UK Research and Innovation

Future Flight Challenge

Socio-economic study

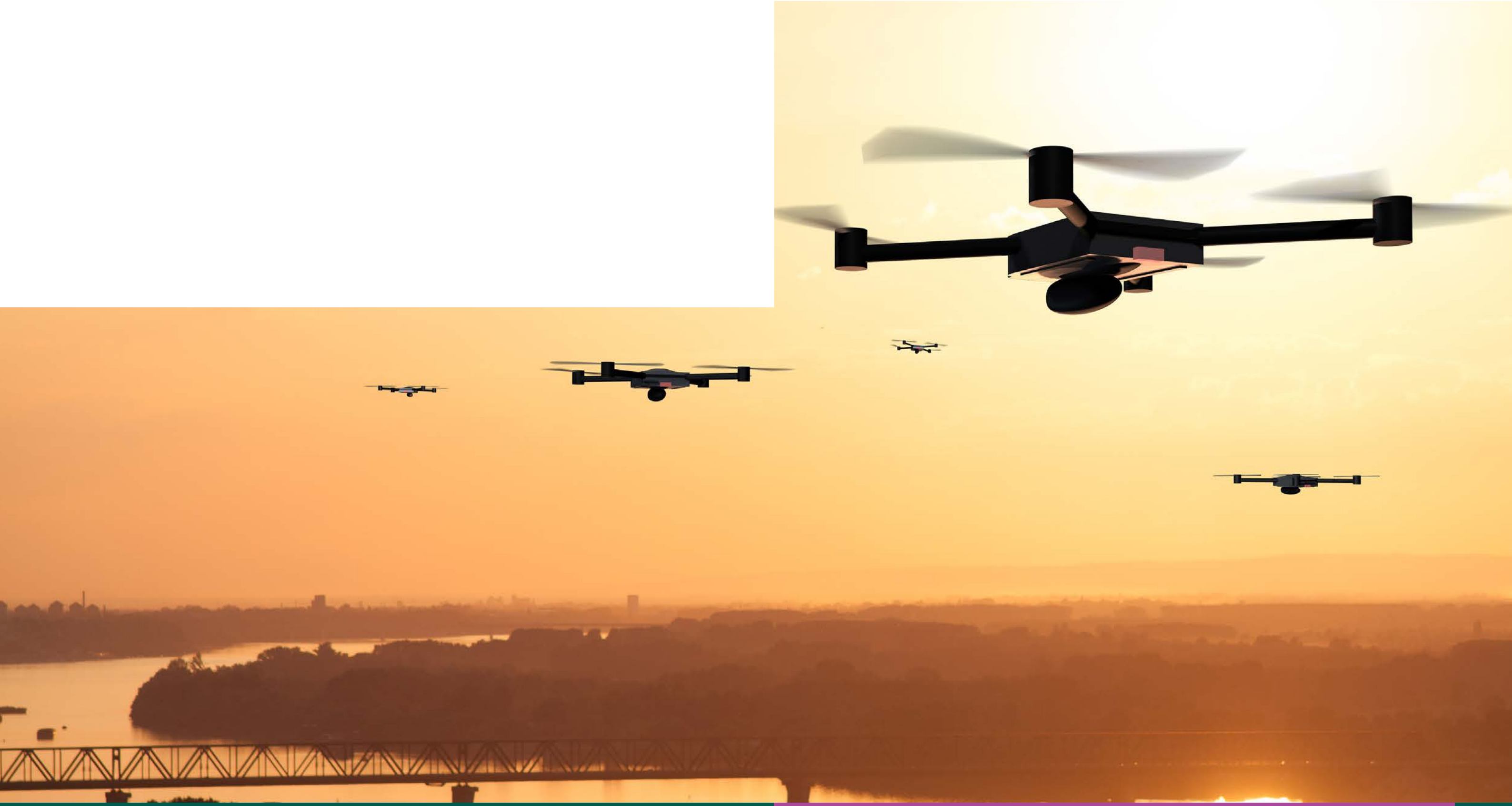
January 2021

In association with

pwc

INDUSTRIAL STRATEGY

Contents



Introduction

1

Introduction

PwC was asked to develop and test a holistic framework for assessing the potential costs and benefits of certain use cases selected by the Future Flight Challenge.

Background

Considerable opportunity exists for developments in aviation technologies to boost the UK economy and deliver wider societal benefits.

The Future Flight Challenge (FFC), a £300 million programme which is part of the Industrial Strategy Challenge Fund (ISCF), aims to stimulate the development and application of new aviation technologies in the UK. The FFC supports new technologies ranging from freight-carrying drones to urban air vehicles to hybrid-electric regional aircraft. It seeks to help position the UK as a global leader in aviation technology.

To support the widespread and safe use of new aviation technologies, the FFC wants to understand the potential costs and benefits (intended and unintended, direct and indirect) of different use cases and their key drivers.

Purpose of this study

UK Research and Innovation commissioned PwC UK to undertake a study to develop a holistic framework that can be used to assess the potential costs and benefits of certain use cases selected by the FFC.

The framework has been tested on six different use cases which represent potentially valuable applications of new aviation technologies.

As such, the study supports the FFC by:

- Developing a **holistic framework of potential costs and benefits** capturing the full range of impacts relevant to each use case
- Identifying the **key drivers of different costs and benefits** and the valuation coefficients to measure their scale
- Identifying the **potential stakeholders impacted** to inform understanding of the incentives across the value chain
- Assessing the **indicative scale of potential costs and benefits** across the given use cases
- Performing **sensitivity analysis** to understand the impact of variations in key cost/benefit drivers

Approach and methodology

2

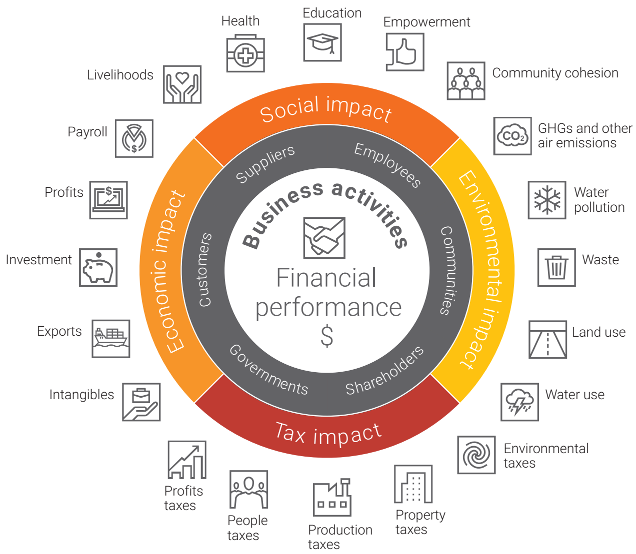
Approach and methodology

2

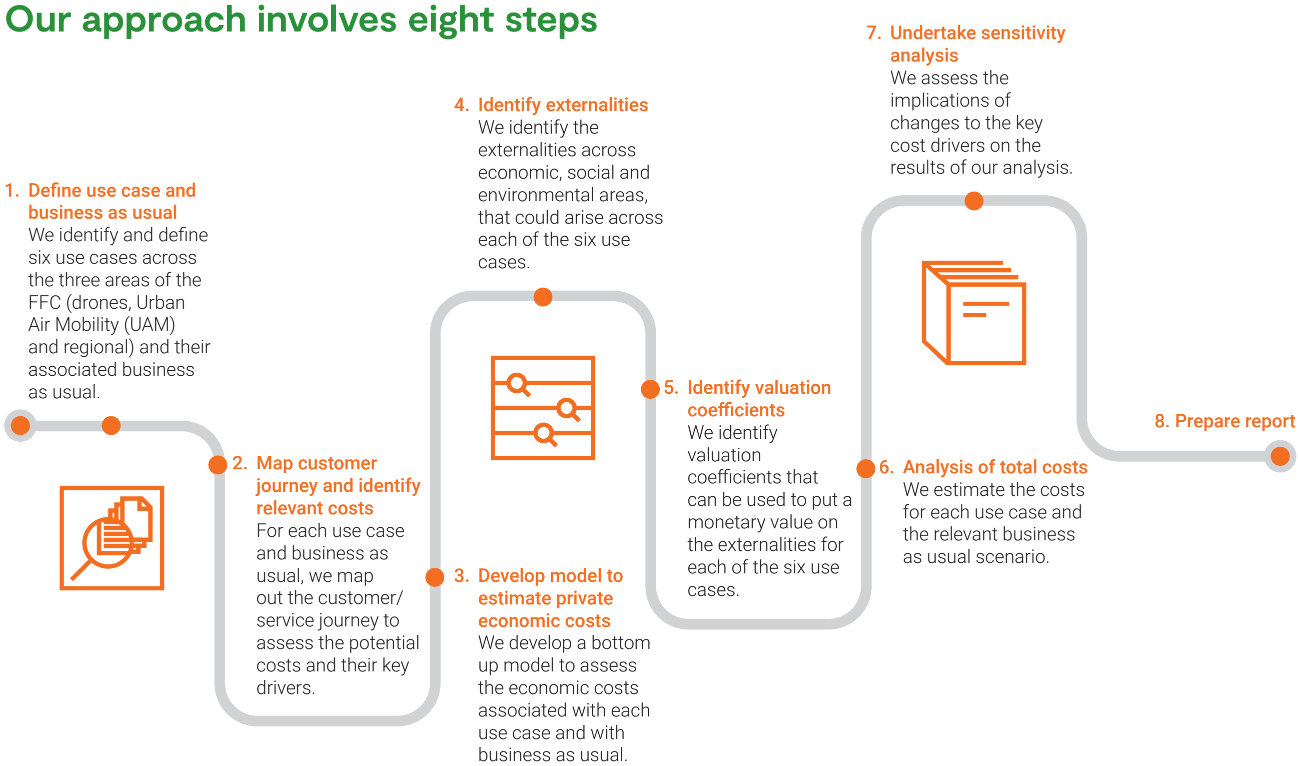
We use PwC's Total Impact Measurement and Management framework to compare the costs of six future use cases with business as usual.

