do in UK cities' section of this report. Many of these operations in the short term can be realised through the existing system of applying for a CAA exemption to operate in a congested area and sticking largely to the existing regulatory framework outlined in the drone code.⁹⁸ But in the longer term, drone integration will entail going beyond the existing framework, allowing regular operations in currently restricted areas, with a level of autonomy, beyond the visual line of sight of an operator (BVLOS) and eventually without an operator at all.

This will mean integrating drone operations into the everyday running of the city. Drones will start to have a significant impact on the city and its operations, affecting the way government and firms are run and organised, the nature of the built environment, and the 'feel' of the city. New systems will need to be put in place to manage the use of drones and integrate them with ground-based systems and traditional aviation. Governance of these systems will need a combination of aviation and city management expertise, and involve city and national governments, airspace regulators and air navigation service providers. Developing these systems will be an evolutionary process building on the limited urban drone operations that exist today, rather than a sudden shift to mass deployment. It will also be a complex process, driven by a mix of factors that include public acceptance, social impact, economic viability, infrastructural and technological possibilities and regulatory frameworks.

This chapter explores some of the major systemic issues and challenges that need to be overcome for the future integration of drones into UK cities, drawing on learnings from the Flying High project's city and wider stakeholder engagement, research into the feasibility of the five use cases and supplemental desk-based research. It considers airspace and air traffic management, infrastructure, governance and public acceptance.

⁹⁸ <http://dronesafe.uk/drone-code/>



How drones could operate in future cities

Existing initiatives

What is being developed around the world?

U-Space

The most significant drone integration programme currently underway in Europe is the U-Space initiative, part of the Single European Sky ATM Research (SESAR) joint undertaking. SESAR is a public-private partnership involving the European Commission, Eurocontrol and a number of air navigation service providers and industry stakeholders. These players have been developing the 'U-Space' concept; a set of digitally-driven services that will enable complex drone operations at scale, involving a high level of autonomy in complex (particularly urban) settings. These services will be part of a future Unmanned Aircraft System (UAS) traffic management (UTM) 'system of systems'. A roadmap for developing these services was published in March 2018.⁹⁹ The roadmap envisions a phased development and roll out of services which will enable increasingly complex operations, up to fully autonomous drone operations in 2035. It ultimately includes integrating drone traffic management with traditional manned aviation, so that drones and traditional aircraft can operate in the same airspace.

99 <https://www.sesarju.eu/node/2993>

NASA Unmanned Aircraft System Traffic Management

NASA is collaborating with the US Federal Aviation Authority on the development of traffic management systems for civilian drones to enable operations in low altitude airspace.¹⁰⁰ The project takes a gradual capabilities approach, split into four sequential technological capability levels. Previous demonstrations have included enabling BVLOS flight in sparsely populated areas, managing drones with both cooperative and uncooperative traffic in moderately populated areas. A forthcoming stage will enable operations in densely populated (i.e. urban) areas and deal with large volumes of traffic.

European Aviation Safety Agency drone categories

The European Aviation Safety Agency (EASA) is in the process of drafting new regulations to cover non-state use of drones, and is taking a risk-based approach that splits drones into three main categories:

- **Open:** This is the lowest risk category, where certified drones would operate according to certain principles without the need to get authorisation from the authority for a given operation.
- **Specific:** A higher risk category requiring authorisation for the drone deployment/type of deployment. This means a risk assessment needs to take place, factoring in the capabilities of the drone, the operator, the environment and the specific task.
- **Certified:** the highest risk category where both the drone and the operator must be certified by a relevant authority.

The different use cases for drones could involve all three categories. Part of the challenge involves integrating the different drone risk profiles outlined here, for drones performing missions of different operational types.

Principles of urban drone integration

Ground-rules for how drone systems should be developed

The integration of drones into city ecosystems will ultimately depend on what is socially acceptable and technically possible, but also on the financial cases and business models. These will have a defining impact on how city drone operations - and the frameworks around them - evolve. Already there is a strong, validated business case for many types of drone operations in cities (notably for media, surveying and construction). Facilitating deployment, pushing the boundaries of what is technologically possible and what is allowed by current regulation will yield a range of new and unexpected benefits that could shape drone integration in unpredictable ways.

Some applications that will have a significant impact on cities (such as proactive infrastructure repair, logistics or passenger transport) are becoming increasingly possible,

¹⁰⁰ <https://utm.arc.nasa.gov/index.shtml>

but have not yet proven their economic and social viability. The business models that emerge around these applications, should they prove plausible, will have a significant impact on the evolution of operational characteristics of urban drone use.

Although the system will evolve naturally, we believe that cities should have a role in shaping that evolution to meet the needs of citizens; to maximise the benefits and mitigate the downsides. Through our stakeholder engagement process we have identified six key considerations we believe must characterise the process of urban drone integration:

- Safety.
- Security.
- Privacy.
- Transparency.
- Accountability.
- Environmental protection (including noise, visual pollution, emissions).

Types of drone operation

Different drone applications operate in fundamentally different ways

When considering the challenges to drone integration in cities, a key factor is the characteristics of drone operation. Current drone use in cities is all of a similar type; piloted, within line of sight of the operator and usually on a one-off basis. The drone applications that have been highlighted by the Flying High project's partner cities, however, are associated with quite different operational characteristics, technologies and regulatory requirements. We have outlined some of these different types of operation below.

These different types of operation could all exist alongside each other in the same urban airspace (in the same altitude range and parts of the city) and even alongside manned aviation, which is currently separate from drone operations due to the 400 foot height limitations. Alternatively, it could be that only certain types of drone operation are appropriate to a particular location or city, though this may limit the benefits drones could bring to that area.

Piloted vs autonomous drones

Current legislation and standards are built around all drone flights involving a human, either directly flying the drone or monitoring a pre-programmed automatic flight. In the future it is very likely that drones will be able to complete missions with a high degree of autonomy. At a minimum they could conduct routine pre-programmed operations without the need for immediate supervision (highly automated), autonomously detecting and avoiding obstacles. In this scenario, drones would need to communicate automatically with other drones and with air traffic control, and make decisions about factors such as landing site or flight path (what the CAA refers to as 'high authority automated systems'). Drones of different levels of autonomy and drones remotely piloted by a human may soon operate at the same time and in the same airspace.

Type and capability of drone used

There is a diverse range of unmanned aerial vehicles, each with very different designs and capabilities; from fixed wing, to multirotor to hybrid, and a range of size, payload type and capability. City skies and management systems will need to accommodate very different types and capabilities of aerial vehicles operating at the same time, in the same airspace. It may be necessary to designate new classes of drone based on capability and autonomy, in addition to the existing classification based on weight and payload. New drone classifications could be subject to different rules and airspace access.

Routine vs one-off deployment

Some drone deployments may require continuous deployment via tethered drones or drones that run the same route repeatedly (e.g. for routine deliveries, inspections or surveillance). Many other operations will be discrete, single deployments to carry out an individual task, for instance a search and rescue operation or to carry out a one-off site survey.

Journey vs contained deployment

Drone deployment could involve a journey from one point to another (e.g. medical delivery between hospitals), while some deployments will necessarily be confined to a limited area (e.g. construction site monitoring), or may involve a tethered drone. The former is likely to involve BVLOS flight, and will have to operate alongside more traditional piloted, visual line of sight flight.

Journey type

Multiple journey typologies may occur - fixed location to fixed location (A to B), fixed location to a variable location (A to X), or from a variable location to a variable location (X to X). A variable location could be one where the location is determined at the start of the operation (e.g. a delivery of a defibrillator to the scene of an incident) or where the end of the operation is unknown at the start (e.g. a police pursuit).

Application type - civic vs commercial vs recreational

There is a range of potential drone operators in urban environments that would need to coexist. Drones being operated for commercial purposes may have to operate alongside drones being used for civic applications such as emergency response. There is also an active research and hobbyist community using drones who will want to access airspace.

Airspace and air traffic management

Defining the rules of the air

Airspace

A major challenge of urban drone integration is how to manage the airspace and air traffic. Under the ANO 2016 it is prohibited to fly a drone (if fitted with a camera) within 150 metres

of a 'congested or built up area', which includes the majority of urban areas, or higher than 400 feet in altitude, without permissions or exemptions from the CAA.¹⁰¹ However, if drones are to be deployed at a larger scale in UK cities there will be a need to streamline access to low altitude urban airspace for drones and to develop new ways to manage that airspace to ensure compliance with regulation, deconflict traffic and identify rogue operators. This would involve new rules for airspace management, new controlled zones or even new airspace classifications or redefining of existing classifications.

Because aircraft generally must operate at least 1000 feet above the highest obstacle within 600 metres in cities, low altitude airspace is unlikely to be heavily occupied at present (with the exception of certain low altitude flight routes, or in exceptional circumstances) Increased drone use could change that.

City stakeholders, including local government, should be involved in what happens in this airspace. They should be able to have some control or decision making power over what goes on in their airspace, should there be a move to increase its usage. Urban airspace could thus be conceived as a separate category from other types of airspace, not just in the sense that, as is the case at present, different rules apply, but also that the city authority would have a role in managing it.

The approach of airspace regulators such as EASA and the CAA is that airspace should not be segregated for particular users or uses, but considered as a national asset to be shared. Thus no one can 'own' the airspace and it can be accessed by all, excluding any temporary segregation for necessary safety or national security purposes, or for testing new technology.

This is the basis of the flexible use of airspace principle developed by Eurocontrol¹⁰² and adopted by the CAA, initially developed to integrate the traditionally separate military and civil airspace. The trajectory of organisations developing solutions for the integration of drones such as SESAR and NASA is to carry forward these principles of non-segregation and equal access to airspace as a shared resource. This implies that there will be no segregated airspace in which autonomous or remotely piloted drones operate exclusively, and no private airspace zones or lanes for exclusive use or rental by a single entity or group of entities.

Drones could, in theory, operate alongside helicopters and even commercial aircraft above and around cities, but they would need to meet certain requirements to operate in both controlled and uncontrolled airspace alongside traditional aviation. This includes being able to sense and avoid other airspace users and be able to fly accurately and follow air traffic control instructions within controlled airspace (if the drone is above 7 kilograms according to the ANO 2016).

¹⁰¹ <http://www.legislation.gov.uk/uksi/2016/765/article/95/made>

¹⁰² <http://www.eurocontrol.int/articles/flexible-use-airspace>

No-fly and special permission zones

Areas where drone use should be heavily controlled

Low altitude airspace away from airports is generally uncontrolled by air traffic services and not widely used by manned aviation. However, should drone operations become commonplace in cities, then in order to maintain safety, privacy and environmental standards it would be necessary to have designated areas of controlled or restricted urban airspace.

These may be areas where drones are not allowed at all without special permission, 'no fly zones', or where only certain types of drone are allowed by default. Restricted areas already exist around airports, military bases, prisons and sensitive sites such as nuclear power stations. It may be necessary to designate additional areas as no-fly or special permission zones for low altitude flight, which may include large parts of cities. It may also be desirable to make the default permission for some currently restricted areas more nuanced, to allow for certain types of operation (such as by the emergency services).

Restricted areas would then be coded into positioning systems such as GPS, a process referred to as geofencing, with operators alerted if the drone trespasses into an unauthorised zone. Geofenced areas may be permanent or dynamic; a temporary no-fly zone could be set up in a particular location during an incident and a set of exclusionary GPS coordinates updated on the drone if, for example, emergency services need to respond to an incident using a drone. Drones (or their operators) with different capability levels could be granted access to different types of location, just as the 'open', 'specific' and 'certified' categories developed by EASA have different requirements, and are further divided into different classes of drone with different certification standards.

Another approach to restricting drone operations is to define specific areas within which a drone must operate. These can also be coded into the drone with GPS or other location data, and the operator is alerted if the drone goes outside this zone. This is referred to as geocaging. This may be necessary to preserve privacy in a scenario where drones are able to operate largely autonomously and BVLOS, though current capabilities may not be robust enough to ensure compliance, as the system could be bypassed by a rogue operator.

Flight paths

Highways of the air

Regular BVLOS drone flights from A to B, such as those involved in delivery or passenger transport, may be best achieved by directing traffic along particular corridors. These would help to manage traffic when the volume of drones in the sky becomes high. They could also be used to mitigate any negative impacts on people on the ground by avoiding residential or sensitive areas. Flight lanes could be layered to enable drones to move in opposite directions or at different speeds along the same paths.

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It may be preferable for flight paths to follow the existing landscape and infrastructure. Flight paths above rivers would reduce the risk of a crash to people and buildings, while following infrastructure such as highways, railways or power lines could reduce nuisance to people under the flight paths. Though here emergency landing sites would need to be identified and the risk to underlying infrastructure assessed.

Should drones become fully integrated with manned aviation it can be expected that remotely piloted or autonomous aerial systems would operate in the same space as helicopters, or even largely replace helicopters. As things stand, helicopters have to fly high enough that they can safely autorotate (glide) away from a built up area in the case of engine failure, and in some places (such as London) that means following particular corridors.

Passenger drones may not follow traditional helicopter design (many are multirotor or vertical take-off and land fixed-wing). Should these become viable there will likely need to be a new regulatory framework, for example including a minimum level of redundancy. However, there may still be an argument for these aircraft following current flight paths as far as possible for safety and to limit noise pollution.

It is also worth noting that while this would not necessarily require segregation of the airspace for drones - in theory anyone could access the low altitude flight paths - it does mean a new approach to controlling that airspace.

UAS traffic management

Developing a drone traffic control

Should low altitude airspace in cities be opened up, including to autonomous systems, it will be necessary to have the infrastructure in place to manage that airspace.

Existing air traffic management systems are based on visual information, communication with a pilot and on the pilot's ability to take action. As usage of unmanned aircraft expands, and if rules around line of sight and presence of an operator are relaxed, new processes will need to be developed to manage increasingly complex and high-volume traffic.

One solution could be to restrict operations to certain capabilities or parameters or by segregating airspace, but current trends are towards the development of a UTM system. A core function of this will be logging, managing and informing different operators of what is in the air.

Drone flights would be logged in a UTM system either before or during the flight. The system would then inform the operator of existing traffic and could manage the flight parameters with dynamic data on obstacles, the weather, and possibly (dynamically) geofenced locations. This system will need to be heavily automated to be efficient. It would need to accommodate both piloted and autonomous systems as well as manned aviation and non-cooperative traffic such as birds or rogue drones.

Another important aspect of the UTM would be how it integrates with air traffic control (ATC). At a minimum, drone flights should be visible to air traffic control to mitigate risk.

Should drones operate in the same airspace as manned aviation, alongside helicopters or even around airports, the UTM will need to communicate with ATC or even function as a single unified air traffic management system for both manned and unmanned systems. As well as integrating with ATC, different types of unmanned systems could also be managed by a single UTM, including connected and autonomous vehicles and autonomous marine vehicles.

Many UTM services already exist in some form,¹⁰³ particularly for flight logging and tracking, and more are in development by both the private and public sector. Many different management systems may need to operate concurrently, much as different air traffic management solutions are used today by different airports and air navigation service providers. Different UTM systems will need to be interoperable to communicate with each other, with diverse types of drones, and quite likely with air traffic control for manned aviation.

If diverse UTMs for different drone fleets or different components of UTM are developed separately, they will all have to either be standardised, regulated and completely interoperable with each other or be interoperable with a centralised system of systems. This could be run by the air navigation service provider (such as NATS) or an entirely new entity. Efforts are ongoing at the international level to coordinate and harmonise UTM development, notably involving NASA, the SESAR's U-Space initiative, the Japanese Ministry of Economy Trade and Industry, and the Global UTM Association.