We use PwC's Total Impact Measurement and Management (TIMM) framework to identify and holistically assess the costs associated with a set of six use cases involving future flight technologies. The TIMM framework, which considers costs across the economic, social, environmental and fiscal dimensions, is aligned with HM Treasury's Green Book and other government guidance on appraisal.

We apply the TIMM framework to compare the potential costs of each use case with how the use cases are currently fulfilled which we refer to as "business as usual".



Our approach involves eight steps



Define use case and business as usual

We consider six use cases covering different applications of future flight technologies.

In the remainder of the report, we refer to the technology used in the first three use cases (powerline inspection, cargo delivery and last mile delivery) as drones.

For the other three use cases (sub-regional air taxi, rural air taxi and urban air taxi) which involve the transportation of passengers we refer to the vehicles as air mobility. The vehicle is a piloted eVTOL (electric Vertical Take-Off and Landing) that transports passengers from one location to another.

Use case	Use case description	Sector	Location
Powerline inspection	Inspection of the Beauly-Denny powerline	Utilities	Beauly-Denny, Scotland
Cargo delivery – mail	Movement of mail from Inverness to Kirkwall	Transport & Logistics	Inverness-Kirkwall, Scotland
Last mile delivery – prescribed medicines	Delivery of prescribed medicine to patient homes	Medical	Urban area
Sub-regional air taxi	Passenger journey from York to Preston	Transport & Logistics	York to Preston
Rural air taxi	Passenger journey between village and village or village and town	Transport & Logistics	Rural area
Urban air taxi	Passenger journey within an urban area	Transport & Logistics	Major city – modelled on London

Analysis of total costs and sensitivity analysis

We test how changes to the key cost drivers influence costs under the use case and business as usual.

We estimate the total costs for each use case and the relevant business as usual scenario. These comprise the private economic costs and the costs of the externalities. We rely upon data in published sources, academic literature, government guidance and PwC proprietary analysis to build our evidence base to support our model.

We use this evidence to establish a set of base case costs for each use case – often underpinned by some key assumptions – and to identify the key cost drivers. We then undertake sensitivity analysis to assess how changes to key cost drivers influence the costs under the use case and business as usual. The cost drivers that we flex as a sensitivity are those that are most material and/or where the uncertainty associated with their value is greatest. We set out below some of the key cost drivers that we examine consistently across many of the six use cases:

1. **Occupancy rate:** The number of passengers per trip in the use cases involving passenger travel affects the cost per passenger as the costs are assumed to be split between them.

2. **Speed:** The average speed at which a vehicle travels determines the number of trips that it can make. If the number of trips increases, the capital costs are split over a greater number of trips thus reducing the cost per trip.

3. **Capex:** Our base case for the uses cases involving passenger travel assumes the "near-term" vehicle and battery costs which reflects assumed production of around 500 units a year (which enables some economies of scale and other advances in the technology and manufacturing process). As a sensitivity, we consider the impact of using the **"immediate term"** costs which reflect production of around 100 units a year.

4. **Maintenance costs:** We assume maintenance costs are dependant on the size of the vehicle - the larger the vehicle the higher the cost of maintenance. As a sensitivity, we test the impact of reducing maintenance, for example, through better build quality requiring less upkeep.

5. **Autonomous vehicles:** In the future, it is expected that drones and air mobility could become autonomous. This means that the pilot costs would be replaced by a marginal increase in maintenance costs and a one-off capital cost for additional avionics. As a sensitivity, we consider the impact of replacing the pilot with avionics.

Powerline inspection

3

Introduction

3

This use case focuses on the annual inspection of the Beauly-Denny powerline (400kV transmission lines) which links 615 steel towers over c220km.

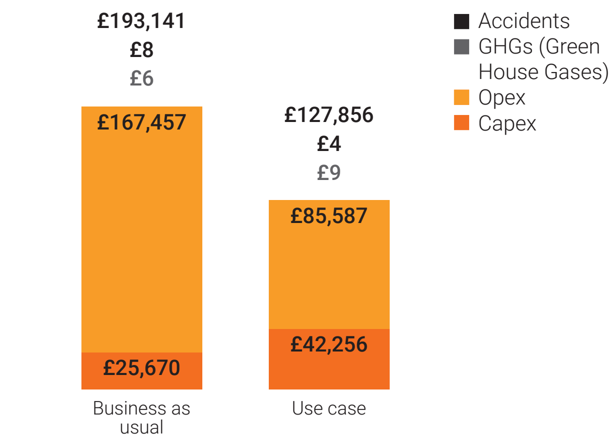
Business as usual: Crew

- A two person team (i.e. camera operator and drone operator) travels from the base location to the site to capture inspection images using a VLOS (Visual Line of Sight) drone.
- At the site, the drone operator pilots the drone to enable the camera operator to capture the prescribed images of components on each transmission tower in accordance with an agreed flight plan.
- The team drives and walks between towers (c.500m apart).
- The images are uploaded and reviewed by an inspection engineer using processing software.
- Each component is graded against the client's published defect standard.
- The results of the tower inspections are uploaded to a visual asset management platform where the client can navigate to each asset using a map-based interface and drill into any component defect rating (1-4) to see photographic evidence of each component defect.

Use case: Remote drone

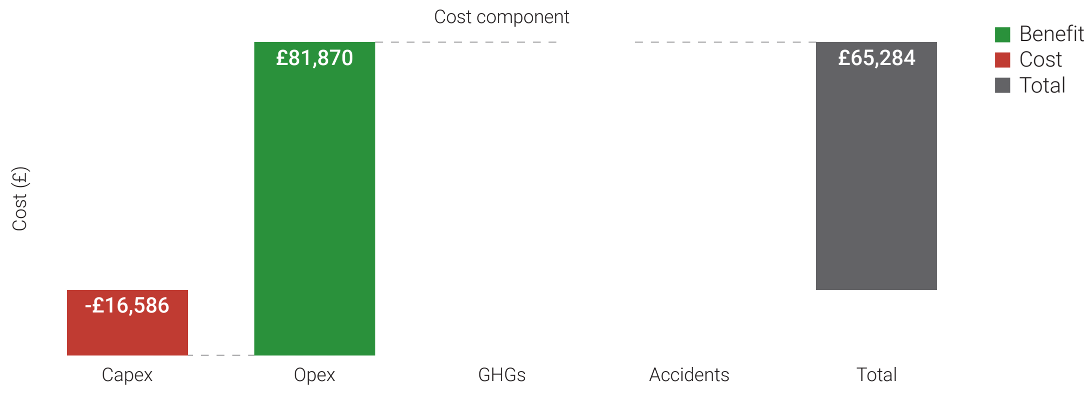
- A BVLOS (beyond visual line of sight) VTOL (Vertical take-off and landing) that can hover to capture inspection information, rather than just for take off and landing), flies to the transmission towers from its base location near Edinburgh and then carries out automated capture of the prescribed inspection images.
- One individual at the command and control station in the Edinburgh headquarters is responsible for remotely piloting the drone and ensuring that its image capture is as prescribed.
- A second crew member, in the field location, is responsible for changing batteries periodically at predefined locations which are selected for ease of access. Opex costs (e.g. 4x4 maintenance, fuel, accommodation and food) have been included within the model.
- The image inspection process is assumed to be the same in the use case and business as usual, with the same associated labour requirements, software and overall cost.
- In our baseline use case we assume that the drone is not autonomous and that a full time pilot is required for each drone.

Key results



Total costs of powerline inspection

The chart on the left presents the cost breakdown for the business as usual and use case to inspect 615 towers on the Beauly-Denny line. The total costs for the use case is expected to be around 34% lower than the business as usual. The chart on the right sets out the scale of difference for each cost driver between the use case and business as usual.



Business as usual and use case powerline inspection cost comparison

The key driver of the differences in costs between the use case and business as usual is the operating costs. This is because in the business as usual we assume that a pilot and inspector travel from tower to tower whereas the use case has a remote pilot and a technician traveling between designated points (which are easier to access) to change the drone battery. The total distance traveled in the use case by the technician is assumed to be half (220km) of the distance travelled to undertake an inspection in the business as usual scenario (440 km). The total elapsed time to complete the inspection in the use case is therefore significantly shorter at 22 days compared to 62 days required for business as usual. We assume 28 towers are inspected daily in the use case compared with the 10 towers business as usual.

In addition, the technician in the use case does not have a specialised role meaning they have lower wages than the inspector in the business as usual scenario. The daily costs of a technician is assumed to be 45% of an inspector.

The capex cost is higher in the use case due to the use of a more advanced drone at an assumed price of £250k, which is depreciated over 4 years.

Sensitivity analysis

We use sensitivity analysis to compare key cost drivers, primarily in the use case, but also for business as usual. The cost drivers that we flex as a sensitivity are those that are most material and/or where the uncertainty associated with their value is greatest:

1. **Capex:** The cost of the drone in the use case is assumed to be £250k, depreciated over 4 years. There is a degree of uncertainty around the cost of the drone as it does not exist at present and its price will be dependent on various factors such as the development of technology and the exact specification of the drone. As a sensitivity, we consider the impact of increasing the cost of the drone by **20%** to £300k.

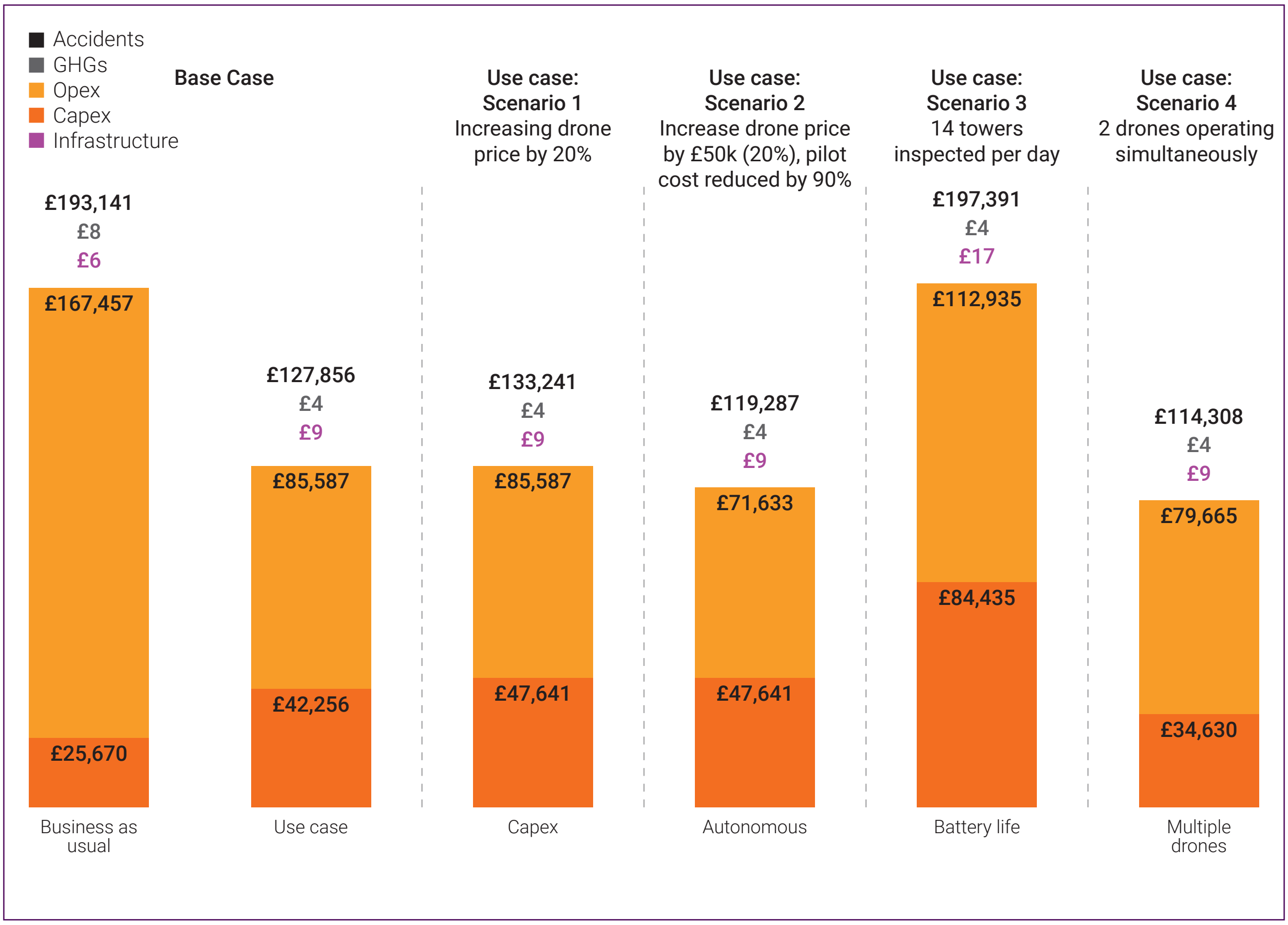
2. **Autonomous:** In this sensitivity analysis we consider the impact of a fully autonomous drone on the costs of the use case. This is because it is likely that this technology will develop and could be applicable for this use case. To model this we add a capital cost of **£50k** and reduce the drone operator costs to **10%** to account for a supervisor who will be responsible for ensuring multiple drones operate as expected.

3. **Battery life:** In the use case we assume that there are significant advances in battery technology, meaning that the drone is able to record footage for 4 towers before the battery needs to be changed. If the battery has a longer life then it would be able to complete the inspection more efficiently, reducing the operating costs and capital cost. Similarly, if the drone has a worse battery life than assumed, the costs would increase. We explore the impact of **halving** the number of towers inspected per day assuming poorer battery performance.

4. **Multiple drones:** The use case assumed that a single drone is guided by a remote pilot who operates it from a separate location. However, in the future, multiple drones could be used in tandem by multiple remote pilots. This would ensure that the ground crew member changing batteries is better utilised. An increased number of drones would also increase the speed at which the inspection can be completed. As a sensitivity, we consider the impact of a single additional drone with an additional operator. This is modelled by doubling the cost of the **pilot, drone** cost and number of **towers inspected** per day.

Sensitivity analysis results

We set out below how changes to the key cost drivers impact the costs under the use case.



Conclusions and next steps

Attractiveness of the use case

- Our analysis shows that the expected costs of undertaking powerline inspection using BVLOS VTOL drones (the use case) is around 34% less than business as usual. This highlights the significant potential for developments in aviation technology to reduce the costs of inspection in areas that are challenging to access.
- This conclusion holds across three of the four sensitivities that we have tested.
- As illustrated through the sensitivity analysis, the length of battery life is a key driver of costs: assuming poorer battery performance by halving the number of towers inspected per day significantly increases the costs of the use case. The expected advancements in battery technology will therefore have a material impact on the costs of the use case.

Assessment of winners and losers

- The use case offers benefits to multiple stakeholders:

  Employees: The use case is expected to reduce the number of accidents occurring whilst travelling on the powerline route and avoid the need for individuals to get in close proximity to the transmission towers (reducing the risks of electrocution and other accidents).

  Asset owners: Inspections are expected to be more cost effective.

Next steps / further analysis

- Our analysis is based on the use of VTOL drones in business as usual: it may be useful to understand how the costs of the use case compare against a business as usual where inspections are carried out using a combination of helicopters and ground patrol.
- Our analysis highlights the importance of adjacent technologies (e.g. use of AI in image processing) to the overall cost of the inspection (c.30% and 45% of the total costs in the business as usual scenario and use case respectively); further work could explore whether and how advancements in image processing could influence the total cost of inspections.
- Our analysis captures the social costs associated with accidents occurring whilst travelling on the route: the analysis could be extended to assess the costs of avoiding accidents related to working in close proximity to powerlines and transmission towers (e.g. electrocution etc).

Cargo delivery – mail

4

Introduction

4

This use case is focused on the transport of cargo (mail) from Inverness to Kirkwall (c.169 km).

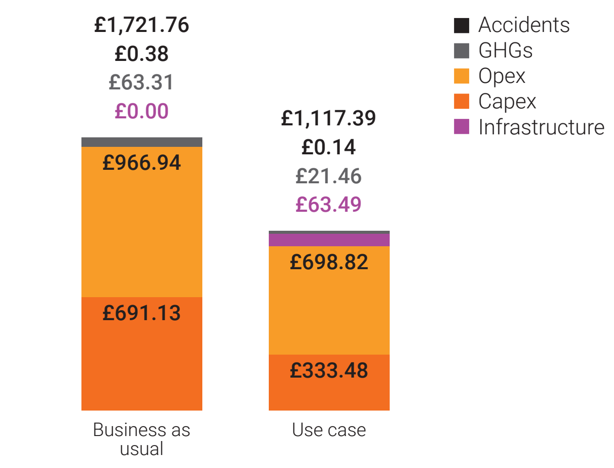
Business as usual: Flight

- An ATR-42-500 turboprop cargo plane is used to transport 2,000 kg of mail each way between Inverness and Kirkwall.
- One return flight occurs every weekday.
- The flight takes 16.5% of the aircraft's operational flight time per day (overall return trip takes 33%); the other 83.5% of operational time is spent delivering other services.
- The capital costs of the ATR-42-500 is benchmarked at $20m depreciated over 15 years, with a residual value of 20%.

Use case: Drone

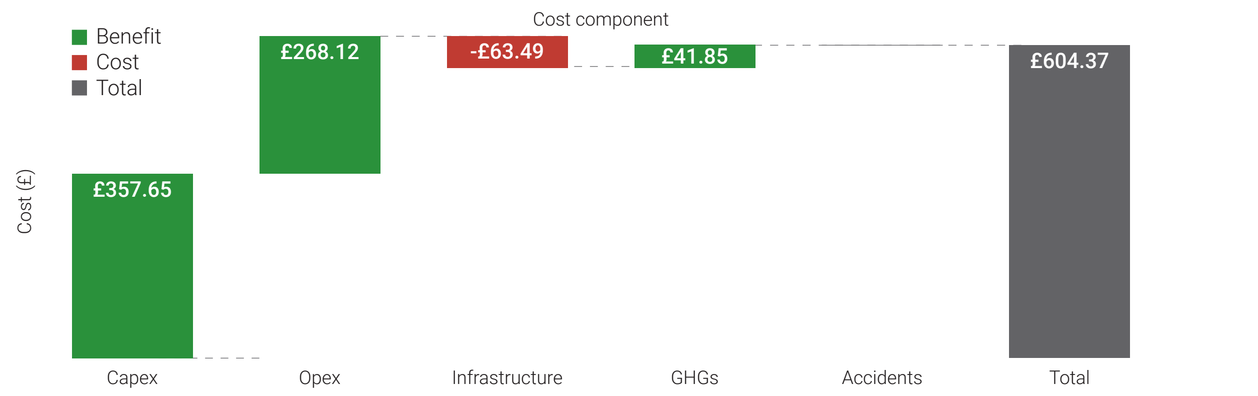
- A BVLOS hydrocarbon powered fixed wing cargo drone is used to complete the round trip.
- The drone has a capacity of 350 kg (or 3.5m3) which means it requires six return trips to transport 2,000 kg per day.
- The drone makes six return flights every weekday between a droneport/landing strip near the logistics depots in Inverness and Kirkwall airport.
- Delivering 2,000 kg of mail from Inverness to Kirkwall uses 41.5% of the drone's operating hours per day. It is important to note that an additional 41.5% of operational time is spent completing the return journeys.
- A droneport/landing strip is built at Inverness (with basic storage facilities).
- The journey from the depot to Inverness airport is 13.8km; if the landing strip in closer, this will reduce transport costs as well as reduce airport fees.
- In our baseline use case a dedicated remote pilot is responsible for flying the drone between Inverness and Kirkwall.