The UTM system can be split into technologies that will need to be built into the drones themselves (though some already is), applications and software for managing drone traffic, and infrastructural requirements such as communications and positioning systems.

The Global UTM Association has identified the following components of a UTM system in its April 2017 report 'UAS traffic management architecture'.¹⁰⁴

- **Identification:** UAS and operator/UAS pilot identification capabilities, to be able to identify UAS pilots/operators and UAS flown in a UTM-monitored airspace.
- **Flight plan (operation) management:** Flight plan/operation data management and authorisation capabilities, to collect (providing common human machine interface for UAS pilot or operator or by interfacing/interoperating with the UAS service supplier system), analyse and validate UAS operations.
- **Flight permissions and directives:** Flight permissions and directives, issued or denied manually or automatically based on data such as airspace restrictions, weather conditions, obstacles, other aircraft, and registration data.
- **Airspace management:** Airspace management capability, to act as the single point for adding or removing any permanent or temporary airspace restrictions (referred to as geofencing at the UAS level).
- **UAS surveillance and tracking capabilities:** to provide situational awareness.

¹⁰³ <https://www.unmannedairspace.info/wp-content/uploads/2017/12/UTM-directory-December-2017.v1.pdf>

¹⁰⁴ https://www.gutma.org/docs/Global_UTM_Architecture_V1.pdf

- **Conformance monitoring:** Conformance monitoring capability, to check the compliance of flight progress in respect of the declared plans.
- **Meteorological information:** to inform on local weather information regarding the operation.
- **Obstacle information:** to inform on obstacles related to the operation.
- **Conflict detection and advisory capability:** to anticipate the risk of collision between UAS and manned aircraft, and of entering restricted airspace.
- **Contingency management:** To inform in the event of emergency situations.
- **Recording and playback capabilities:** to provide evidence during post-flight phases (e.g. incident investigation, statistics).

Further to these, there will need to be capabilities on the drone itself, including:

- **Navigation and piloting capabilities,** which are essential to the conduct of safe operations.
- **Geofencing** (or geo-limitation) capability support, to respect constraints imposed (stay-in and stay-out volumes).
- **Identification capability,** to ensure cooperative surveillance.
- **Detect and avoid capabilities** for obstacles.
- **Termination and return-home capabilities** for reducing the risk in case of contingencies.
- **Operation planning,** to support the UAS pilot or UAS operator in defining the operation.
- **Monitoring and control support,** to follow in-flight UAS operations.

Many of these systems are already in place. The challenge is in unifying them, having them interact with autonomous systems and dealing with traditional aviation and non-cooperative traffic.

Capability-driven approach

Permissions for drones need to be linked to what they are capable of

Development of an urban UTM system is envisioned by key players in Europe and America (SESAR, NASA and the Federal Aviation Administration) to be evolutionary and to involve multiple stakeholders working on different component solutions that would feed into a UTM system of systems. UTM component developments have been largely led by industry to date, but collaboration with governments and regulators will be key.

As the system evolves it will need to accommodate drones with differing levels of capability. It will have to provide particular services that require particular capabilities and infrastructure to be in place, even though there may be minimum requirements for drones to operate at all. For example, some form of digital signal broadcast to tracking systems,

known as electronic conspicuity, would be required. This capabilities-driven approach would involve:

1. Defined levels of capability required of the drone system. These would have to access...
2. ...defined capability levels of service of the UTM, in particular types of environment that have...
3. ...defined capability levels of infrastructure.

For example, only drones that broadcast their location, have certified navigation capability with sense and avoid technology could operate above 400 feet in an area of over 90 per cent mobile coverage.

This capability-driven approach will allow advanced applications to be tested and deployed while still accommodating legacy drone systems. EASA are evolving regulation alongside product standards for drones, that will be split into different classes for different drone capabilities, effectively endorsing the capabilities approach.¹⁰⁵

Communications and data infrastructure

Safe operation of drones needs reliable communications networks

For drones to be integrated into airspace, they will need to communicate with the air traffic management system and with other drones. Depending on the application, drones might use different communication methods including mobile phone networks, satellite, and other radio communication.

Mobile phone networks are a promising way to handle communications because the infrastructure already exists, and can be used for control and monitoring of BVLOS operation. Mobile networks are also fast and secure.

There is normally good mobile coverage in urban areas, however these networks are optimised for use on the ground. Their coverage is not necessarily as good in the air. In cities there are also often issues around bandwidth due to the high volume of users. Using mobile phone networks also benefits from upgrades to the mobile infrastructure, such as the upcoming 5G capability which will greatly improve speed, latency and capacity.¹⁰⁶ Since the mobile phone system already has the ability to identify cell phones through SIM cards, this capability could be used to identify drones. Mobile phone towers could also be used to help drones find their location by triangulating between several towers.

Although satellite communication is unlikely to be used as a primary method to communicate with drones in most circumstances (where mobile data networks are cheap, reliable and secure), drones will still likely make use of global navigation satellite systems such as GPS and Galileo. To improve accuracy, drones may also use the European

¹⁰⁵ <https://www.easa.europa.eu/document-library/opinions/opinion-012018>

¹⁰⁶ https://whatsag.com/g/5g-advantages_disadvantages.php

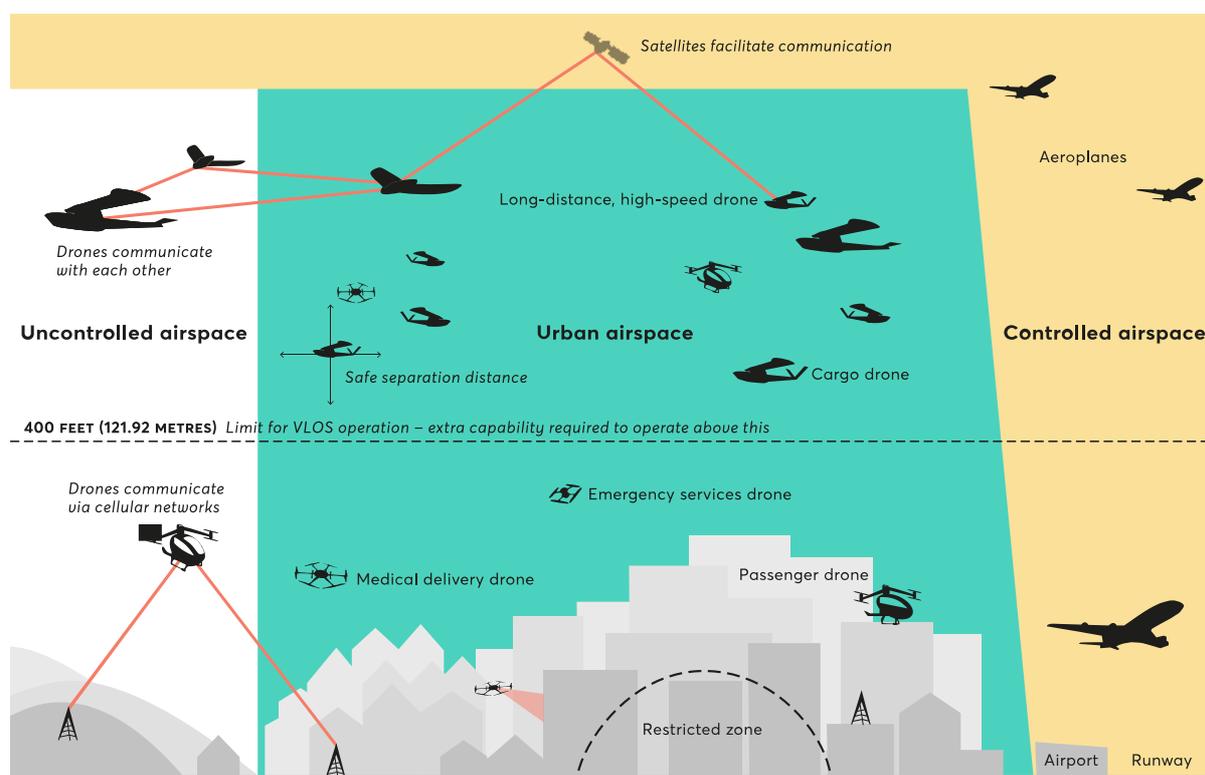
Flying High: shaping the future of drones in UK cities

Geostationary Navigation Overlay Service, which improves the accuracy of satellite navigation systems.

For applications where there is an existing radio network, that could be used too. For example, emergency services drones might connect to the emergency services network which is currently under development.

For all of these communications methods it will be important to map out the signal strength in the places the drones will travel. For mobile networks, it's unclear how well they'll be able to be used for communication because they are optimised for ground use. Also, buildings in cities can interfere with signals such as GPS.

Drones will also need to communicate with each other for sense and avoid capabilities. These may be similar to the current sense and avoid systems on aircraft such as FLARM, which broadcasts location data and monitor/sense for nearby aircraft. Some off the shelf drones come with basic sense and avoid ability.¹⁰⁷ However, this is limited and mostly focused on sensing and avoiding obstacles in close proximity to the drone, rather than airborne collision avoidance, which is a more complex challenge.



The illustration above summarises how urban airspace might be managed in the future, illustrating a distinct, low altitude 'urban airspace' where drones could operate and where the city would have some jurisdiction.

¹⁰⁷ <http://droneanalyst.com/2016/09/22/sense-and-avoid-for-drones-is-no-easy-feat>

Ground-based infrastructure

Large-scale drone use in the air would require some changes on the ground

Changes to the built environment

The proliferation of drone technology, if it occurs on the scale described in this report, would have an evolutionary effect on the built environment, and on the very nature of our cities. Certain drone applications or types of operation could result in the need for new physical infrastructure. If systems become highly automated they will require fixed docking stations to take off and land from. This would give them designated take off and landing points, which could be integrated with charging or refuelling capability.

Several companies are currently offering or developing different types of docking station, often combined with charging capabilities, or automated battery swapping. A high level of deployment, routine automated flights or particular applications such as delivery will increase the need for docking stations. This could be a temporary/mobile or permanent fixture, which may be placed on the top of buildings, at ground level, integrated into existing transport infrastructure or on other types of infrastructure such as lampposts. It is likely that these docking stations will be integrated with battery charging; how this may affect the grid and associated emissions will need to be considered, as demand for electricity increases with the growth of electric road vehicles.

Drone systems could affect the way buildings themselves are constructed. For example if drone delivery hubs are on the roof there will need to be a way to easily access the rooftop or to transport goods to and from it. New buildings could be designed to accommodate this, but it could be a serious challenge retrofitting old buildings. The visual impact on the built environment would also need to be considered.

Passenger terminals and logistics hubs

Other potential changes to the built environment include terminals for personal transport or hub stations for logistics. Many remotely piloted or autonomous aerial systems for personal mobility are currently being tested or are under development. These could end up being deployed at scale as flying taxis, or simply be a cheaper, autonomous electric alternative to helicopters. So far the viability of this technology, and particularly the business case around mass deployment, has not been proven. However zero emissions and autonomous passenger aviation technology in cities can be expected to evolve and eventually may lead to entirely new operating models. Where small electric air mobility solutions are deployed in some form in cities, these would need terminal infrastructure around them.

Package delivery of some kind has been identified as an application of interest by the Flying High partner cities. Even if this is limited to urgent items or medical items, a built

environment solution will be needed to send and receive goods. This could either work as a local hub model, point to point or from a hub to an unknown location.

Counter drone systems

A key part of an air traffic management system for drones will be understanding what it is in the sky at any one time. This will involve a UTM having access to operator registration information, and flights logged by operators. Drones may have a mandatory electronic conspicuity device such as a transponder or the ADS-B (Automatic Dependent Surveillance - Broadcast) technology currently used by commercial aviation. This will enable identification of cooperative traffic, but should increasingly advanced drone technology continue to become readily accessible, there may need to be ways to identify and respond to non-cooperative air traffic.

A raft of solutions are being developed for this, which include jamming the radio frequencies to block remote control of a drone, and even means to safely take drones out of the sky, for example using nets with parachutes.

One approach would be to have ground-based systems to detect rogue drones around particular sites, and counter-drone mechanisms to deal with them. This may mean fixed infrastructure such as radar, signal jammers and drone capture technology placed on or near certain sensitive sites such as prisons or government buildings. Alternatively this could be a capacity that sits with the police, to be deployed as needed. The solution will depend on the capability and availability of potentially harmful drone technology, and if drones operated with malicious intent are able to blend into a future where seeing a drone in the sky is an everyday occurrence.

Policy

Implications of drone integration for government policies

Regulatory frameworks

The existing national regulatory framework around drones is set by the Department for Transport (DfT) and regulated by the CAA. There are international efforts to coordinate new policy frameworks and standards for drones, brought together by the Joint Authorities for Rulemaking on Unmanned Systems.¹⁰⁸ Policy relating to drones will be a mixture of policies and standards at the international, national and local level. Local government in cities should have flexibility with respect to drone operations, within a larger national and international framework.

The operational rules covering drones in the UK have a set of default restrictions and ad hoc exemptions that are appropriate for the current level of technological capabilities. The huge increase in drone use in recent years has put pressure on the regulator to deal with

¹⁰⁸ <http://jarus-rpas.org/>

an increasingly large volume of applications for permission and exemption. In the future, operations that would currently require exception from the CAA may well become routine, including operating in dense areas and BVLOS. Future operations are also likely to involve a high degree of automation, both of the drones themselves and the traffic management system.

EASA is currently developing new regulation for drones, based around different categories of risk (open, specific, certified),¹⁰⁹ and it is plausible that the UK will adopt this framework. It includes registration of drones that pose certain risks (e.g. are able to transfer 80 joules of terminal kinetic energy), or are in the certified category. It will also facilitate the permissioning of operations beyond the standard restrictions (including BVLOS) through the use of standard scenarios associated with particular drone capabilities and operator requirements. These standard scenarios will need to evolve to take into account autonomous systems and urban operations.

As the technological possibilities increase and safety, security and privacy challenges are able to be mitigated, a new default set of rules governing urban skies will be needed. A range of standards will be required for a UTM system of systems to operate. Standards around this are likely to be needed for drone capabilities such as engine type, power source, redundancy, electronic conspicuity, communications and failsafe protocol. Additionally standards will be needed for how the UTM manages traffic, for instance how flights are logged and permissions is granted or denied, how volume of traffic is or isn't restricted and possibly how the system communicates and receives information from air traffic control.

Management of urban drone use

Controlled airspace has traditionally been administered by air navigation service providers; this is typically a government entity though NATS in the UK is a joint venture between the government and private sector shareholders (primarily airlines).

The management of drones in cities presents an entirely new challenge for aerial traffic management. This includes how it relates to aircraft, altitudes and distances that are very different from those currently managed by air traffic control, as well as dense populations and associated safety and privacy risks. A UAS traffic management system will thus be quite distinct from traditional air traffic management, even if some of the principles will be maintained.

The UTM will most likely need to integrate with traditional air traffic control if airspace is not to be segregated for use by drones. It is likely that many different UTMs will be developed and operated by different players at the same time, but these components will need to be interoperable and be part of a system of systems accountable to the state in some form. The system of systems could be a set of interoperable solutions governed by state-set standards, or it could a piece of digital infrastructure itself, managed by or on behalf of the state.

¹⁰⁹ <https://www.easa.europa.eu/easa-and-you/civil-drones-rpas>

As low altitude airspace directly impacts on the city environment, cities should have a voice in how this airspace is managed. Indeed, low altitude drone traffic management services could be run by, or on behalf of, the local authority. Cities could pick solutions from a set of state-standardised services offered by sanctioned providers, just as air traffic control services are procured locally.

Drone traffic management services may also involve traditional aviation service providers such as NATS, or an entirely new private or public body created to manage low altitude drone traffic. At a minimum the city authority needs to have a strong voice in the management of its low altitude airspace. The best way to achieve this may be for the city to run or be responsible for procurement and oversight of these services.

Similarly local low altitude rules of the air should be set by cities within a national framework. This could be analogous to the highways department as a local authority, where specific rules are set with an overarching national framework. Cities could set rules around low altitude flight paths and restricted areas. Noise levels are already managed at a local level, but local authorities would have to take drones into account and factor noise into local drone traffic rules.

The business model for the operation of the UTM and how it will be paid for will also need to be determined. This could be delivered as a national service funded out of general taxation, but that would depend on being able to justify the use of public money through measurable social benefit or economic growth. Another option would be a pay to play system where users of the airspace must pay for UTM services either on point of delivery or as a subscription. This could be a public model like a road tax or toll for the sky, or a private model where users pay a privately owned operator for services.

Environmental impact

Increased drone use could have an adverse environmental impact and this will need to be assessed when considering higher levels of deployment, particularly the impact on noise, visual and light pollution, climate change and air quality, effect on wildlife and life cycle of the drone technology.

Noise from aviation can be a major nuisance, the extent of which is related to the type of noise, intensity and the relative background. Currently there is no legal limit on the level of noise permitted from a drone, indeed there is no legal environmental limit for noise from aviation.¹¹⁰ There are noise limits for occupational exposure and aircraft technical standards to limit noise, as well as noise being taken into account for planning applications around airports and for airspace classification.

Individual cities may also have particular policies on aviation noise. The CAA has a role of monitoring aviation noise and collaborating on and reviewing research into its effects and how they can be reduced. A recent study by NASA found that drone noise was more annoying than that of road vehicles, possibly attributable to greater familiarity with the

¹¹⁰ <http://www.caa.co.uk/Consumers/Environment/Noise/Noise/>

latter.¹¹¹ Legislation proposed by EASA includes restrictions on the noise permissible by drones of different classes.

Although drones are much quieter than helicopters, they also operate closer to the ground and may be used in larger numbers. Noise caused by drones will be a factor in any policy decision related to the increased uptake of drones. One approach to this would be technical noise-limitation standards in the UK.

People may dislike the sight of large numbers of drones and at night time low flying drones could contribute to light pollution. This will be a factor in considering and managing deployment levels in urban spaces and, in addition to noise considerations (which are often context dependent), may lead to operating hours and geographical restrictions on some types of drone operation. This could mean drones are not allowed to operate in particular areas at particular times.

Other environmental issues include the increased emissions from power stations resulting from large scale use of drones, the possible contribution to e-waste caused by difficulty of recycling drone technology and the impact increased drone deployment could have on wildlife, particularly disruption to birds. This will all need to be considered as drone use increases and an appropriate policy response formulated, if necessary.

Public acceptance

In addition to technical and regulatory barriers to developing an urban drone system, public acceptance will be key if drones are to integrate into city life. This will be necessary both in creating demand for drone services and for people to be comfortable enough living around drones for them to operate.

A recent DfT study on public perception of drones showed that awareness of drone technology and regulation is low and people tend to have a negative opinion of drones.¹¹² The same study, reflected in other similar investigations,¹¹³ found that greater acceptance of drone technology is contingent on a number of factors, notably familiarity with the technology, the operator and application, and if the technology is delivering a personal or societal benefit.

The engagement with the Flying High project's partner cities found that public dialogue and accountability are vital for any future integration of drones into city skies. Consultation on local drone policy and mechanisms by which people are able to input to policy and system design will be critical. Alongside this it is important that the public has an understanding of existing rules. Previous surveys, such as that carried out by the Royal Aeronautical Society in the UK,¹¹⁴ show that people by and large do not understand the current framework.

111 <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170005870.pdf>

112 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/579550/drones-uk-public-dialogue.pdf

113 <https://www.nesta.org.uk/blog/public-perception-of-drones/>

114 http://www.comresglobal.com/wp-content/uploads/2016/06/160513_Royal-Aeronautical-Society_DronesPolling_Tables.pdf

Demonstrations of the technology is one very powerful way to engage the public, in addition to a campaign of workshops, focus groups and online consultations. The DfT's recent public dialogue on drone use¹¹⁵ is a good example of previous public engagement around drone technology that was in depth and sustained over time, providing an interesting snapshot of opinion across the UK.

Openness

In addition to procedural transparency, another tool that can engage citizens and drive acceptance is open data. One way to use open data would be by having publicly accessible aspects of a UTM system. This can help people stay informed and to better understand how drones are operating in their city. This could mean being able to log on to a site or use an app to identify the operator of a drone flying in the vicinity of your property, what type of data it is collecting, or even use an app to identify it via a mobile phone. It could also mean being able to log on and see all of the local drone operations that are ongoing in your area.

It would also be desirable to make the data collected by drones open where possible, and compatible with multiple public agencies. For example, where drones are being used to monitor traffic congestion, or capture aerial photography for city planning. This could have the effect not only of engaging the public, but also encouraging the development of new products and services based on drone data. These new products would themselves further normalise the productive use of drones.

Distributional impact and inclusivity

Many drone uses could have a negative impact on inequality, affecting different sections of society in different ways. It will be important that the system evolves in such a way as to avoid this and promote inclusivity. Uneven impact could relate to inequalities in access to drone services, to disproportionate effect on certain types of jobs, or on particular communities.

Certain applications and system design characteristics are more likely than others to create inequalities or negatively affect certain groups. For example, the use of drone mobility and delivery is likely - at least initially - to be a premium service only accessible to the wealthy. Should operating models involve fixed take-off and landing points there may be noise issues for people in the vicinity of these. To promote equitable development, these issues will need to be considered and steps taken to ensure that technology deployment is inclusive.

¹¹⁵ https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/579550/drones-uk-public-dialogue.pdf

What we have found

- There are clear benefits to, and enthusiasm for, using drones for many tasks in UK cities
- There is a lot to do - but to unlock these benefits, we need to address issues of public confidence, feasibility and stakeholder alignment in particular
- We propose a programme of challenge prizes to shape drone technology for good, and to earn a drone dividend for Britain

Around the world, drone technology is developing. Services are being created and rethought thanks to the new possibilities they bring.

Drone technology is already operating in our cities today and will continue to develop with its own momentum, regardless of what the UK chooses to do.

But the UK has the choice whether it wants to lead, or whether it wants to follow. Whether it wants to shape how drones are used, or let others do the shaping.

Based on extensive discussions with cities, technologists, regulators and other stakeholders, we have come to some conclusions around the issues preventing the realisation of public benefit from the use of drones in UK cities today. For each of these conclusions, we present recommendations for issues need to be resolved and what should happen next.

The benefits of drones are recognised by cities

We have found broad enthusiasm for some uses for drones in the UK - but not for all

Our close engagement with five cities, and the competition among 15 others to participate in the Flying High project revealed a **huge appetite for socially beneficial uses of drones**. These are primarily uses supporting city, public and emergency services.

There was far less interest in the more commercial or speculative uses of drones, such as to carry parcels or people.

The public discussion on drones, sometimes influenced by PR for drone companies, is not sufficiently focused on these socially useful use cases. A great deal of publicity has been given to speculative use cases like flying cars and delivering online shopping. There may be a place for these in the long term, particularly to solve specific local problems (such as access to island communities), but these are a distraction from the more immediate and socially beneficial uses drones could be put to. Industry - and the public discussion on drones - should first focus on these.

The use cases we have focused on in this report - medical logistics, connecting remote communities, road and fire incident response, urban regeneration - have broad support

among city stakeholders. Polling evidence suggests they do among the public too. These are the uses that represent the most beneficial opportunity for drones in the UK today.

Given this enthusiasm, the opportunity of drones is worth pushing for.

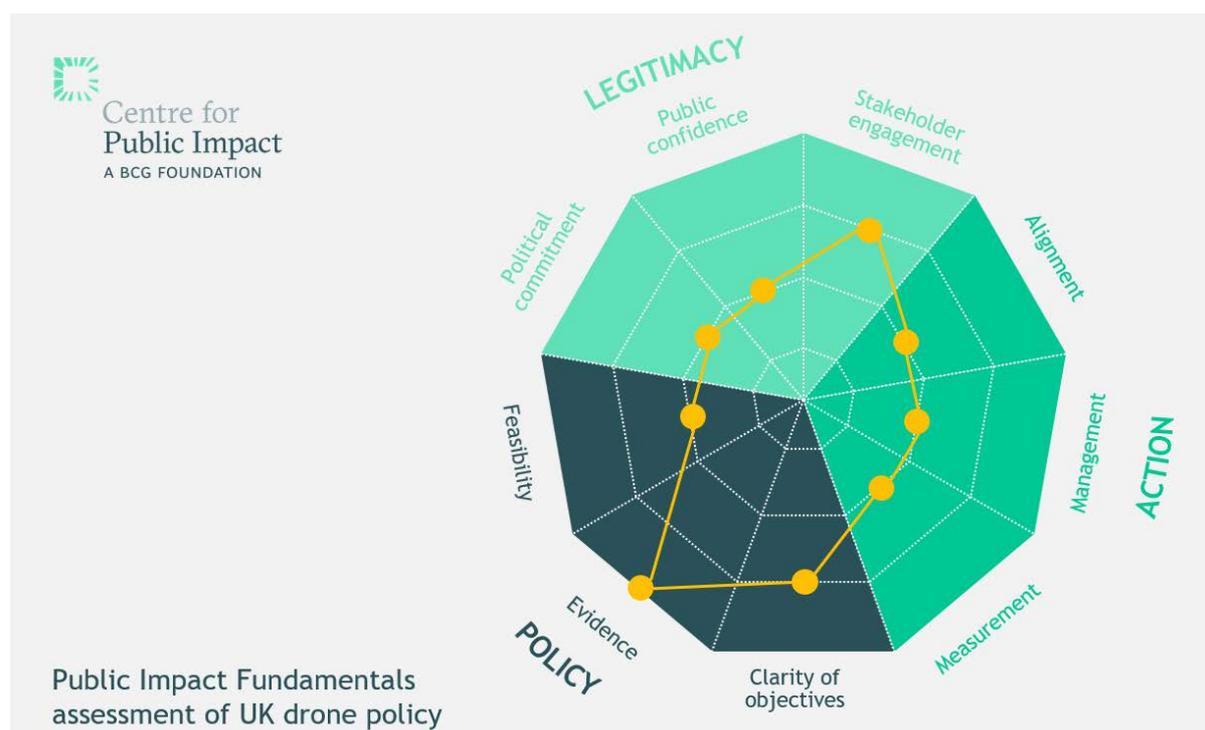
We have identified three key areas that we recommend for further action. Progress is needed on technical and regulatory feasibility, stakeholders need to be aligned and the public engaged.

What is to be done?

A framework for choosing our course of action

To understand where we currently are and where the barriers and challenges lie in relation to unlocking the opportunity of drone technology, we have worked with the Centre for Public Impact (CPI). CPI's Public Impact Fundamentals are an evidence-based framework for assessing the likelihood of success of public policies.

The better an initiative performs against each of their nine elements, the greater the chance of the policy achieving its intended outcomes. CPI's current assessment of drone policy in the UK is below.



CPI's assessment of the current state of drone policy in the UK, carried out for the Flying High project. Credit: Centre for Public Impact

Through our research and engagement over the course of the Flying High project, we have identified as three key areas that we recommend for further action: feasibility, alignment

and public confidence. A consolidated effort to strengthen these elements will impact other areas and increase the likelihood of bringing about positive outcomes for citizens from this technology.

The Centre for Public Impact and the Public Impact Fundamentals - CPI has developed a framework to analyse public policy interventions and assess the causes of their success or failure: the Public Impact Fundamentals. The three Fundamentals – legitimacy, policy and action – provide a structured, evidence-based approach to identify the strengths and weaknesses of programmes. Our conclusions focus on one aspect of Legitimacy (public confidence), one aspect of Policy (feasibility) and one of Action (alignment) as being particularly critical for the future of drones in the UK.

Based on this analysis, we have focused our conclusions on the three areas of public confidence, technical and regulatory feasibility, and alignment of the key stakeholders. These are areas in which there is room for further work, where a challenge-based approach would help, and which are critical to improving the likelihood of success.

Public confidence

Drones can only take off with the consent and confidence of the public

We found a **general lack of knowledge about the potential of drones, the detail of the policy environment that governs them, and uses they can be put to** among the public and also many city stakeholders. The conversation has barely started on what drones should do and how they should be governed. This has not manifested itself as widespread scepticism; it's more that strong opinions are yet to form among people outside of the drone industry. This means that we are at a critical and formative moment in public and official perceptions of drones. The decisions we make, and the language that we use now, will have lasting repercussions.

The general public has not yet played a major role in shaping the future of drones. Their involvement, their chance to shape the emergence of the consensus, and their chance to judge with their own eyes what emerges, will be crucial. Self-reported attitudes to drones are currently not hostile, but self-reported knowledge is low. It is important not to see this as a public relations problem to be solved through messaging and targeted information. Experience of previous new technologies shows that patronising the public, seeing them simply as an audience to be informed, is not the solution. They need to be part of the same ongoing conversation.

Recommendations

Future development of urban applications of drones in the UK needs to be led by cities but with strong support from central government, stakeholders and regulators. Alongside this, the public need to be meaningfully involved in decision-making, because it is only with

public support that drones can be used. If they are not involved, the drone industry risks a public backlash.

Where public money is invested in developing drones, it should primarily be around public service use cases.

If the UK wants to avoid falling behind, it urgently needs to make a proactive decision to lead.

Feasibility

Operating at scale and in complex environments is not possible with today's technology, regulation or infrastructure

Although drone technology is developing quickly, we have identified numerous **cross-cutting technical barriers to large-scale operation**.

A major issue affecting all of the use cases we researched was safe operation beyond visual line of sight in complex urban environments. A related issue is how airspace will be managed in the future to avoid conflicts between different drones, and between drones and manned aircraft, when the skies above our cities get busier.

For many use cases, integrating drones into broader complex systems is a challenge. Making the most of drones in the NHS - for example - requires integration into, and rethinking of, large-scale medical logistics networks. In construction sites, drones bring the greatest benefit if they bring live information directly into building information management systems. For emergency services they would need to be integrated into planning, command and communications systems.

Drones operating at scale will likely need a more robust communications network - more bandwidth, more coverage, more redundancy - than is available at present.

And then there is a plethora of smaller, more self-contained but equally crucial technical issues that need to be resolved, such as: operating in poor weather, achieving longer endurance, developing secure systems and navigation that overcomes some of the technical limitations of GPS. These are set out in the technical chapters of this report.

Existing regulations are not suitable for much larger-scale operation.