Key results



Total costs of cargo delivery

The chart on the left shows the total costs of delivering 2,000 kg of mail from Inverness to Kirkwall for the use case and business as usual. The total costs includes capex, opex, infrastructure costs, the costs of accidents and the costs of greenhouse gas emissions. The drone is £600 (35%) less expensive than the business as usual scenario.



Comparison of costs of use case and business as usual

The chart above shows the scale of difference for each cost driver between the use case and business as usual. The largest difference is in the capital costs associated with the vehicle. The cost of the ATR-42-500 cargo plane is approximately £17m compared to the £810k for the drone. The capital costs are adjusted to account for differences in expected vehicle life and 'service utilisation' (the proportion of the operating hours required to complete the service). The opex is also expected to be lower in the use case, primarily driven by lower fuel consumption and maintenance costs.

Capex for the use case reflects the expected costs of purchasing a single drone to complete the trip, however if a greater number of drones were purchased then the supplier would benefit from economies of scale. It is expected that a proportion of this benefit could be passed on to the buyer. Therefore, as a sensitivity, we test the impact of reducing the cost of the drone by 25%.

Sensitivity analysis

We use sensitivity analysis to assess the implications of flexing key cost drivers, primarily in the use case, but also for business as usual. The cost drivers that we flex as a sensitivity are those that are most material and/ or where the uncertainty associated with their value is greatest:

1. **Capex:** In our base case use case we assume a capital cost of £810k per drone. This is for a single drone completing the route we use in our example. However, if a larger number of drones were purchased, then the producer would experience a degree of economies of scale. Some of this benefit would be passed onto the consumer, lowering the price in the use case. As a sensitivity, we examine the impact of decreasing the cost of the drone by 25% of the base case cost (to £608k).

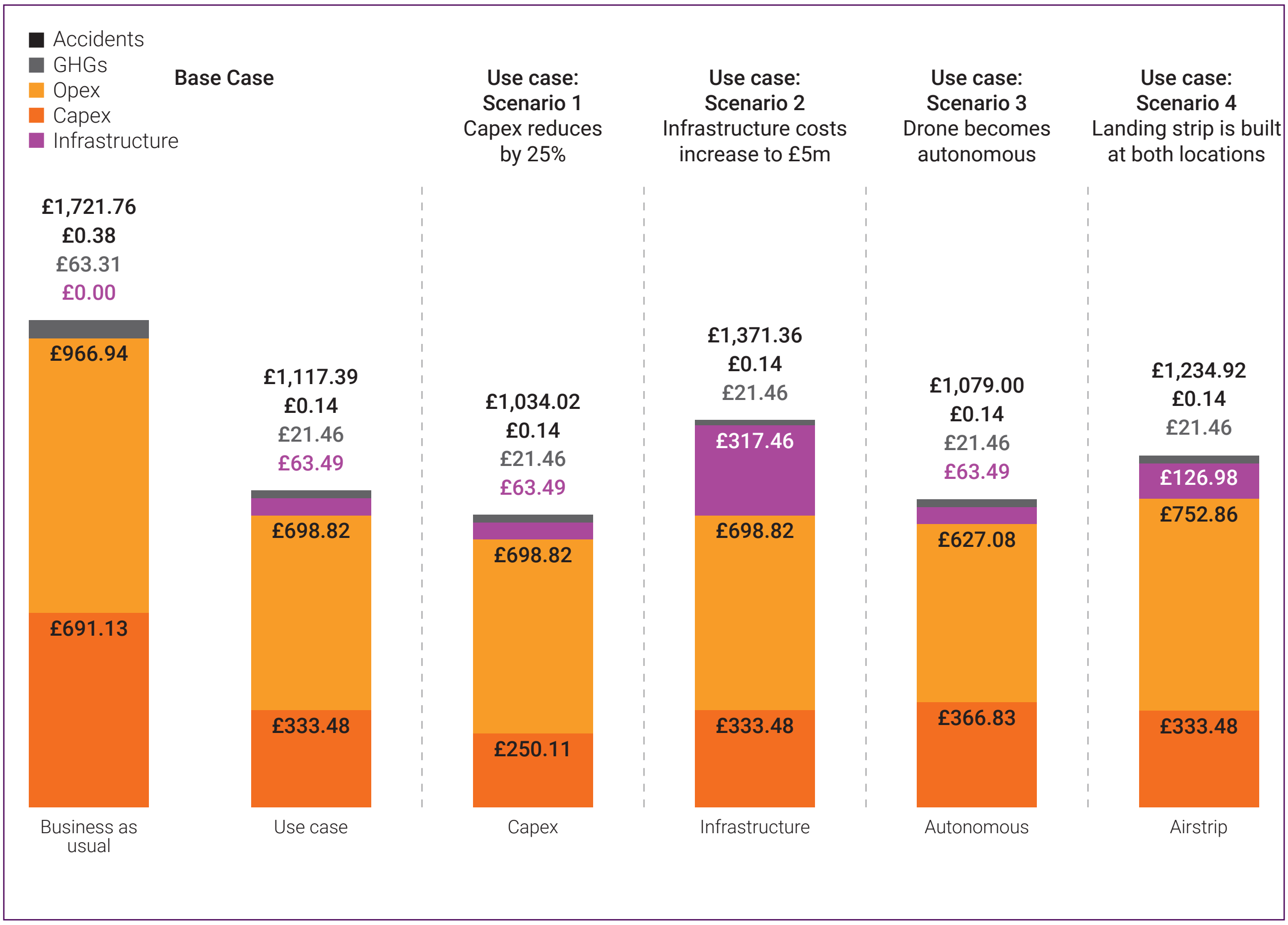
2. **Infrastructure:** We assume that Inverness will have a small droneport with storage facilities for the drone,1.6km from the depot, thus reducing transport costs between the airport and depot. However, in Kirkwall, we assume the drone lands at Kirkwall airport as the airport is located in close proximity to the depot. As the drone can land on a 400m grass or dirt runway, we have assumed a conservative capital cost of £1m to develop the runway and storage facilities at Inverness. In our sensitivity analysis, we examine the impact of increasing the cost to **£5m** to account for unexpected costs or invest in a more advanced runway. We attribute the total costs of the infrastructure to this journey, however, we acknowledge that the infrastructure could be used for other journeys and therefore the costs could be shared across all users of the infrastructure.

3. **Autonomous:** As technology continues to advance, it is possible that drones such as those used in this use case will become fully autonomous. By this we are assuming that the drone will complete the journey itself and only require a remote pilot to oversee operations. We assume that a remote pilot will oversee 10 drones simultaneously, thus reducing pilot costs to 10% of the baseline case. We assess the impact that this could have on the private economic costs by also increasing the capital costs of the drone by **£81k** (to incorporate more avionics) and increasing maintenance costs by **10%** (associated with the increased capital costs).

4. **Landing strip:** In our base case for the use case we assume that a simple landing strip and storage facilities will be built at Inverness close to the depot. As a sensitivity, we consider the impact of building a similar landing strip at Kirkwall as well. We capture the effect of this by **doubling the infrastructure costs** to account for building another runway and storage facility at Kirkwall. We have also doubled **cargo loading costs** to account for the fact that loading will have to be completed at both ends of the journey where this cost was previously accounted for in the airport fees. Finally, we have **removed the airport fees** and reduced the distance between the depot and landing strip in Kirkwall to **1.6km**.

Sensitivity analysis results

We set out below how changes to the key cost drivers impact the costs under the use case.



Conclusions and next steps

Attractiveness of the use case

- Our analysis suggests the total costs of transporting mail from Inverness to Kirkwall would be around 35% lower in the use case compared with business as usual.
- Our analysis assumes that all the costs of infrastructure are attributable to this service: if the infrastructure can be used for other routes, its costs could be shared across more users making the use case significantly more attractive.
- This use case highlights the significant potential of using aviation technology to transport cargo more cost-effectively.

Assessment of winners and losers

- The key stakeholder impacted by this use case are the mail operator, the drone and infrastructure provider, the airline used in the business as usual case, the airport owners and ground service providers at the airport:

  The winners are likely to be the mail operator who is able to transport mail more cost effectively and the drone and infrastructure provider.

  Potential losers are the airline, the airport and ground service providers as cargo planes are replaced by drones.

Next steps / further analysis

- Our analysis considers the use of a single drone delivering mail for a single provider on the Inverness to Kirkwall route: it would be useful to understand the impact on costs if drones are used more extensively over a network of routes.
- Further analysis could be undertaken to assess the impact of different levels of payload on the costs in the use case and in business as usual.
- Further analysis could also be undertaken to understand the impact of extending the scope to other mail operators, operators of other forms of cargo (e.g. time critical deliveries that could benefit from multiple services throughout the day) and other routes.
- As the use of drones increases and replaces the use of cargo planes, it could have a more material impact on other externalities (e.g. wider economic benefits) which will need to be assessed to capture the full costs of the use case and the business as usual scenario.

Last mile delivery – prescribed medicines

5

Introduction

5

The following use case covers last mile delivery of prescribed medicines. We assume the delivery is within an urban area.