The current system in which drone use is extremely tightly restricted by default, with exceptions granted on a case-by-case basis, works for now. However, operation at larger scale will inevitably put this under strain. Many of the default prohibitions - operations in built-up areas, near buildings and people, around airports, around secure sites like prisons - are problematic for the use cases we have identified, particularly if they are to operate at a larger scale. While the restrictions are justified for now, they might be treated in a more nuanced way once more sophisticated management of airspace is in place.

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There is also currently a gap in the regulation of autonomous systems - one that also applies to autonomous vehicles. Going beyond remotely-piloted drones and on to self-piloting drones will not be possible until this is resolved.

Finally, the **necessary infrastructure** is not in place for large-scale operation.

Drones operating in small numbers and with blanket exclusions from flying in problematic areas (such as near airports, people or buildings), as at present, do not need significant infrastructure. They can be piloted by a single qualified individual with permission from the CAA. But at scale, different drone uses will inevitably come into conflict with each other. At present there is no drone equivalent of the air traffic control system to safely manage the airspace in our cities. On top of this, global navigation systems such as GPS are not accurate enough for some of the use cases that require highly precise flight, and communications infrastructure is often not up to scratch.

Recommendations

Future development of drones in the UK needs to solve all these individual technical, regulatory and infrastructure barriers. But these are not just problems in isolation: the increasingly complex environments drones will encounter as services scale up and infrastructure develops means that drones need a safe environment in which to be tested.

We therefore recommend the creation of testbeds in which drone services can be developed, with the facilities and regulatory approvals to support them.

Regulation will also need to change: routine granting of permission must be possible, blanket prohibitions in some types of airspace must be relaxed, and an automated system of permissions - linked to an unmanned traffic management system - needs to be put in place for all but the most challenging uses.

And we will need a learning system to share progress on regulation and governance of the technology, within the UK and beyond, for instance with Eurocontrol.

Finally, the UK will need to invest in infrastructure, whether this is done by the public or private sector, to develop the communications and UTM infrastructure required for widespread drone operation.

Alignment

Government, business and regulators need to be pulling in the same direction

When we started working on the Flying High project, there was **surprisingly little alignment between the different players in the UK drone industry**. Government, regulators, technologists and service providers had some interaction, but few forums in which to share their work. Organisations worked in silos; initiatives duplicated each other's efforts in some areas while leaving gaps in others.

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Technologists and even government funding focused on individual uses, generally without considering the bigger picture. Tech push, rather than demand pull, is the dominant model.

Cities and the public were an afterthought. Neither government nor industry made any sustained effort to discuss the future of drones in cities; city-led initiatives varied in scope and ambition but were generally on a small scale.

The Flying High project has kickstarted cooperation, information sharing and created forums for these organisations to speak with each other. It put cities at the heart of the conversation. It looked at demand, rather than pushing technology for technology's sake. Nesta's role as a neutral arbiter, without a commercial or policy agenda, was key to playing this role.

But this is just a first step. An engagement exercise like the Flying High project has been a good start, but it's not enough to build lasting alignment if it isn't sustained.

Recommendations

The convening and coordination of stakeholders built during the Flying High project needs to continue in order to build on the alignment that has emerged during this phase. The network needs to broaden to include a wider range of cities than the five core cities we have worked with. This network is important because it can set the general direction and vision for drones in the UK. It can also play a role in defining the clear communications that are essential for achieving public support, and to inform and support engagement with the public.

As decisions are made, testing is carried out and new services are developed, the public must be part of the conversation, not just be seen as an audience.

All future activity should have a significant and meaningful element of public engagement built in.

Opportunities and threats for the UK

There is a prize for the UK if we get this right

Through our industry mapping, engagement with national stakeholders and our work with the five cities that partnered in the Flying High project, we have seen **clear evidence that drones are an opportunity for the UK**. Hundreds of companies already operate in the sector and can benefit from new business. UK universities have research strengths in the area. There is public support for many (though not all) use cases. Public authorities can save money or provide new and better services thanks to drones.

We have also seen a threat: UK policy responses to drones are behind those of leading countries. The US, EU, China, Switzerland and Singapore in particular have taken bigger steps towards reforming regulations, creating testbeds and supporting businesses with innovative ideas.

The prize, if we get this right, is that we shape this new technology for good - and that Britain gets its share of the economic spoils.

Challenge prizes could unlock progress

Challenge prizes have been used to kickstart transatlantic flight, driverless cars and private spacecraft. The same approach can put the UK ahead on drones

Challenge prizes reward the first or best organisation to solve a technical challenge. They:

- Create better solutions to technical problems: prizes incentivise new thinking and reward the best solutions, wherever they come from, however they work.
- Bring together innovators and help them thrive: prizes help innovators by providing access to information, ideas, profile-raising opportunities, investment and expertise.
- Unlock systemic change: prizes raise awareness, inform policy and shape the future of markets and technologies.

We believe that challenge prizes offer an opportunity to realise the benefits of drones in UK cities, solve the technical challenges, build momentum behind use cases that have social benefit, and offer a means of building public and political engagement with the future of drone technology. Live and public demonstrations of the technology offer a tangible example of what the future of the technology might hold.

They are an open and democratic way of moving technology forward - rather than the closed and secretive pushing of technology that can so easily lead to growing public mistrust.

Challenge prizes have long been part of the pedigree of aviation. Historic examples of challenge prizes in comparable settings date back as far as the early 20th century, with the Daily Mail prizes and Orteig Prize that led to the first cross-channel, transatlantic and solo transatlantic flights. More recent examples include the Ansari XPRIZE (the first privately built and funded human spaceflight) and the DARPA Driverless Car Challenge which led to breakthroughs in autonomous vehicle technologies.

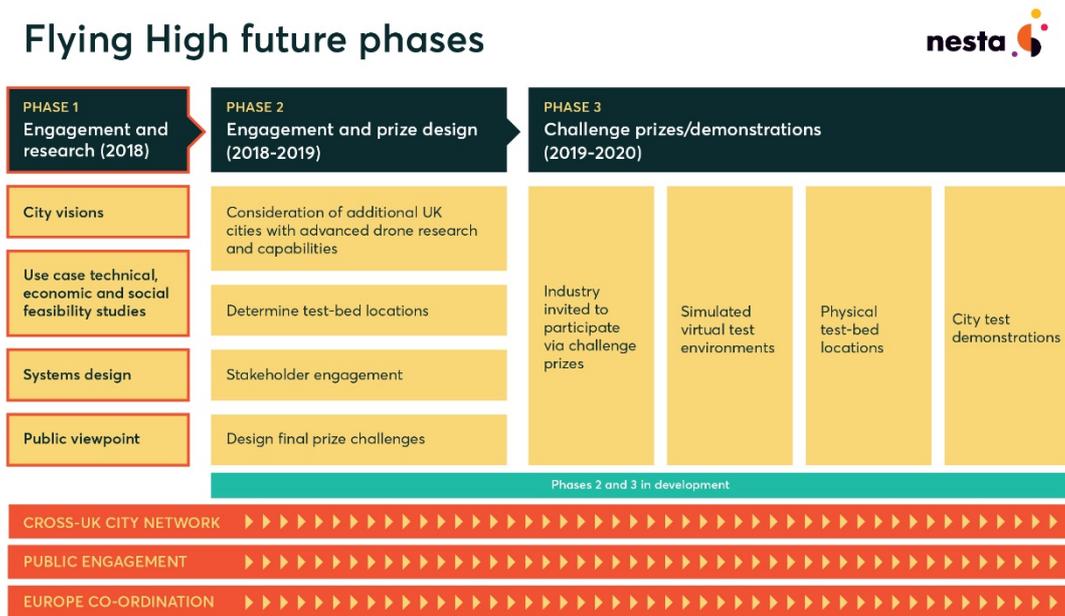
We propose that the challenge prizes should:

- Be developed by city-led consortia to run a series of challenge prizes based around socially beneficial use cases.
- Invite industry to develop drone platforms that meet these needs, and solve the key technical and infrastructural obstacles to their progress.
- Invite competitors to develop, test and demonstrate their solutions in testbeds: first in virtual environments, then in testing facilities, and finally in real urban environments.

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- Use these testbeds both as an opportunity to prove the technology, and in order to meaningfully engage with the public and involve them in decision-making about the future of drones.
- Use the challenge process to complement the building of further alignment between stakeholders and to inform the development of policy in the field.

We propose that the challenge prizes be based around delivering the use cases like those identified in this study; the five cities who have participated in the Flying High project so far could form the core of the city consortia, but this should not preclude other cities from joining the process.



Methodology

The Flying High project has been an exercise in bringing everyone under one roof to identify what needs to be done

The Flying High project report you are reading outlines the key findings of a unique project led by the innovation foundation Nesta, with support from the Centre for Public Impact, WPI Economics, research consultancy Science Practice, PwC, Glass, five UK cities and a number of research associates.

The objective: to explore with cities if and how drones could operate in urban environments.

The programme was structured around several observations:

- **While drone technology has made significant progress, UK projects to date have been largely focused on technology push** rather than demand pull, and on individual drones operating in isolation, rather than drone systems operating at scale in complex environments. The Flying High project therefore aimed to explore where there was demand for drone technology in UK cities.
- **Demand alone isn't enough**; there needs to be proven economic, social and technical viability for these uses. The Flying High project aimed to understand the feasibility of selected use cases to understand whether what is desired is possible.
- The introduction of new technologies is inherently political and social. The Flying High project aimed to better **understand the views and motivations of key stakeholders on the future of drones**, and to make a first step towards a shared vision for what the rules, regulations and systems could look like in the future.

To this end, this phase of the Flying High project featured a number of workstreams:

- City engagement.
- Technical feasibility.
- Economic and social feasibility.
- Key stakeholder engagement.
- Industry and research mapping.
- Systems research.
- Public impact analysis.

City engagement

We worked with five UK cities to better understand their visions for the future

The Flying High project aimed to assess the feasibility of future applications for drones through engagement with cities. Cities are the locations in which many of the most complex and challenging use cases will be located, they are the authors of local economic strategies, the problem owners of many of the issues that drones can be used to address and, in addition, have unique legitimacy through their democratic structures.

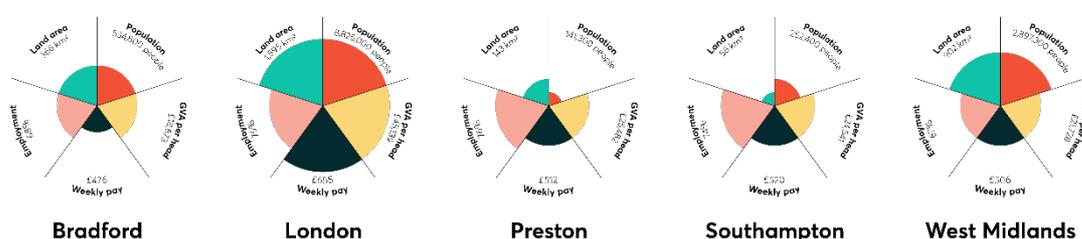
Through engagement with cities, our research aimed for breadth: different geographies, different perspectives and different priorities.

Between December 2017 and January 2018, we invited UK cities to apply to the project. All applied as consortia led by local authorities, but with varying degrees of participation by other public sector institutions (such as emergency services and public health bodies as well as businesses, universities and other organisations). In total, 20 cities applied.

An expert panel including key national stakeholders such as the Civil Aviation Authority and the Department for Transport was convened by Nesta. The panel selected the final five cities, based on quality of applications (including the contribution the cities proposed to make to the research), diversity of city size/type and geographical spread.

Five cities were selected:

- Bradford (consortium lead: City of Bradford Metropolitan District Council).
- London (consortium lead: Transport for London).
- Preston (consortium lead: Preston City Council).
- Southampton (consortium lead: Southampton City Council).
- West Midlands (consortium lead: Transport for West Midlands, West Midlands Combined Authority).



These diagrams provide a high-level comparison between cities in terms of population (nomis area reports for the year 2016)¹¹⁶, gross value added (GVA) per capita (calculated from 2016 ONS regional

¹¹⁶ <https://www.nomisweb.co.uk/home/profiles.asp>

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GVA figures¹¹⁷ and 2016 nomis area report population figures), median gross weekly pay for full-time workers according to 2017 nomis area report), land area (for the year 2015 according to ONS Standard Area Measurements),¹¹⁸ and employment (percent of population aged 16–64 in employment from nomis area reports for the year 2017).

The primary purpose of city engagement was to understand and develop city-led ‘visions’ for the future of drones; how drones could be used to further the diverse strategic aims of these five cities.

The secondary purpose was to inform technical, economic and social feasibility studies conducted on one specific use case for each city. Early in the process Nesta consulted with each of the cities to identify what this one key use case could be, and to explore each in greater depth. These consultations informed the detailed technical and economic feasibility chapters of this report, which outline how such use cases could operate at scale, and how specific instances of them (that could inform pilot projects).

Cities engaged with the Flying High project by allocating staff time to the project. Each of the five city and technical leads worked closely with Nesta throughout the programme by gathering information and introducing relevant stakeholders to support the development of the report. They acted as a vital conduit between the Flying High project team and key stakeholders in the city. Using their local knowledge, each city lead brought together a local task force that was best suited to work with the city during the project.

Task forces included local authority officers, public sector representatives, researchers, community organisations and local drone industry professionals. Each task force held meetings at least every month, where they decided on possible use cases for the technical feasibility study and contributed towards the development of the city’s vision.

To expand participation in the project, each city hosted a workshop facilitated by Nesta, inviting a wide range of stakeholders to debate the possible roles of drones in their city and to help shape the city’s vision.

Nesta also encouraged shared learning amongst the five participating cities and set up a number of online platforms for sharing documents and news, as well as the opportunity to discuss relevant issues and share knowledge. The five cities were brought together for an away day part-way through the project, held at the University of Southampton. Here they shared experiences and lessons learned during this phase of the programme, and were given a presentation on existing and future drone regulation by the Civil Aviation Authority.

Some cities additionally arranged for drone demonstrations to be held and surveys conducted with their residents. This data informed the development of the city’s vision.

117 <https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/regionalgrossvalueaddedincomeapproach>

118 <https://ons.maps.arcgis.com/home/item.html?id=765d780b6c33498a8db80d1d2c5966cd>

Technical feasibility

Our technical experts engaged with industry and cities to delve into five promising use cases

If city engagement provided the Flying High project with breadth, the technical feasibility studies provided depth. These studies examined in greater detail the five priority use cases identified in partnership with each of the five cities. They asked: what would this type of service look like and what would its benefits be? How would a very specific instance of that use case operate? What would it require? What challenges need to be overcome? The objective was for these studies to be able to inform the design of pilot programmes that reflect the key features of operation in the real world, and at scale.

The use cases were selected in order to respond to genuine needs in each of the cities, and to achieve a spread of different types of service (public vs private), drone (such as high endurance requirement vs low, different weights of payload, etc.), mission (logistics vs observation), and with applications in different sectors of the economy. They also aimed to look at operational parameters that pushed current technical and regulatory boundaries and could provide a focus for further R&D, rather than just looking at what is currently possible.

The technical feasibility studies were primarily informed by engagement with technical experts and city stakeholders through interviews and workshops, augmented by desk-based research. The outlines of the five use cases published in this report highlight the key features and technical parameters we learned through this process, and give an indication of the technological developments needed in order to deliver each of these five services.

Economic and social feasibility

Our economic team investigated the viability of the five use cases

The economic and social feasibility studies aimed to assess the commercial and social viability of each use case (given certain operational assumptions). These helped to answer the question: assuming this use case is technically feasible, is there a solid economic rationale for it, taking into account the broader social impact?