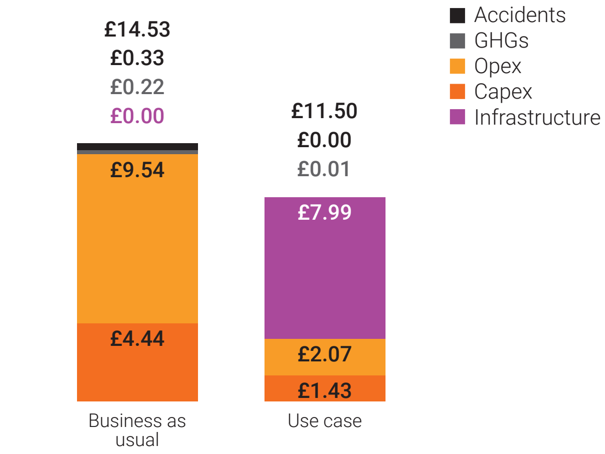
Business as usual: Delivery by car

- A member of the pharmacy staff delivers prescribed medicines to four patients at their homes from a pharmacy.
- The staff member then drives back to the pharmacy.
- The cost of driving is based on running a new van that travels 20,000 miles a year on average.
- The value of the pharmacy staff member's time is taken from the Annual Survey of Hours and Earnings using the gross hourly pay for a dispensing chemist in pharmacies (rather than a qualified pharmacist).
- The distance between the patient homes is assumed to be 4.26km with a total trip length of 21.3km.

Use case: Drone delivery

- An autonomous battery powered drone delivers the prescribed medicines to four patients at their homes from a central hub.
- The drone has a range of 40km with a maximum payload of 4kg (refrigerated and secure).
- The drone is based at a central hub located away from an urban centre.
- Patients will each have a kiosk outside their home which is integrated with a window in their house (not stand-alone).
- The direct distance between patients is assumed to be 3km and the total trip length is 15km (using a land-to-air distance ratio of 1.42).
- Service utilisation associated with this trip is assumed to be 15%, meaning the drone spends 85% of its operational time completing other deliveries.
- In our baseline use case we assume that the drone is autonomous, meaning that there is a pilot overseeing a number of drones including the one in our use case. We have assumed that the pilot is simultaneously monitoring 20 drones.

Key results



Total costs of last mile delivery

The chart on the left shows the costs of delivering prescribed medicines to four patients at different locations in an urban area. Total costs for this service are 21% lower in the use case than business as usual, largely due to lower vehicle opex and capex (only 30% of business as usual).

Comparison of costs of use case and business as usual

The chart above presents the differences in costs between business as usual and the use case. The capital costs are benchmarked at double the price of a DJI Matrice 600 (£10.4k) with an uplift of 20% to account for the addition of a cargo box. The lower labour costs in the use case are driven by the assumption that the drones are autonomous and only require a supervisor to oversee their use. The supervisor is assumed to be full time and responsible for 20 drones simultaneously; in contrast, the business as usual is more labour intensive because a member of the pharmacy staff is responsible for delivery.

The costs of infrastructure at the central hub (the ‘drone in a box’) and the kiosk infrastructure at patients’ homes form the largest cost driver in the use case. The ‘drone in a box’ infrastructure is assumed to cost £129k which is spread over an expected lifetime of 10 years.

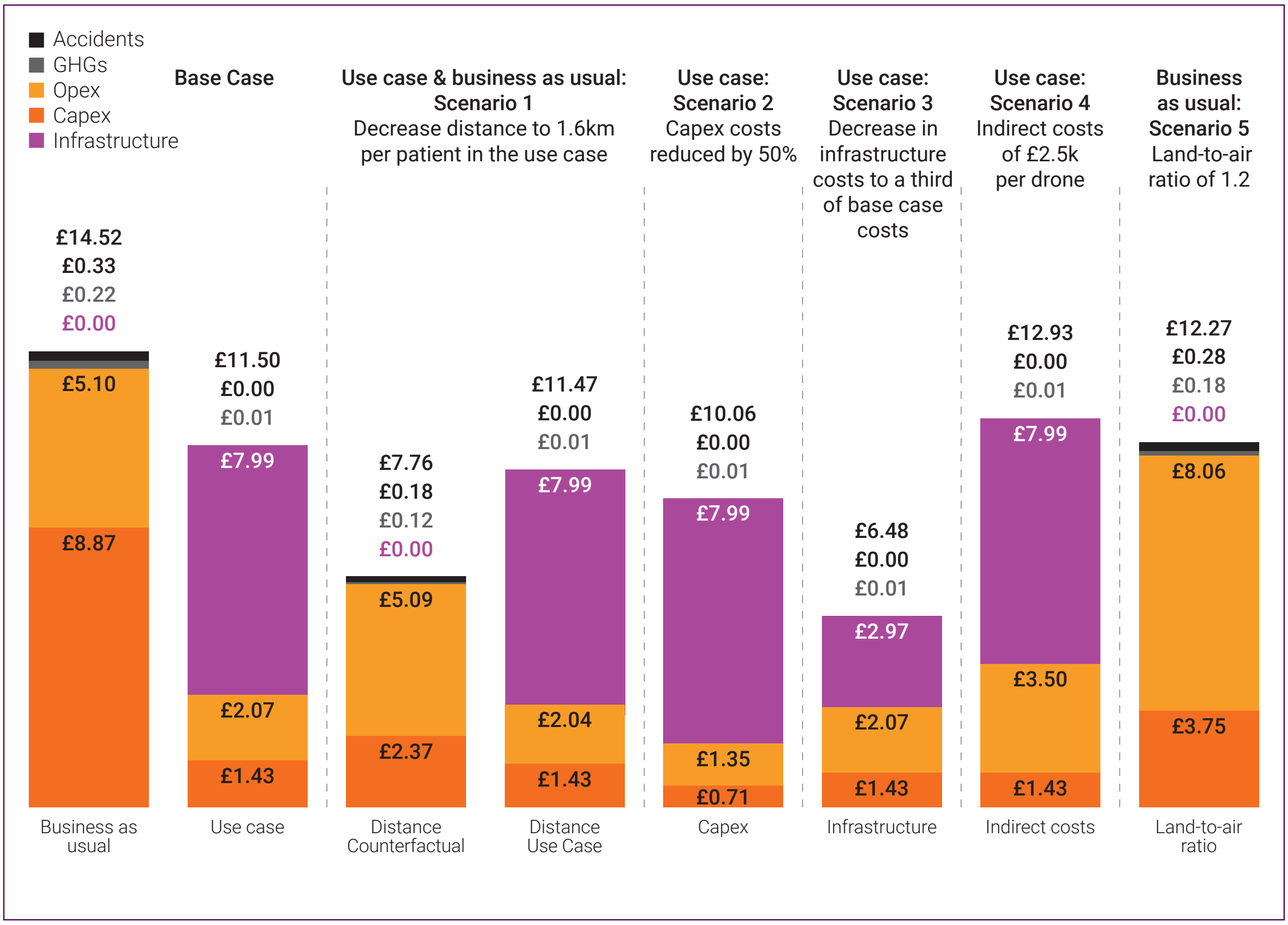
Sensitivity analysis

We use sensitivity analysis to assess the implications of flexing key cost drivers, primarily in the use case, but also for business as usual. The sensitivity analysis focuses on those drivers which are most uncertain and most material and, therefore, are likely to have the biggest influence on the overall costs of the service. The costs drivers we consider are:

1. **Distance:** We assume an average distance of 3km per patient in the use case. As a sensitivity, we consider the impact reducing the average distance between patients is to **1.6km** for the use case (and consequently 2.3km for business as usual assuming the land-to-air distance ratio remains 1.42).
2. **Capex:** We assume that the capital cost of the drone is double that of a DJI Matrice 600. This is to account for the higher specification required of the drone (e.g. battery life, autonomous) to complete the number of deliveries assumed. However, if drone uptake becomes widespread and technology advances, then significant economies of scale and manufacturing efficiencies could drive price of the DJI to **£5.2k**. As a sensitivity, we consider the use of drones costing £5.2k to model this scenario.
3. **Infrastructure:** Infrastructure costs are a key driver of total costs in the use case, they account for 80% of total costs (at £129k depreciating over 10 years with a 20% residual value). If last-mile drone delivery becomes more pervasive, the infrastructure cost could be driven down by economies of scale. As a sensitivity, we assess the implications if infrastructure costs are reduced to a **third of the base case costs**.
4. **Non-labour opex:** We have not included wider operating costs beyond those directly linked to the drone and the associated labour requirements. Operating costs such as insurance or licensing are currently uncertain as the drone delivery market, especially in urban settings, has not matured. As a sensitivity, we assess the impact of additional annual non-labour elements of opex totalling of **£2.5k per drone**.
5. **Land-to-air-ratio:** We have assumed a land-to-air ratio of 1.42 in our base case. This means that for every mile travelled by air, a car has to travel 1.42 miles. Operating by air allows vehicles to take a more direct route than is possible by road. However, this value varies by context.
   In our sensitivity analysis we consider the impact on the business as usual price if we use a more conservative value of **1.2**.

Sensitivity analysis results

We set out below how changes to the key cost drivers impact the costs under the use case.



Conclusions and next steps

Attractiveness of the use case

- Our analysis shows that the costs of delivering prescribed medicines to four patients at different locations in an urban area could be 20% less using a delivery drone compared to a business as usual case where pharmacy staff are responsible for their delivery.
- This use case is focused on delivery in an urban area where patient density is likely to be higher than in rural areas. If the use case was applied in a rural area, we would expect the benefits of using a delivery drone to be greater than those observed in urban areas as patients are likely to be located further apart.
- Our use case also assumes kiosk infrastructure can - and would - be built at patients' homes in urban areas. This assumes availability of space outside homes to accommodate a kiosk that is secure and can safely store the medicine. Further assessment is required to understand the practicalities of implementing this use case in areas where patients reside in apartments/flats.

Assessment of winners and losers

- The key stakeholders impacted by this use case are pharmacies, their patients, the NHS and drone operators:

  The winners are pharmacies, whose staff can now spend more time on other value adding tasks, patients, if the service can be extended, and drone operators, if there is an increase in the use of drones

  The losers are likely to be whoever needs to pay for service: currently, it is provided by pharmacies without being specifically rewarded through their existing contracts.

Next steps / further analysis

- Our current analysis focuses on the delivery of prescribed medicine to patients in an urban area. Going forward, it would be instructive to understand:

  How the costs change if the delivery is applied to rural areas

  How the costs change with the number of patients served

  How the costs compare against an alternative business as usual such as online pharmacies (e.g. Pharmacy2U)

  The impact on different groups of patients

- In addition, the structure of our analysis where there are four patient deliveries per day does not capture the potential social benefit that could be realised by extending the service to additional (new) patients. Further work could explore the social benefit associated with providing the service to a larger group of patients.

Sub-regional air taxi

6

6

Introduction

The "sub-regional" use case focuses on a journey of about 108 km from York to Preston. These two cities were chosen to illustrate an instance where there is no direct route by rail so the distance travelled is much longer than the direct distance. We compare the differences in costs for an individual using an air mobility vehicle (the use case) to travel from York to Preston with travel by train (the business as usual).

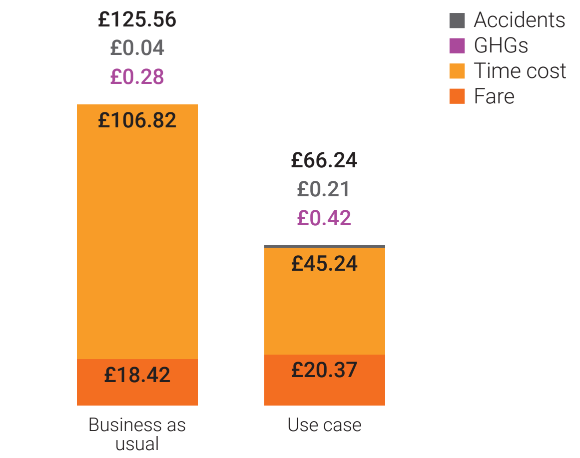
Business as usual: Train

- The individual commutes by train from York to Preston.
- The train takes 2 hours and 31 minutes.
- The individual takes the train twice every working day of the year (equivalent to 229 days).
- The individual purchases an annual season ticket for £8,440.
- The value of an individual's time is provided using the approach provided by DfT, using webTAG values for 2020, for a car driver this is £32.70 per business hour.

Use case: Sub-regional air taxi

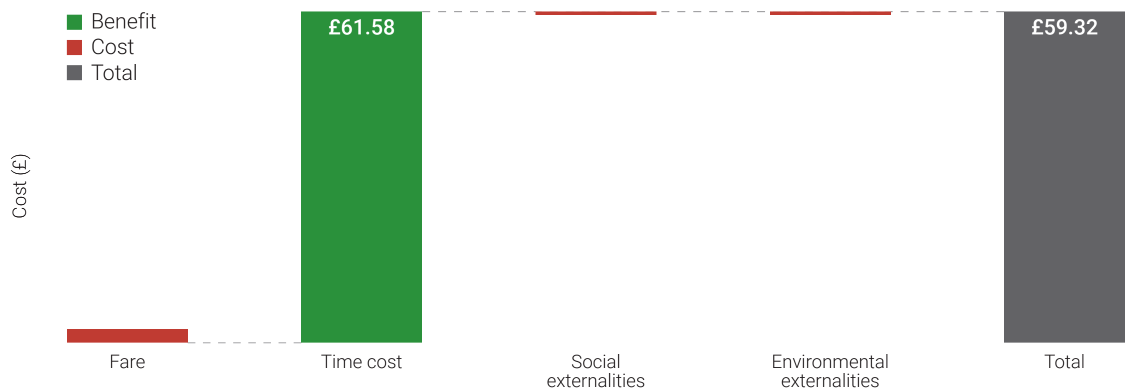
- The use case is a battery powered air mobility vehicle.
- The use case reflects a 'near term' scenario where the costs of the air mobility are based on assumed (global) production of around 500 units a year: this enables some economies of scale and other advances in the technology and manufacturing process.
- The vehicle has 12 seats.
- One seat is used by the pilot - we also consider the sensitivity of the costs if the vehicle is autonomous.
- The regulatory environment poses no barriers to operation of the air mobility.

Key results



Total costs per person per journey

The chart on the left sets out the costs per person per journey which includes the generalised cost of travel (i.e. fare and time costs), the cost of accidents and the costs of greenhouse gas emissions. The costs are 47% lower in the use case relative to business as usual.



Comparison of costs of use case and business as usual

The chart above presents the cost differences between the use case and business as usual. The time cost in the business as usual scenario is significantly greater than in the use case as the total time spent on the journey in the business as usual is 3 hours and 16 minutes as compared to 1 hour and 23 minutes in the use case. This use case is an example where poor transport connectivity currently exists between two cities/towns. Locations with better connectivity will provide a less pronounced benefit from using the air mobility. In turn, routes with poorer transport links will experience greater benefits when using the air mobility.

Our analysis assumes an incremental uptake of air mobility in the use case which means in the majority of cases we expect individuals to use trains as assumed in business as usual. If - or as - the use of air mobility becomes more widespread, we would expect the capital costs to fall, for example due to economies of scale. In addition, as the uptake of air mobility increases (at the expense of trains), it is likely to start to have a more material impact on other externalities (e.g. air quality) which will need to be assessed to capture the full costs of the use case and the business as usual scenario.

Sensitivity analysis

We use sensitivity analysis to assess how changes to the key drivers influence the total costs. We select a set of key drivers based on the materiality of their potential impact and the uncertainty associated with their value. The key drivers that we flex as a sensitivity for this use case are:

1. **Occupancy rate:** The number of passengers per trip affects the cost per passenger as the costs are assumed to be split between them. Our base cases assumes that the occupancy rate is 55% (i.e. the fare is split between 6 people out of a capacity of 11). As a sensitivity, we consider the impact of **three additional passengers**, increasing occupancy to 82%.

2. **Speed:** The average speed at which a vehicle travels determines the number of trips that it can make. If the number of trips increases, then the capital costs are split over more thus reducing the cost to each passenger. Our base case assumes a speed of 240 km/hr and, as a sensitivity, we increase the **speed to 320 km/hr**. This impact the number of trips as well as journey time.

3. **Capex:** Our base case assumes the "near-term" vehicle and battery costs which reflects assumed production of around 500 units a year (which enables some economies of scale and other advances in the technology and manufacturing process). As a sensitivity, we consider the impact of using the **"immediate term"** costs for the vehicle and battery which reflect production of around 100 units a year. The "immediate term" costs are **double** the "near term" costs.

4. **Maintenance costs:** Maintenance costs are estimated to be about one quarter of operating costs (approximately 23%). This reflects the size of the vehicle and therefore the cost of maintenance is also expected to be greater. As a sensitivity, we test the impact of **reducing maintenance costs by 50%**, for example, through better build quality meant less upkeep was needed.

5. **Infrastructure costs:** In our base case, infrastructure costs are assumed to be £71k per annum (17% of total private economic costs). In practice, infrastructure costs depend on factors such as the quantity and quality of infrastructure as well as technology. As a sensitivity, we consider the potential impact of increasing infrastructure cost of air mobility by **50%**.

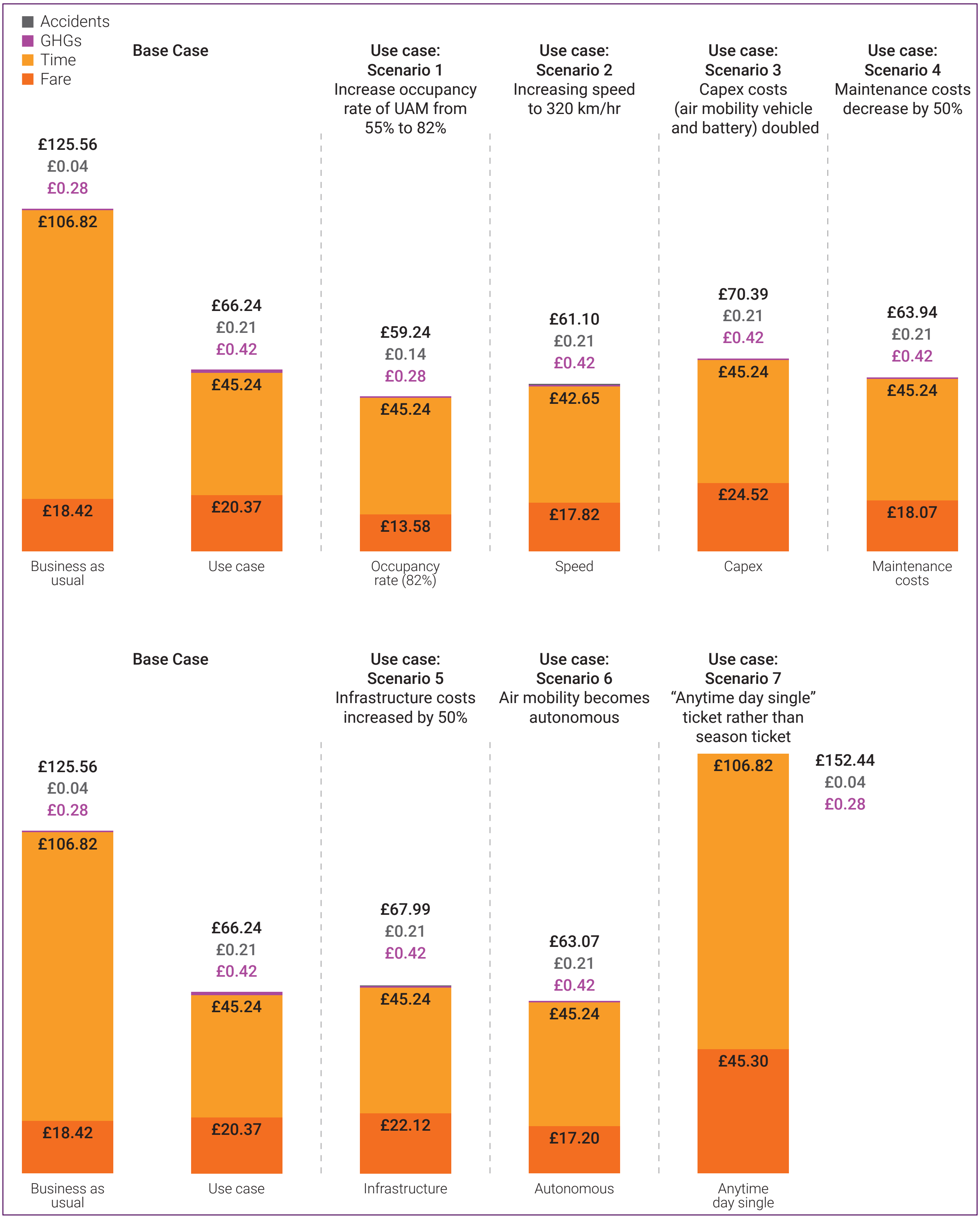
6. **Autonomous:** In the future, it is expected that air mobility could become autonomous. An autonomous air mobility vehicle would mean an additional revenue generating seat available to passengers. In addition, the pilot costs would be replaced by a marginal increase in maintenance costs and a one-off capital cost for additional avionics. As a sensitivity, we consider the impact of replacing the pilot with an upfront capex cost of **£50k per air mobility vehicle**.