The economic assessment identified the parameters that affect the costs and benefits associated with the selected use cases over a 10 year period. For each use case, drivers of economic impact were identified, alongside mechanisms to quantify these drivers. Social benefits, such as public health impacts or network efficiency gains, were also priced into the model.

The use cases published in this report summarise the findings of this economic modelling.

Key stakeholder engagement

We convened key stakeholders and regulators to develop a shared vision for drones

We built a network of key organisations with an interest and stake in the future of drone applications. This network was regularly called upon to discuss emerging findings of the project and to build their capacity to work together on each use case.

Industry and research mapping

We looked into the current UK drone industry landscape

The opportunities for the UK drone sector are not just a function of the demand for (as evidenced through city engagement) or feasibility of (evidenced through the technical and economic feasibility research) drones in the UK. They also depend on an understanding of the landscape of UK industry and research in the sector.

We worked with AI start up Glass, PwC and Nesta's innovation mapping team to map the UK drone sector and better understand where the strengths and weaknesses of British industry and research are, and where some of the key opportunities arise.

Glass have developed tools using artificial intelligence to interpret text to identify companies working in a given sector. They scanned the web to identify companies working in the drone industry that had a UK address on their site, or that had a .co.uk domain name. This generated a list that was supplemented with data from Gateway to Research on UK recipients of UK and European government funding for drone projects. PwC worked with us to categorise these players according to if they were a technology developer, drone-powered service provider (e.g. using drones for surveying or agriculture inspection), provider of services to the drone industry (such as insurance, training, or maintenance), an academic institution or 'other'.

The Nesta innovation mapping team then created an interactive map to display this data, allowing users to explore the UK drone industry. This tool provides an excellent overview of the UK drone industry, with the caveat that drone service providers are undercounted (as many of these are sole traders or do not have .co.uk address or a UK address on their webpage).

Systems requirements

Understanding drone systems at scale

Some of the key properties of how drones will operate in cities are emergent properties of scale.

One car only needs a road, but managing heavy traffic in cities requires physical and systemic adjustments: the highway code, traffic lights, lanes, speed limits, driving tests and so on.

If they are to operate at significant scale in complex urban environments, drones will need something similar; a skyway code to complement the highway code.

Our research into systems requirements extrapolates findings from the technical and economic feasibility studies, understood through the lens of the findings from the cities, to paint a picture of some of the requirements and challenges associated with integrating drones into city ecosystems in the medium- to long-term.

Public impact analysis

Predicting the impact of drone policy

To understand the likelihood of achieving the objective of future phases of the Flying High project, we have used the Centre for Public Impact's (CPI) framework, the Public Impact Fundamentals. The three fundamentals (legitimacy, policy and action) provide a structured, evidence-based approach to assess and understand what can be done to maximise the chances of a policy or initiative achieving public impact.¹¹⁹

The framework was developed with the support of leading practitioners and senior academics around the world and has been tested against more than 300 cases internationally. In developing the framework, CPI sought to develop a framework underpinned by cutting-edge thinking from academia and tested by government officials so that it can be immediately usable.

Each of the fundamentals has three elements that collectively contribute to its performance:

- Legitimacy comprises public confidence, stakeholder engagement and political commitment.
- Policy comprises clear objectives, evidence and feasibility.
- Action comprises management, measurement and alignment.

To diagnose the likelihood of a policy or initiative achieving its intended outcomes, each element is assessed using a four-point scale (weak, fair, good or strong).

A diagnosis always reflects an assessment at a certain point in time and can be used to look back at the moment of initiative design, understand its current status and/or evaluate future developments.

¹¹⁹ See: <http://www.centreforpublicimpact.org>

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It is important to note that elements can mutually reinforce or be in tension with each other. Focusing on improving one element, for instance stakeholder engagement, might have knock-on effects on other elements.

Glossary

Term	Acronym	Definition
Air traffic control	ATC	Services that guide aircraft and deconflict airspace
Automatic dependent surveillance - broadcast	ADS-B	A type of electronic conspicuity device
Civil Aviation Authority	CAA	The UK's aviation regulator
Class A/B/C/D/E/F/G airspace		Airspace is divided into different classes with different rules on what is and is not permissible. Classes A-E are controlled airspace, classes F and G are uncontrolled airspace
Controlled airspace, uncontrolled airspace		Controlled airspace is airspace that can only be used following instructions from air traffic control. Uncontrolled airspace is open to general aviation to fly in using visual flight rules without air traffic control
Electronic conspicuity	EC	A class of technologies that make an object such as a drone visible to electronic systems such as air traffic control
Eurocontrol		Intergovernmental agency that oversees and coordinates air traffic control across the continent of Europe
European Aviation Safety Agency	EASA	European Union agency that oversees aviation safety
Fixed-wing		Drones that gain their lift from wings, like a plane
Hybrid VTOL fixed-wing		Drones that take off vertically using rotors, then fly forward using wings
Multi-rotor		Drones that gain their lift from rotors, like a helicopter
National Air Traffic Services	Nats	The company that runs the UK's air traffic control system

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UAS traffic management system, unmanned traffic management system, urban air traffic management system	UTM	An air traffic control system for drones. The terms are used interchangeably
Unmanned aerial system, unmanned aerial vehicle	UAS, UAV	Drone
Vertical take-off and landing	VTOL	Drones that can take off vertically, like a helicopter, rather than along a runway, like a plane
Visual flight rules, Instrument flight rules	VFR, IFR	When using visual flight rules, a pilot flies their aircraft based on what they can see. In instrument flight rules, the pilot follows the instrumentation in their cockpit, instructions from air traffic control and follows a flight plan
Visual line of sight, Extended visual line of sight, Beyond visual line of sight	VLOS, EVLOS, BVLOS	There are three broad categories of drone flight: flight within visual line of sight is flying a drone where the pilot controlling the drone is nearby and can see the drone; extended visual line of sight is flying a drone further than the pilot can see, but with another operator able to see it; flying beyond visual line of sight is flying a drone with a pilot who cannot see where the drone is, and relies on the instrumentation on the drone for all situational awareness
Air navigation service provider	ANSP	Body that provides air navigation services to manage air traffic on behalf of a company, region or country

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Appendix: technical and economic feasibility studies

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.

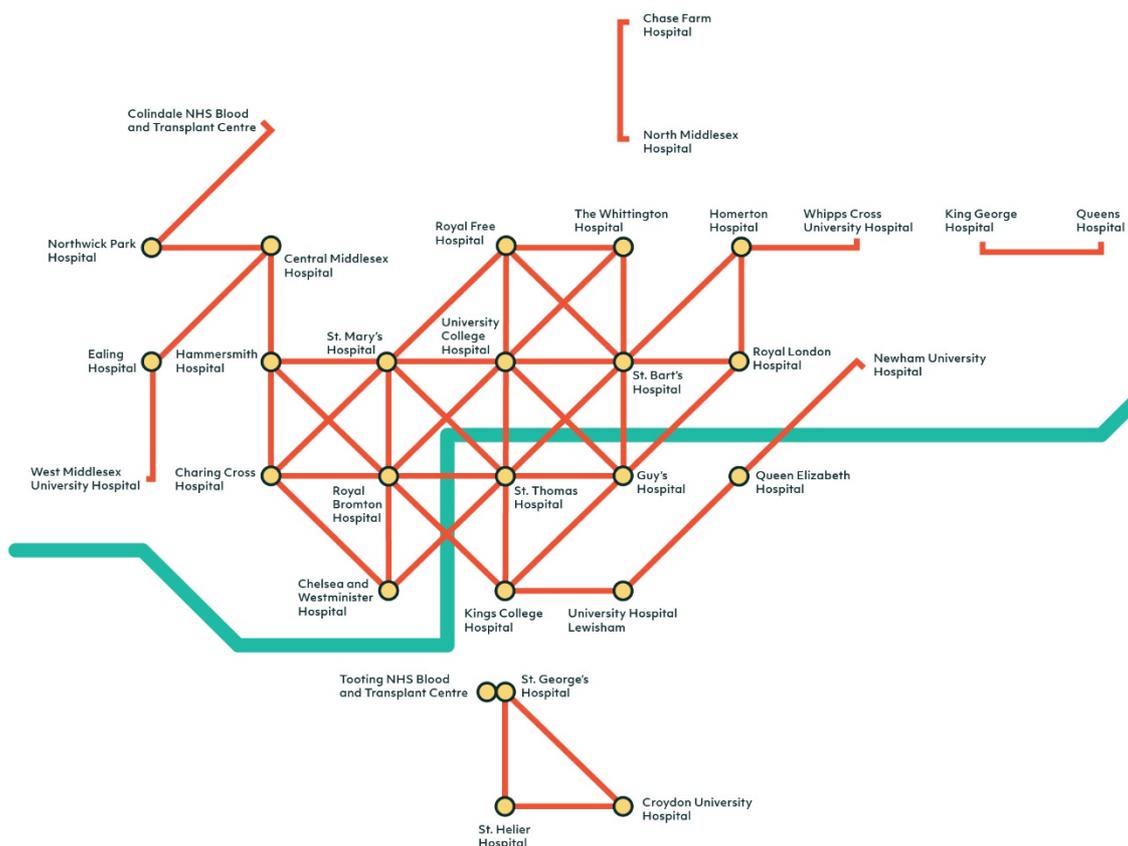
We consider the opportunity for drone-based medical logistics in London, in general and focus specifically on the technical and economic factors relating to the movement of pathology samples between Guy's and St Thomas' hospitals in central London.

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.

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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.¹²⁰ 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 networks¹²¹ and a shift towards delivering care closer to the home¹²², as well as an initiative to provide one stop shops¹²³ to speed up diagnosis.

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

121 <https://improvement.nhs.uk/resources/pathology-networks/>

122 <https://improvement.nhs.uk/resources/moving-healthcare-closer-home/>

123 <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.¹²⁴ In addition, the flight times of drones are

¹²⁴ <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 km¹²⁵ 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

¹²⁵ <https://data.london.gov.uk/dataset/land-area-and-population-density-ward-and-borough>

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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.

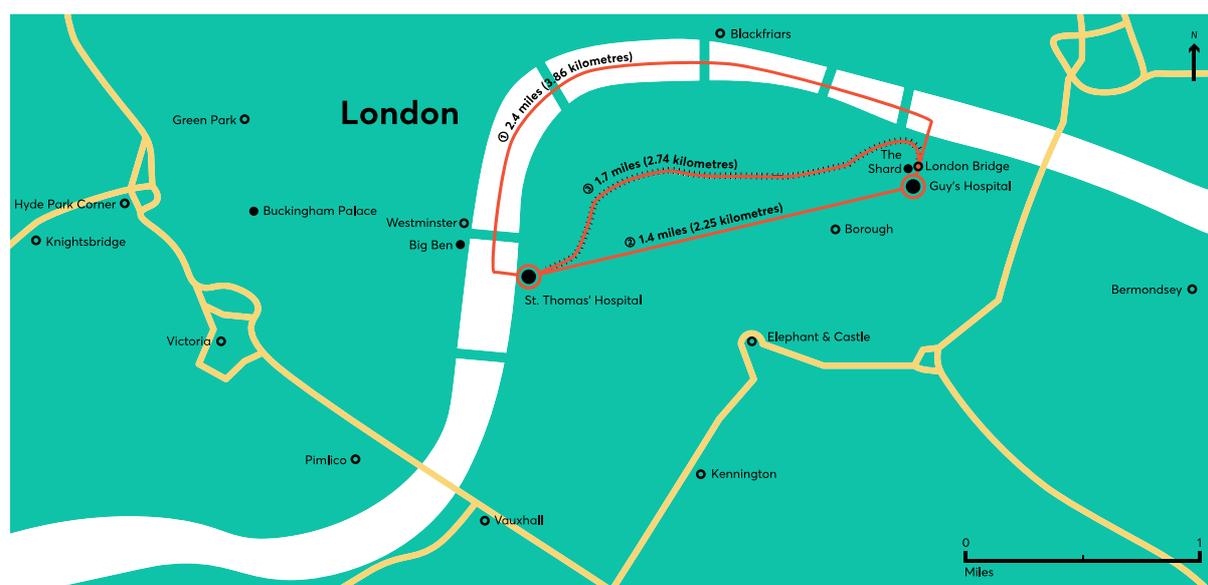
The ability to have a low-cost, fast delivery connection on demand could allow a more even flow of samples to the laboratory and avoid the risk of turnaround delays that can be associated with batch processing. As well as speeding up turnaround time, a drone delivery connection could enable a seven-day 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.¹²⁶
- 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.

¹²⁶ <http://www.pla.co.uk/Safety/Use-of-drones/unmanned-aerial-vehicles-UAVs>

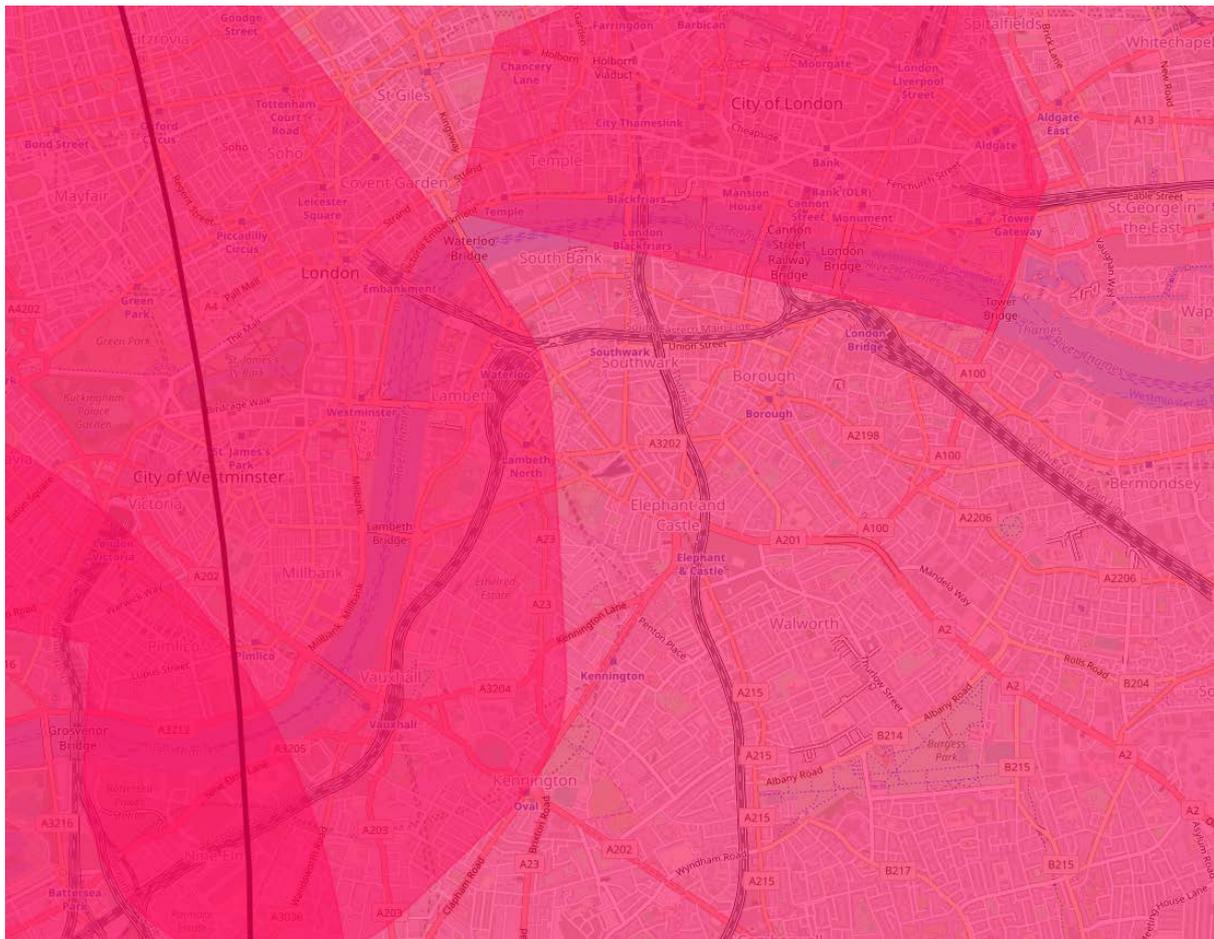
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- Avoids flying over buildings people and roads.