7. **Cost of train fare:** In business as usual, we assume that the individual uses a season ticket for the trip and attribute a share of its total cost. However, if the individual purchases an "anytime day single" ticket then the cost for the trip from York to Preston increases from £18.42 to £45.30. As a sensitivity, we consider the impact of increasing the **price of the train ticket to £45.30**.

.

Sensitivity analysis results

We set out below how changes to the key cost drivers impact the costs under the use case.



Conclusions and next steps

Attractiveness of the use case

- Our analysis suggests the costs of using air taxis for interregional journeys between two areas with relatively poor transport connectivity are around 47% lower compared to the use of trains in the business as usual scenario.
- The key driver of the cost difference is the time taken to complete the journey, which is expected to be around 2 hours faster in the use case. As a result, the time costs for passengers using the train (business as usual) are £90 compared with £38 in the use case.

Assessment of winners and losers

- The key stakeholders impacted by this use case are passengers, air taxi operators and train operators:

  The two winners are passengers, who benefit from a significantly shorter journey time, and air taxi operators, who have a new market opportunity

  The losers are train operators if they lose customers to air mobility technology: if this becomes pervasive, it could also impact their other customers.

Next steps / further analysis

- Our analysis focuses on an incremental uptake in the use of air taxis. As a next step, it would be instructive to assess how increasing use of air taxis (at the expense of trains) may result in wider economic benefits as well as more significant environmental impacts (e.g. air quality, agglomeration etc).
- Our analysis focuses on business travellers; further analysis could be undertaken the assess the impact on passengers who use the service for non-work related trips.

Rural air taxi

7

7

Introduction

The following use case focuses on a 25 km journey undertaken by an individual from village to village or village to town. We assess the differences in costs between the use of a car in the business as usual scenario, compared to an electric air mobility vehicle in the use case.

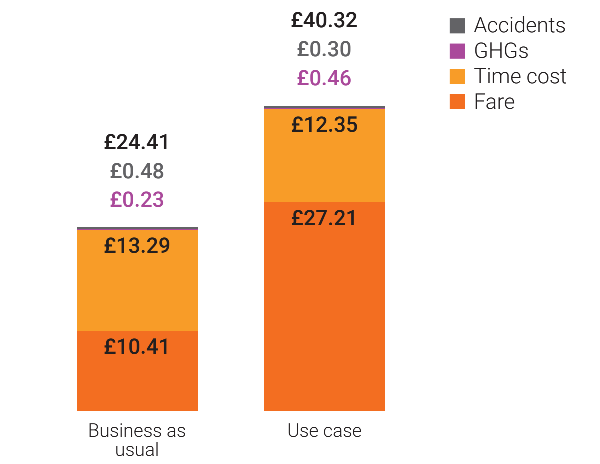
Business as usual: Car

- Individual drives 25 km from A to B in a rural setting.
- The cost per mile of owning and driving the car is based on the individual having a new car that is driven an average of 12,000 miles a year.
- The value of an individual's time is provided using the approach provided by DfT, using webTAG values for 2020, for a car driver this is £19.82 per business hour.

Use case: Rural air taxi

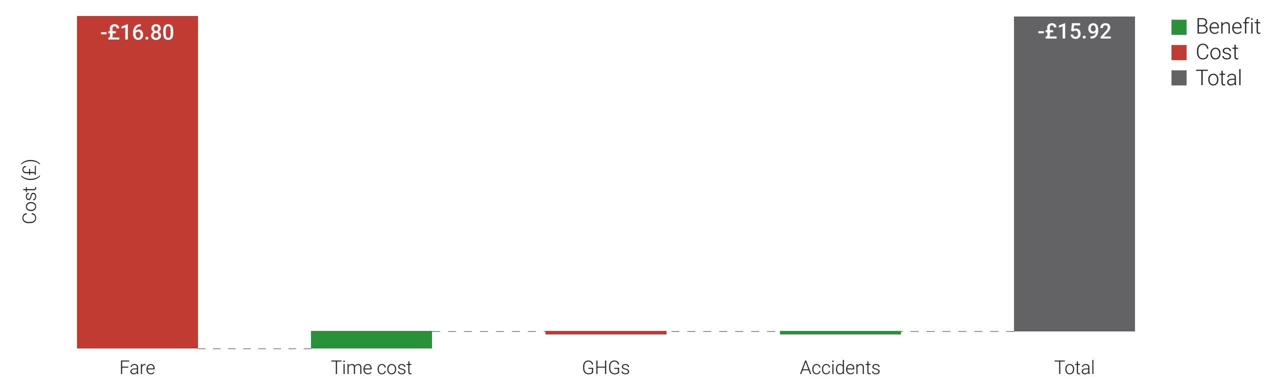
- The use case is a battery powered air mobility vehicle.
- The use case reflects a 'near term' scenario where the costs of air mobility are based on assumed (global) production of around 500 units a year: this enables some economies of scale and other advances in the technology and manufacturing process.
- The vehicle has four seats; one seat is used by a pilot.
- The regulatory environment does not pose any barriers to operation.
- Vertiports are distributed widely enough that the air mobility vehicles offer a time saving opportunity for individuals wishing to use it: a passenger travels an average of 10 minutes to or from a vertiport.

Key results



Total costs per person per journey

The left hand chart sets out the costs per person per journey which includes the generalised cost of travel (i.e. fare and time costs), cost of accidents, and cost of greenhouse gas emissions for business as usual and the use case. The use case is expected to be around 65% more expensive than business as usual.



Comparison of costs of use case and business as usual

The chart above shows the differences in costs between the use case and business as usual. The largest difference in costs is driven by the higher fare in the use case as we assume the four seater air taxi carries only one passenger and one pilot. The time costs in the use case is expected to be around 37% lower than business as usual, reflecting a shorter journey time.

Our analysis assumes an incremental uptake of air mobility in the use case which means in the majority of cases we expect individuals to drive as assumed in the business as usual scenario. If - or as - the use of air mobility becomes more widespread, we would expect the capital costs to fall, for example due to economies of scale. In addition, as the uptake of air mobility increases (at the expense of using cars), it is likely to start to have a more material impact on other externalities (e.g. air quality) which will need to be assessed to capture the full costs of the use case and the business as usual scenario.

Sensitivity analysis

Sensitivity analysis is used to assess how changes to the key drivers influence the potential costs. We select the drivers based on the potential materiality of their impact on costs and the uncertainty associated with the assumption. We set below some of the key drivers that we flex as a sensitivity.

1. **Occupancy rate:** The number of passengers per trip affects the cost per passenger as costs are split evenly between all paying passengers. Both the use case and business as usual assume the journey is completed by one individual. As a sensitivity, we consider the impact of **an additional passenger** in the use case.

2. **Time per trip:** The number of trips that the air mobility vehicle can make is influenced by the number of **operational days** and the **time per trip**. In turn, the time per trip depends on the flight ready hours, time to disembark and board and speed. As a sensitivity, we consider the impact that **doubling** the time taken for boarding, disembarking,landing & take-off. This will increase journey times and reduce the number of trips that the air mobility vehicle completes, in turn causing the capex and other non-variable cost per trip to increase.