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,¹²⁷ 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.

¹²⁷ <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 an 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)¹²⁸, 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

¹²⁸ 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 drone 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.¹²⁹ 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.¹³⁰ 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 there 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.

¹²⁹<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3971384/>

¹³⁰<https://wrightacoustics.com/white-paper>

- **Weather/climate:** Current multi rotor drones generally have recommended operating restrictions of 0-40°C and wind limitations of 19 knots¹³¹, 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 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.¹³²

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.

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

132 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.

- 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 specific radio equipment, it must comply with Ofcom regulations¹³³. 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 2018¹³⁴. It applies to 'operators of essential services', which includes healthcare organisations. It requires¹³⁵ 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)¹³⁶, 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 traffic 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

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

134 <http://www.legislation.gov.uk/ukxi/2018/506/contents/made>

135 <https://ico.org.uk/for-organisations/the-guide-to-nis/>

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

the flight control system to autonomously react to any potential conflict. Traffic lanes should be developed with specified rules and regulations defined.

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 2018¹³⁷. It applies to 'operators of essential services', which includes healthcare organisations. It

¹³⁷ <http://www.legislation.gov.uk/uksi/2018/506/contents/made>

requires¹³⁸ them to take technical and organisational measures to manage security risks, such as having processes for incident handling.

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 as 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 project¹³⁹ 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

¹³⁸ <https://ico.org.uk/for-organisations/the-guide-to-nis/>

¹³⁹ <https://www.nesta.org.uk/news/drones-in-our-cities-by-2020-predict-a-quarter-of-people-rising-to-half-by-2024/>

use of drones is also likely to help reduce congestion and pollution, with associated social benefits to the city, as a whole.

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).¹⁴⁰

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. £1,500¹⁴¹. 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.

¹⁴⁰ 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.

¹⁴¹ The baseline 2018 salary estimate was £35,000; this was updated to 2019 prices using recent OBR CPI estimates found here: <http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/>

Flying High: shaping the future of drones in UK cities

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 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.

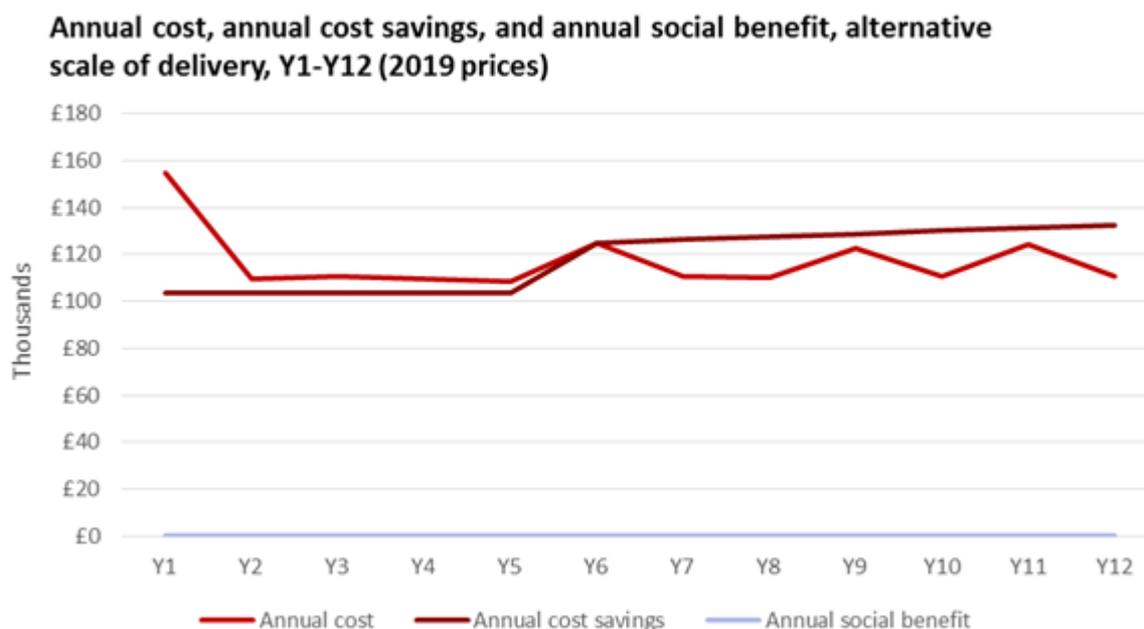
For patients, the difference in speed of getting these samples transported by drone rather than by the current courier service is small, as 95 percent per cent of samples are already processed the day they are collected.

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 drones¹⁴² 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.

¹⁴² Beginning with three in Y1, increasing to four in Y6, five in Y9 and six in Y11.



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.

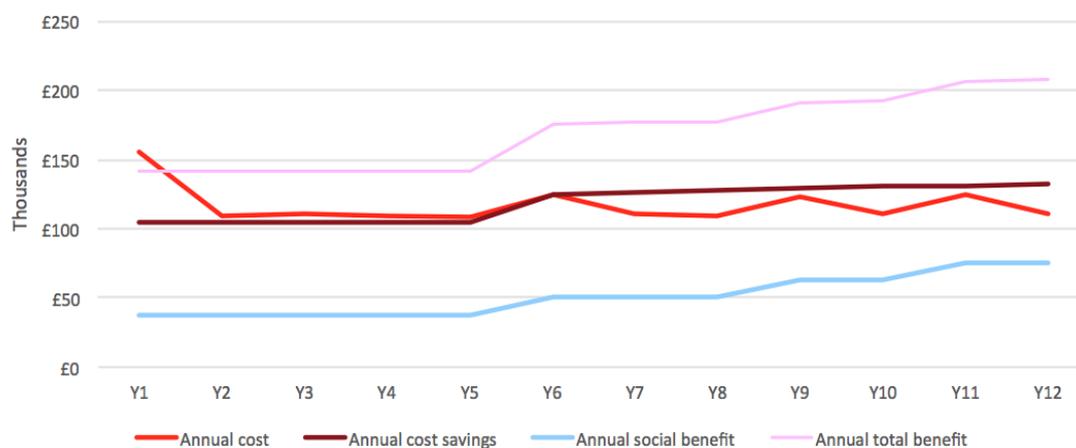
Depending on the type of sample and mode of delivery, drones can help improve medical outcomes for patients

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 £50,000.¹⁴³ 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.

143 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.¹⁴⁴ 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.¹⁴⁵ As well as causing death and injury, road traffic incidents cause serious disruption to travel.

¹⁴⁴ <http://www.worldlifeexpectancy.com/cause-of-death/road-traffic-accidents/by-country/>

¹⁴⁵ <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.¹⁴⁶
- 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.

¹⁴⁶ <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.¹⁴⁷

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

¹⁴⁷ <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 minutes¹⁴⁸. 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.¹⁴⁹

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

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

149 <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 2016¹⁵⁰, 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.

¹⁵⁰ Data extracted from http://data.dft.gov.uk/road-accidents-safety-data/dftRoadSafety_Accidents_2016.zip

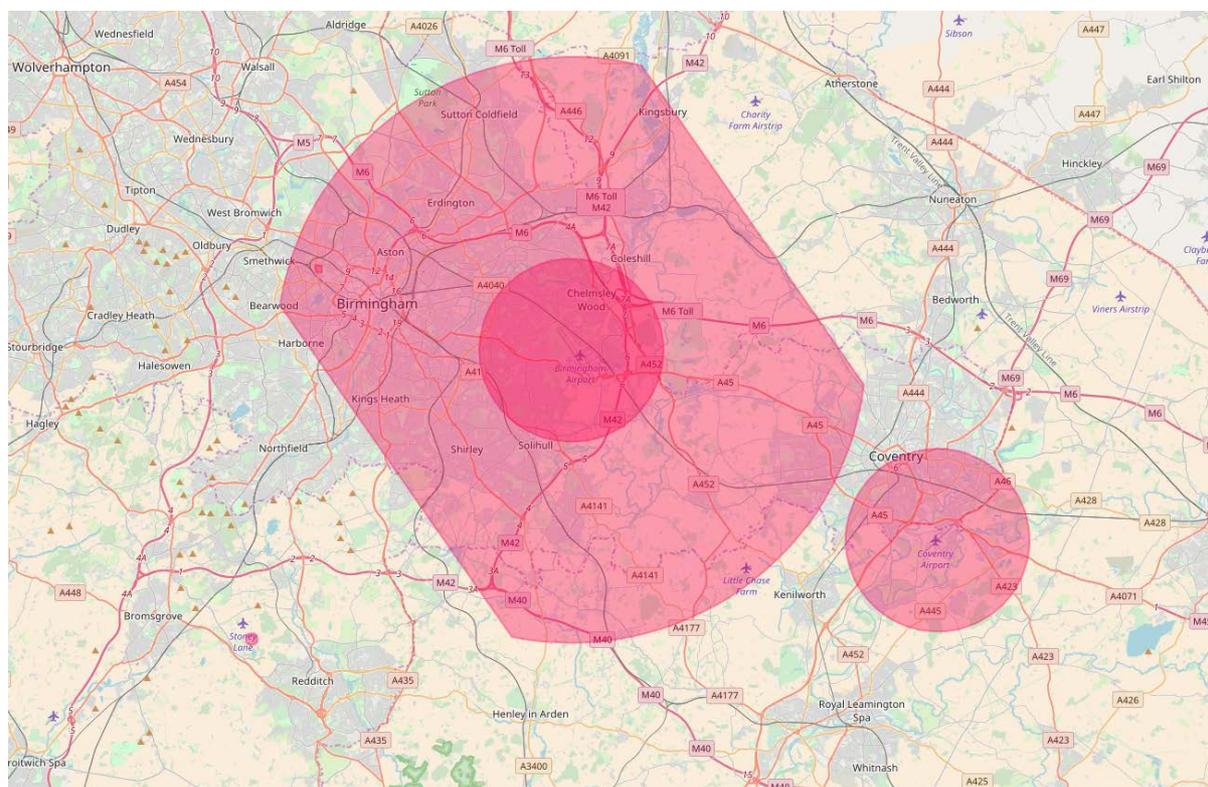
Technical attributes

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).

Flying High: shaping the future of drones in UK cities

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 zone. 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 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 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.

- o 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.
- o 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.
- o The broadcast of real-time HD video feeds from the crash site to the emergency services.
- o 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.
- o 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.
- o 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.
- o 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.
- o 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.
- o 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.
- o 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

- o 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.
- o 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 an 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)¹⁵¹, 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.

¹⁵¹ 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 0-40°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 landing¹⁵². 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.¹⁵³

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.

¹⁵² Based on Flying High technical forum.

¹⁵³ 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 an emergency response operation the drone may be required to operate beyond its regulatory limitations in some circumstances. It is suggested that regulation addressing this need with special dispensation should certain conditions be met as is currently the case with VLOS operations (E4506).¹⁵⁴
- 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.¹⁵⁵ 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)¹⁵⁶, 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 traffic 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.

¹⁵⁴ <https://publicapps.caa.co.uk/docs/33/1233.pdf>

¹⁵⁵ <https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/drones-advice>

¹⁵⁶ <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 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)¹⁵⁷ 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)¹⁵⁸.

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

¹⁵⁷ 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>

¹⁵⁸ 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. £1,500¹⁵⁹. 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.

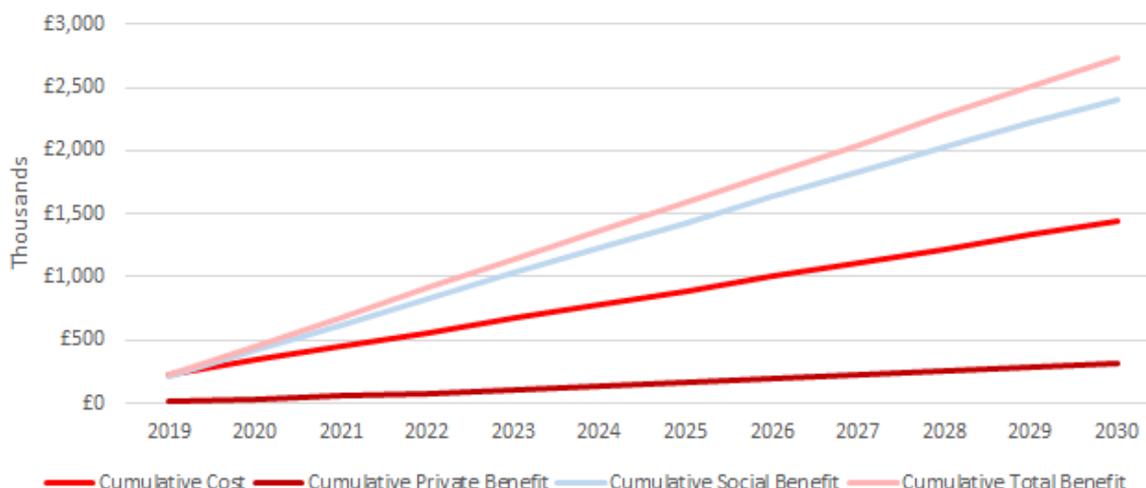
There is a strong economic benefit from using drones as a rapid response to traffic incidents.

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.

¹⁵⁹ The baseline 2018 salary estimate was £35,000; this was updated 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.

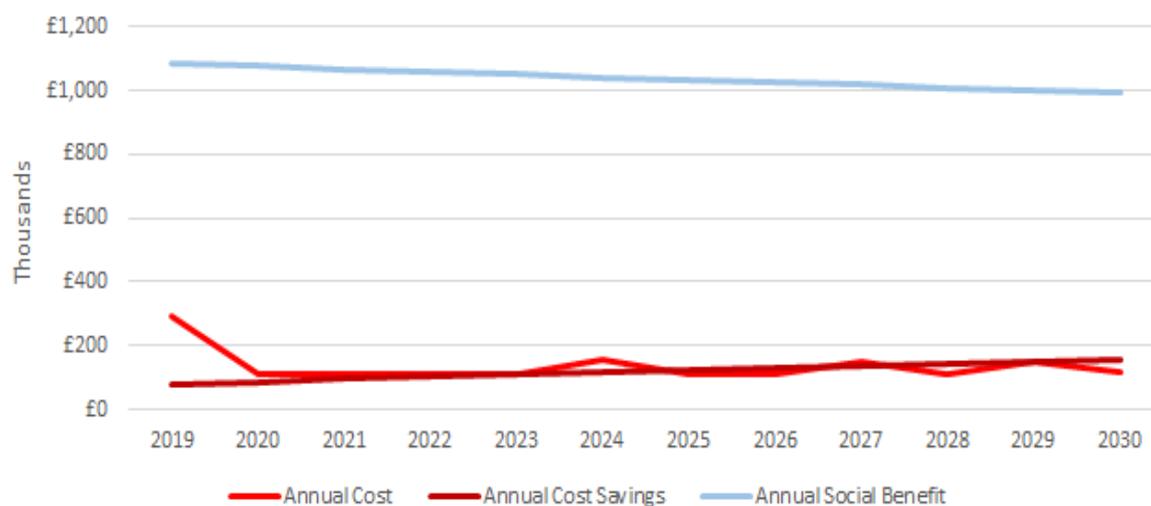
Covering a wider area and improving integration into the wider emergency response system can lead to further benefits

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 Midlands¹⁶⁰ 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:

¹⁶⁰ 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)

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- 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.

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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.¹⁶¹

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 facilities¹⁶²					
		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

¹⁶¹ Ticket prices checked with Wightlink and Red Funnel Ferries on 5 July 2018 for travel on 6 July 2018.

¹⁶² 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.¹⁶³ 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.¹⁶⁴ The drones' ability to fly directly across the Solent reduces delivery times by up to two

¹⁶³ <https://improvement.nhs.uk/resources/pathology-networks/>

¹⁶⁴ <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).

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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. ¹⁶⁵		
	Ad-hoc deliveries	Emergency deliveries
St Mary's Hospital on the Isle of Wight	107	1

¹⁶⁵ 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 product¹⁶⁶). There are special containers for short journeys, made of thermally insulating plastic, weighing five to seven kilograms. It is recommended not to transport more than 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

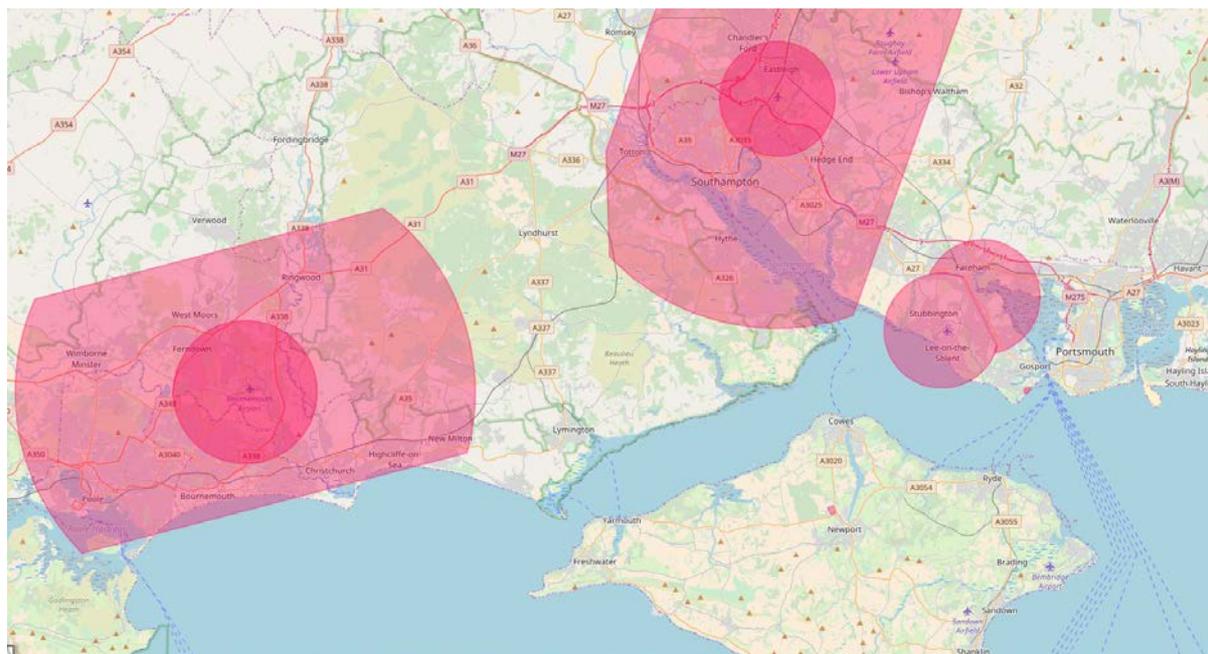
The proposed routes are over open water and parks/forests. This is in order to avoid buildings and highly populated areas, reducing risk and nuisance.



166 <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 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)¹⁶⁷
- 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:

¹⁶⁷ <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,¹⁶⁸ 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

¹⁶⁸ <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 an 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), 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 landing¹⁶⁹. 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.¹⁷⁰

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.

¹⁶⁹ Based on Flying High technical forum.

¹⁷⁰ 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.¹⁷¹ 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 2018.¹⁷² 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),¹⁷³ 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.

¹⁷¹ <https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/drones-advice>

¹⁷² <http://www.legislation.gov.uk/uksi/2018/506/contents/made>

¹⁷³ <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. £1,500¹⁷⁴. 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 £50,000.¹⁷⁵

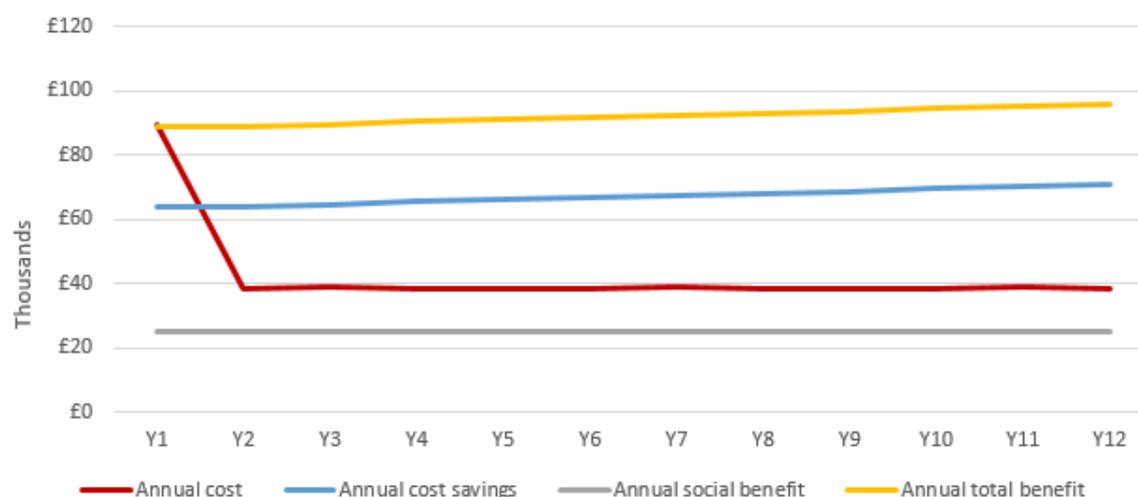
Deploying a drone to connect the hospitals can unlock significant savings and improve the efficiency of the hospital network

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.

¹⁷⁴ The baseline 2018 salary estimate was £35,000; this was updated to 2019 prices using recent OBR CPI estimates found here: <http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/>

¹⁷⁵ This is an indicative model as there was no obvious way to value the dynamic and distributed effects of intra-hospital deliveries.

Total Cost, Total Private Benefit, and Total Social Benefit, Annual



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 £50,000.¹⁷⁶ 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).

¹⁷⁶ 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)

Flying High: shaping the future of drones in UK cities

- 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 possible

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 M55.¹⁷⁷

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.¹⁷⁸ 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.

¹⁷⁷ <http://www.lancashirelep.co.uk/city-deal/near-you/north-west-preston/preston-western-distributor.aspx>

¹⁷⁸ <http://www.lancashirelep.co.uk/city-deal.aspx>

Flying High: shaping the future of drones in UK cities

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.¹⁷⁹

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.

¹⁷⁹ <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.¹⁸⁰ 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

¹⁸⁰ <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 2016/17.¹⁸¹ 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

¹⁸¹ <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.¹⁸² 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).¹⁸³

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.

¹⁸² <http://www.lancashirelep.co.uk/lep-priorities/growth-deal.aspx>

¹⁸³ <https://www.niauk.org/event-listing/engineering-technology-solutions-exhibition/>

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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.

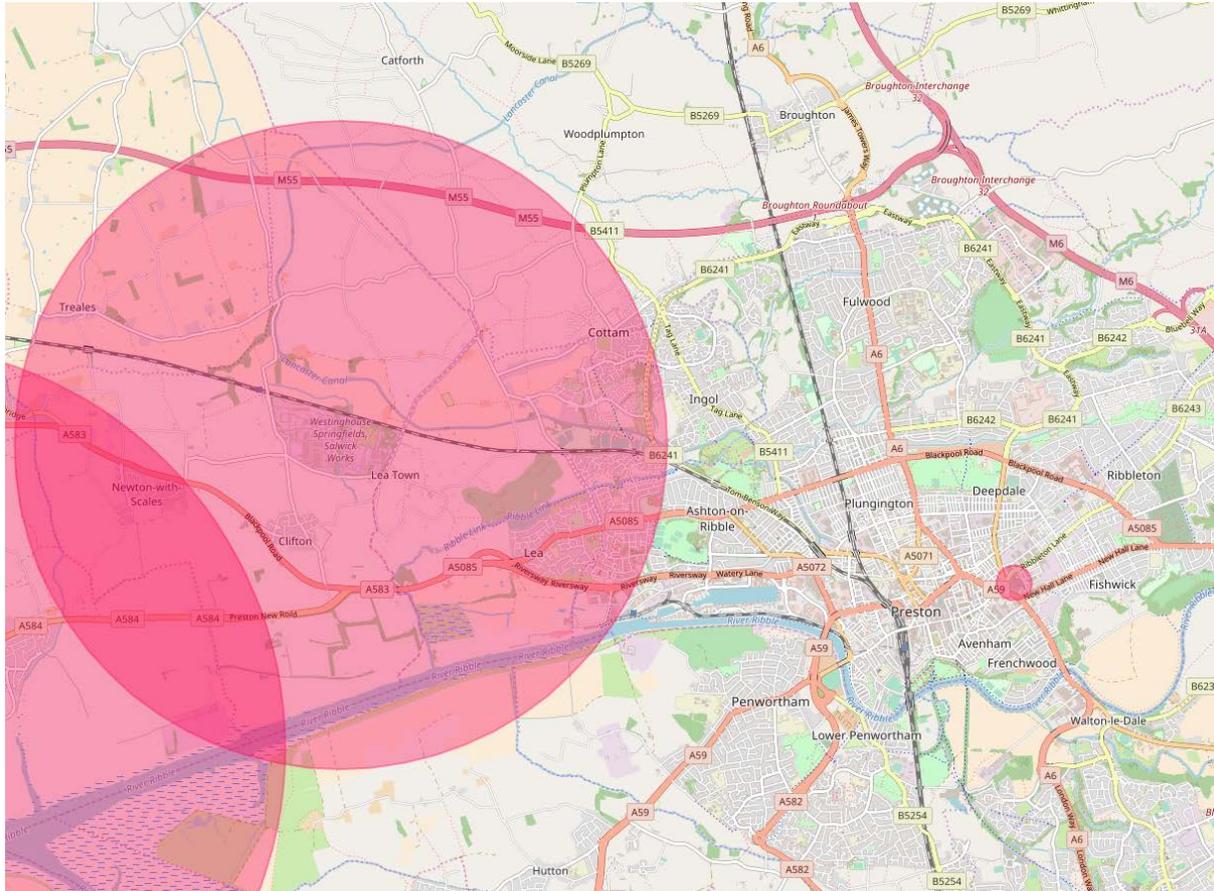
The main elements of the scheme are:

- 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 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 need to be 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 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 an 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),¹⁸⁴ 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

¹⁸⁴ 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.¹⁸⁵ 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.¹⁸⁶ 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.

¹⁸⁵ <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3971384/>

¹⁸⁶ <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.¹⁸⁷

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.¹⁸⁸ 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.

¹⁸⁷ 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.

¹⁸⁸ <https://www.ofcom.gov.uk/about-ofcom/latest/features-and-news/drones-advice>

- This use case will need to comply with the EU General Data Protection Regulation (GDPR),¹⁸⁹ 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 traffic 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

¹⁸⁹ <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.^{190 191} 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

¹⁹⁰ https://policy.ciob.org/wp-content/uploads/2016/05/CIOB-Productivity-report-2016-v4_single.pdf page7 and

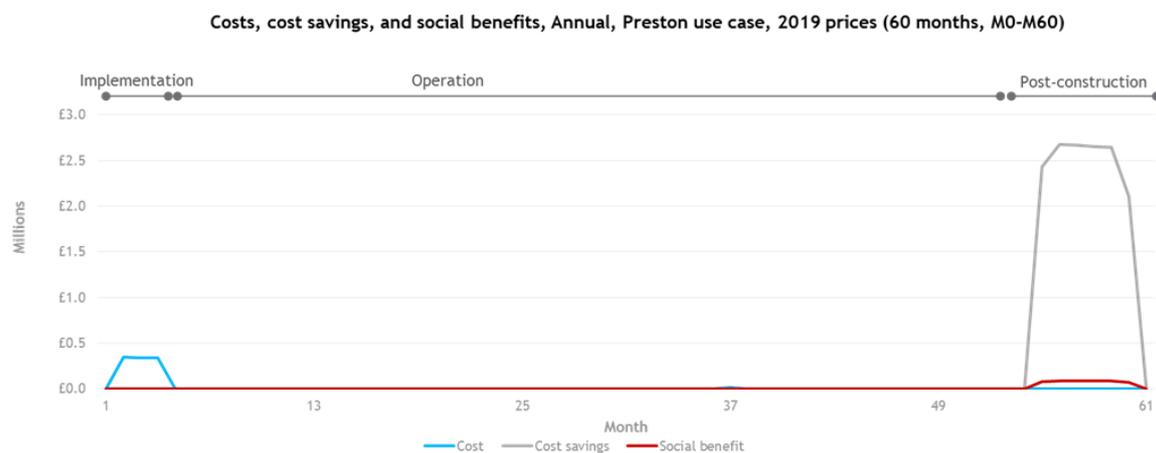
<https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/labourproductivitybyindustrydivision>

¹⁹¹ <http://wpieconomics.com/publications/off-site-construction/>

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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.

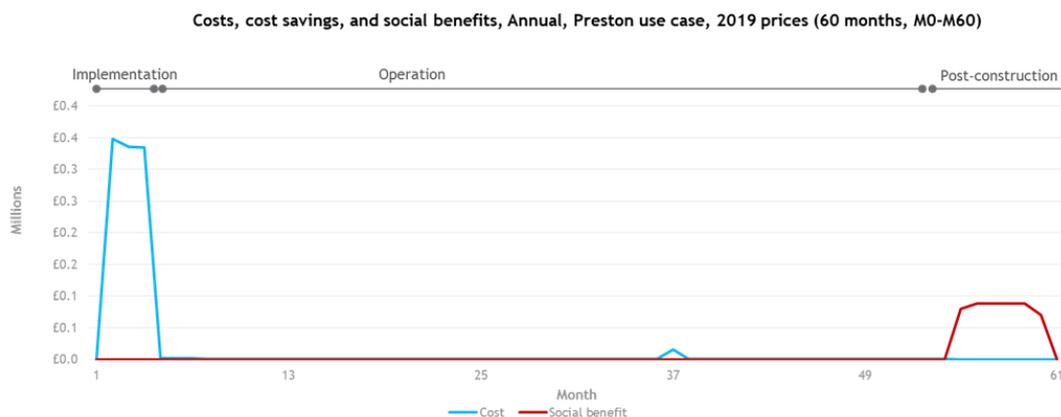
As can be seen from the graph below (which illustrates the 40 per cent run over scenario), there are three key phases to consider in terms of the estimated impacts of the drone deployment:



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.

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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 overrun 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)

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- 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

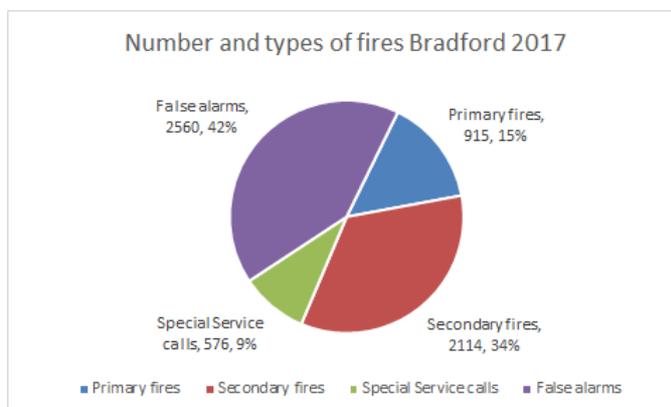
The case for fire and rescue drones in Bradford

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

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District. Bradford has had several major fire incidents in recent years, such as the Drummond Mill¹⁹² and Prospect Mill¹⁹³ fires in 2016, in addition to major flooding, most recently in 2015¹⁹⁴.

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,¹⁹⁵ the West Midlands¹⁹⁶ and Kent.¹⁹⁷

WYFRS invested in a drone in February 2018,¹⁹⁸ 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

192 <https://www.bbc.co.uk/news/uk-england-leeds-35436802>

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

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

195 <https://zoinet.org/wp-content/uploads/2018/01/12.Manchester.pdf>

196 <https://www.wmfs.net/16054/>

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

198 <http://www.westyorkshirefire.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 rules¹⁹⁹ (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.

¹⁹⁹ <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 2010.²⁰⁰ 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.²⁰¹

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 reduce 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

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

201 <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:
 - o Identifying people trapped in buildings.
 - o Identifying structural damage and risks to structural integrity.
 - o 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

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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.

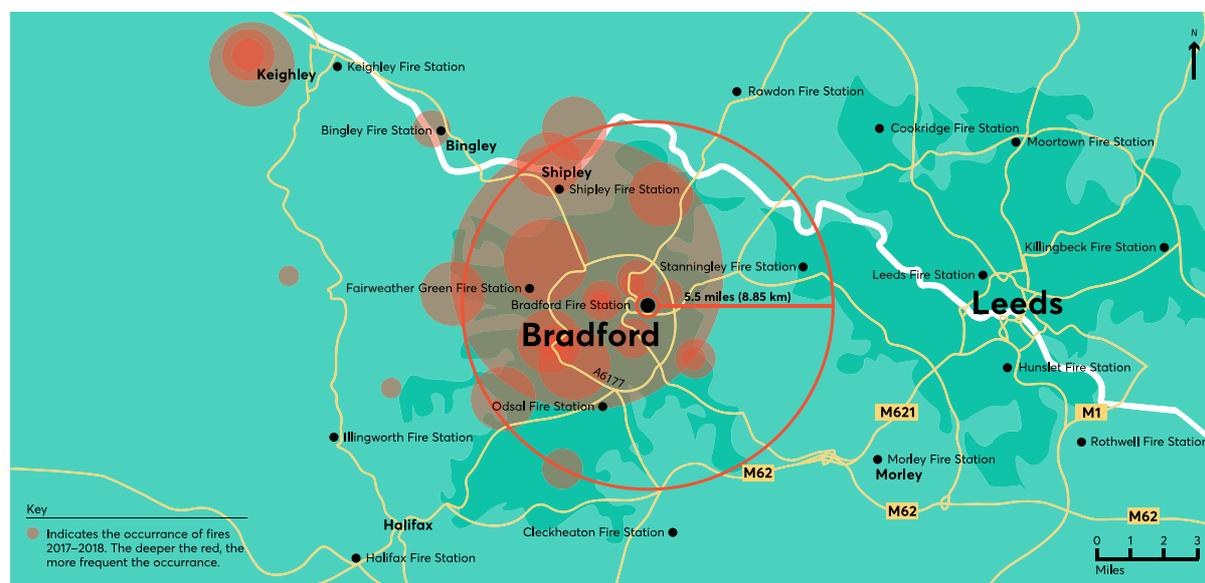
A single service would be able to cover the majority of incidents reported in Bradford District in 2017-18, which were clustered around Bradford itself and the nearby town of Bingley, also part of the City of Bradford Metropolitan District Council. The drones would need to cover an area with a radius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

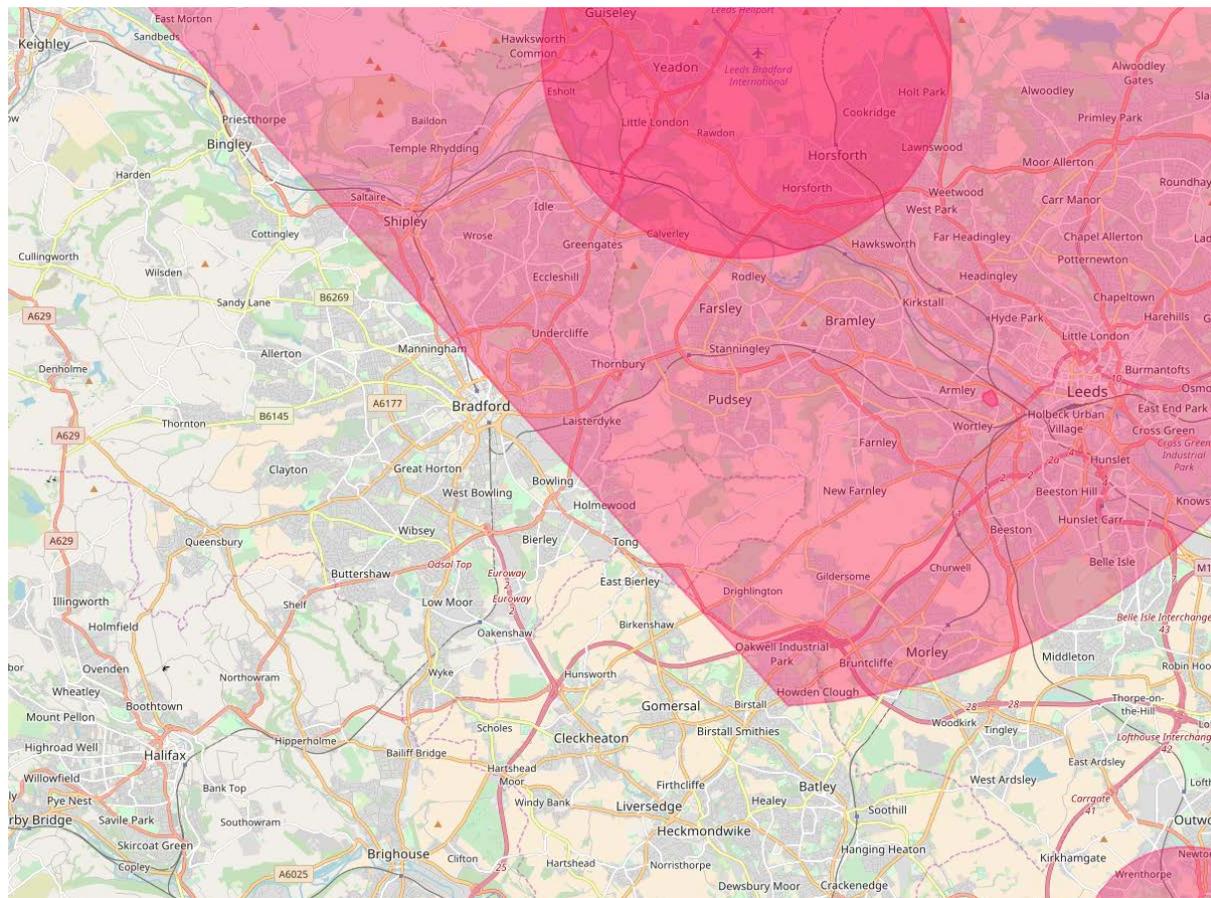


Airspace and altitude

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

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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 an 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),²⁰² 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

²⁰² http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v1.0.pdf

15 knots for take off and landing²⁰³. 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.²⁰⁴

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 an emergency response operation the drone may be 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)²⁰⁵.
- 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.

203 Based on Flying High technical forum.

204 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.

205 <https://publicapps.caa.co.uk/docs/33/1233.pdf>

- As the drone will be using radio equipment, it must comply with Ofcom regulations.²⁰⁶ 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),²⁰⁷ 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 traffic 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.

²⁰⁶ <https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/drones-advice>

²⁰⁷ <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 as 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 member²⁰⁸. 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. £284²⁰⁹. 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.²¹⁰ 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 cases²¹¹, and an operator injury in 1.5 per cent of cases²¹². 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 £2,099,890.²¹³

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.²¹⁴

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

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

210 Appliances 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.

211 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.

212 https://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

213 Note 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 updated 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 updated by inflation to produce a final figure of £2,099,890.

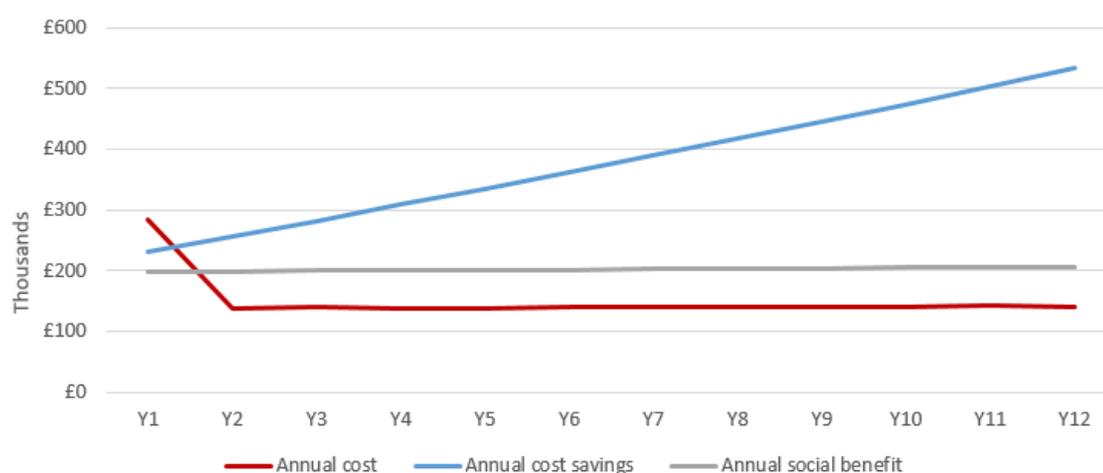
214 Based on a total budget of the West Yorkshire Fire and Rescue Service of c. £81,912,000, of which Bradford District costs are approximately £21,297,000. We estimate an efficiency gain of 0.25 per cent of this budget, estimated at £52,000.

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.

Total Cost, Total Private Benefit, and Total Social Benefit, Annual



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 updated to their predicted 2019 figures. This has been conducted using the latest OBR CPI inflation figures²¹⁵ to update 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

²¹⁵ 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.²¹⁶ 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.

²¹⁶ 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.²¹⁷ 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

²¹⁷ 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)²¹⁸ 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)²¹⁹.

218 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/populationestimatesforukenglandandwalescotlandandnorthernireland>

219 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**²²⁰ for each one. Additionally, following from discussions with industry partners an initial training cost of **£1,345**²²¹ 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

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

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

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vehicle with 2 officers per hour is £64.70²²² and an hour of ambulance time is £206.03²²³. 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	<ul style="list-style-type: none"> · 2 ambulance hours · 4 police officers (6 hours) · 1 fire response unit (1 hour) <p>£1,622.87</p>	<ul style="list-style-type: none"> · 2 ambulance hours · 4 police officers (4 hours) · 1 fire response unit (1 hour) <p>£1,364.07</p>	<ul style="list-style-type: none"> · 2 ambulance hours · 4 policemen (3 hours) · 1 fire response unit (45 minutes) <p>£1,163.73</p>	<ul style="list-style-type: none"> · 2 ambulance hours · 4 policemen (2.5 hours) · 1 fire response unit (30 minutes) <p>£1,028.10</p>
Serious	<ul style="list-style-type: none"> · 3 ambulance hours · 4 police officers (3 hours) · 1 fire response unit (1 hour) 	<ul style="list-style-type: none"> · 3 ambulance hours · 4 police officers (2 hours) · 1 fire response unit (1 hour) 	<ul style="list-style-type: none"> · 3 ambulance hours · 4 police officers (1.5 hours) · 1 fire response unit (45 minutes) 	<ul style="list-style-type: none"> · 3 ambulance hours · 4 police officers (1 hours) · 1 fire response unit (30 minutes)

222 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>. Up rated 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/>

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

	£1,516.00	£1,386.62	£1,250.98	£1,115.35
Slight	<ul style="list-style-type: none"> · 0 ambulance hours · 2 police officers (1 hour) · 0 fire response units 	<ul style="list-style-type: none"> · 0 ambulance hours · 2 police officers (1 hour) · 0 fire response units 	<ul style="list-style-type: none"> · 0 ambulance hours · 2 police officers (45 minutes) · 0 fire response units 	<ul style="list-style-type: none"> · 0 ambulance hours · 1 police officer (30 minutes) · 0 fire response units
	£64.70	£64.70	£48.36	£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 casualties²²⁴ and incidents²²⁵ 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 uncertainty²²⁶, 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

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

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

226 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 incident²²⁷. Data from Highways England²²⁸ 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.

²²⁷ 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-1am and 4pm-8pm, 60 per cent flow from 10am-4pm and 8pm-10pm and 40 per cent flow from 10pm-6am.

²²⁸ 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 figures²²⁹ 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.²³⁰ 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.

²²⁹ 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/>

²³⁰ 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.²³¹ 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

²³¹ 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 productivity²³².

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.²³³ 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 CO₂ emissions come from construction, with approximately 16 per cent of that coming from the manufacturing and construction process.²³⁴ 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,

232 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>

233 <http://wpieconomics.com/publications/off-site-construction/>

234 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/31737/10-1316-estimating-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 CO² pollution that could be connected with Preston's projects, given their scale,²³⁵ a figure that we estimated at over **58,000 tonnes** per month. This provided the baseline CO² 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 into 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

235 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/31737/10-1316-estimating-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 cost²³⁶ of £35,638²³⁷ for each one. Additionally, following from discussions with industry partners we estimate an initial training cost of **£1,345**²³⁸ 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**²³⁹.

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

236 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.

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

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

239 The cost of one FRU appliance per hour, <http://www.wyfs.co.uk/wp-content/uploads/2015/10/Special-Service-Charges.pdf>, £265, updated 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**.²⁴⁰ 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**²⁴¹, and an operator injury in **1.5 per cent of cases**²⁴².

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 2019.²⁴³ 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,

²⁴⁰ Appliances 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.

²⁴¹ 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.

²⁴² https://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

²⁴³ <http://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.