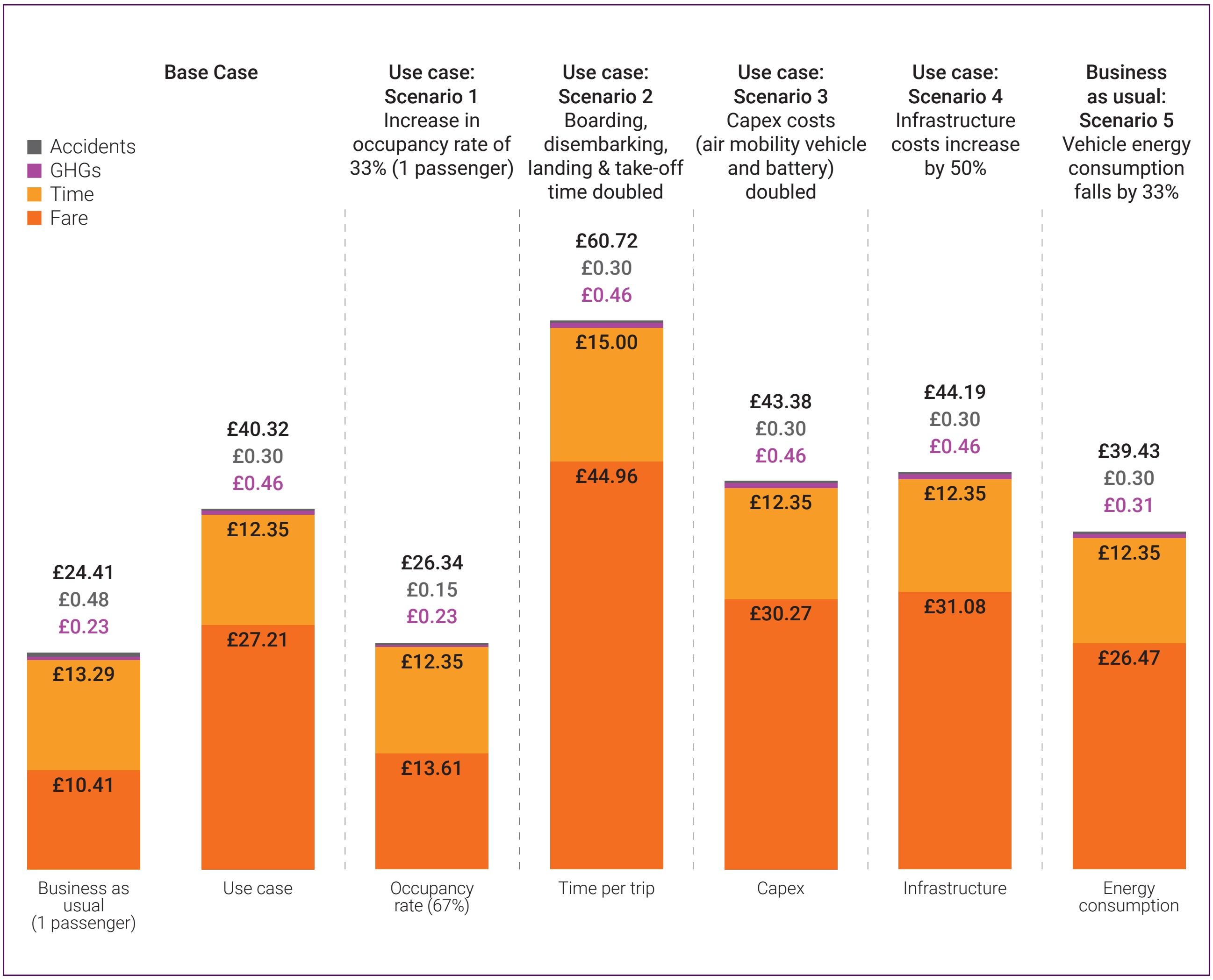
3. **Capex:** In our baseline use case we estimate the cost of capex such as batteries and air mobility vehicles in the **"near term"**, assuming that they are lower than they would be now, in the "**immediate term"**. This is driven by the fact that production costs are forecasted to diminish over time as technology, experience and pervasiveness drive manufacturing cost reductions. In our sensitivity analysis we **double** the cost of batteries and vehicles to demonstrate the impact that higher capex would have on the cost per passenger per journey.

4. **Infrastructure costs:** Infrastructure costs form a significant proportion of costs associated with air mobility (28% of total cost per air mobility vehicle). They are influenced by several factors including uptake, technology growth and prevalence. As a sensitivity, we consider the impact if infrastructure costs are **50%** more than those modelled in the base case.

5. **Energy consumption:** The cost of powering air mobility is dependent on a range of factors including speed, weight, engine efficiency and load. In the model, due to uncertainty around future air mobility energy requirements, energy consumption is not a function of distance, though in reality this would be the case. As a sensitivity, we consider potential impact of decreasing energy consumption by a **third** to account for decreased mileage.

Sensitivity analysis results

We set out below how changes to the key cost drivers impact the costs under the use case.



Conclusions and next steps

Attractiveness of the use case

- Our analysis shows that the costs of using an air taxi for a journey between two places in a rural area could be 65% more costly than business as usual which assumes the use of private cars. This is primarily driven by the higher "fare" element of the costs as our base case assumes that only one of the three available seats is occupied. The pilot is assumed to occupy the fourth seat.
- Even if we double the number of fare paying passengers to two, the fare costs are still around 8% more than those in business as usual, although they are much reduced. This suggests that the use case is less attractive than business as usual (even across the range of sensitivities that we test). We note however the use case is marginally faster than business as usual and, therefore, has a lower "time cost"element.

Next steps / further analysis

- Going forward, it may be instructive to test instances where we would expect the use case to be more attractive than business as usual, for example, by focusing on specific groups of individual (e.g. those who do not own cars and have to rely on public transportation).
- The number of passengers assumed in the business as usual scenario is also an important driver of costs. Our analysis assumes that there is one passenger per car in business as usual. If we assume there are more than one passenger in the car in the business as usual scenario, the costs in the business as usual will be even lower than the use case.
- If the use of air mobility becomes more widespread in urban areas, this could drive down the capital costs of the air taxi due to economies of scale. It may be useful to explore how the utilisation of drones in urban areas is likely to evolve and therefore the implications on the costs of using air taxis in rural areas.

Urban air taxi

8

Introduction

8

This use case focuses on a 10km journey for business purposes within a city. We compare the costs of a standard ridesharing service in business as usual and an air mobility vehicle in the use case.

Business as usual: Ridesharing

- The individual uses a ridesharing service.
- The individual books the service, waits to be picked up, travels from A to B and then gets dropped off at their final destination.
- The duration of the journey depends partly on the extent of congestion; this can cause wait and journey times to increase which affects the personal time cost as well as the fare.

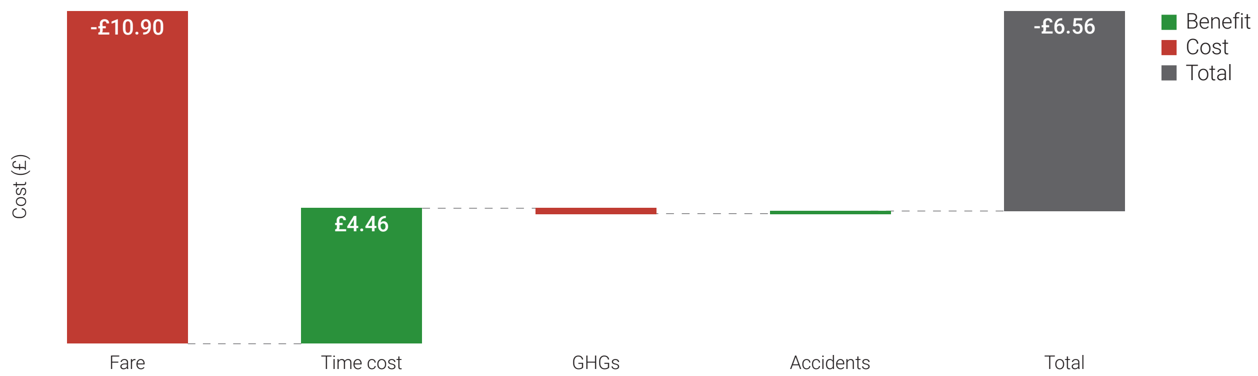
Use case: Urban air taxi

- The use case is a battery powered air mobility vehicle.
- The use case reflects a 'near term' scenario where the costs of the air mobility vehicle are based on assumed (global) production of around 500 units a year: this enables some economies of scale and other advances in the technology and manufacturing process
- The vehicle has four seats, one of which is used by the pilot.
- The regulatory environment does not pose any barriers to operation.
- Vertiports are spread widely enough that air mobility vehicles offer a time saving opportunity for individuals wishing to use them; passengers walk an average of 5 minutes to or from a vertiport.

Key results

Total costs per person per journey

The chart on the left sets out the costs per person per journey which includes the generalised cost of travel (i.e. fare and time costs), cost of accidents, and cost of greenhouse gas emissions for business as usual and the use case. The use case is expected to be around 21% more expensive than business as usual.



Comparison of costs of use case and business as usual

The chart above sets out the differences in costs between the use case and business as usual. The passenger incurs a higher fare in the use case as we assume the four seater air mobility vehicle is carrying one passenger and one pilot. However, if there is an increase in the number of passengers the fare costs for air mobility will be split across the total number of passengers and therefore reducing the costs. We expect this use case to be attractive to business users who are willing to trade off a higher "fare" for a shorter journey duration.

Sensitivity analysis

Sensitivity analysis is used to assess how changes to the key drivers will influence the potential impacts. We select the drivers based on the materiality of their potential impact and the uncertainty associated with the assumption. We set below some of the key drivers that we flex as a sensitivity.

1. **Occupancy rate:** The number of passengers per trip is a determinant of the cost per passenger as it is assumed that the costs are split between the total number of passengers. The business as usual scenario and use case both assume the journey is completed by one individual. In our sensitivity analysis we consider the impact of **an additional passenger** in the use case.

2. **Time per trip:** The number of annual trips for the air mobility is influenced by **operational days** and the **time per trip**. In turn, the time per trip is driven by flight ready hours, time to disembark, board and speed. If, for example, the boarding, disembarking and landing & take-off time all **doubled** then this would reduce the number of annual flights.

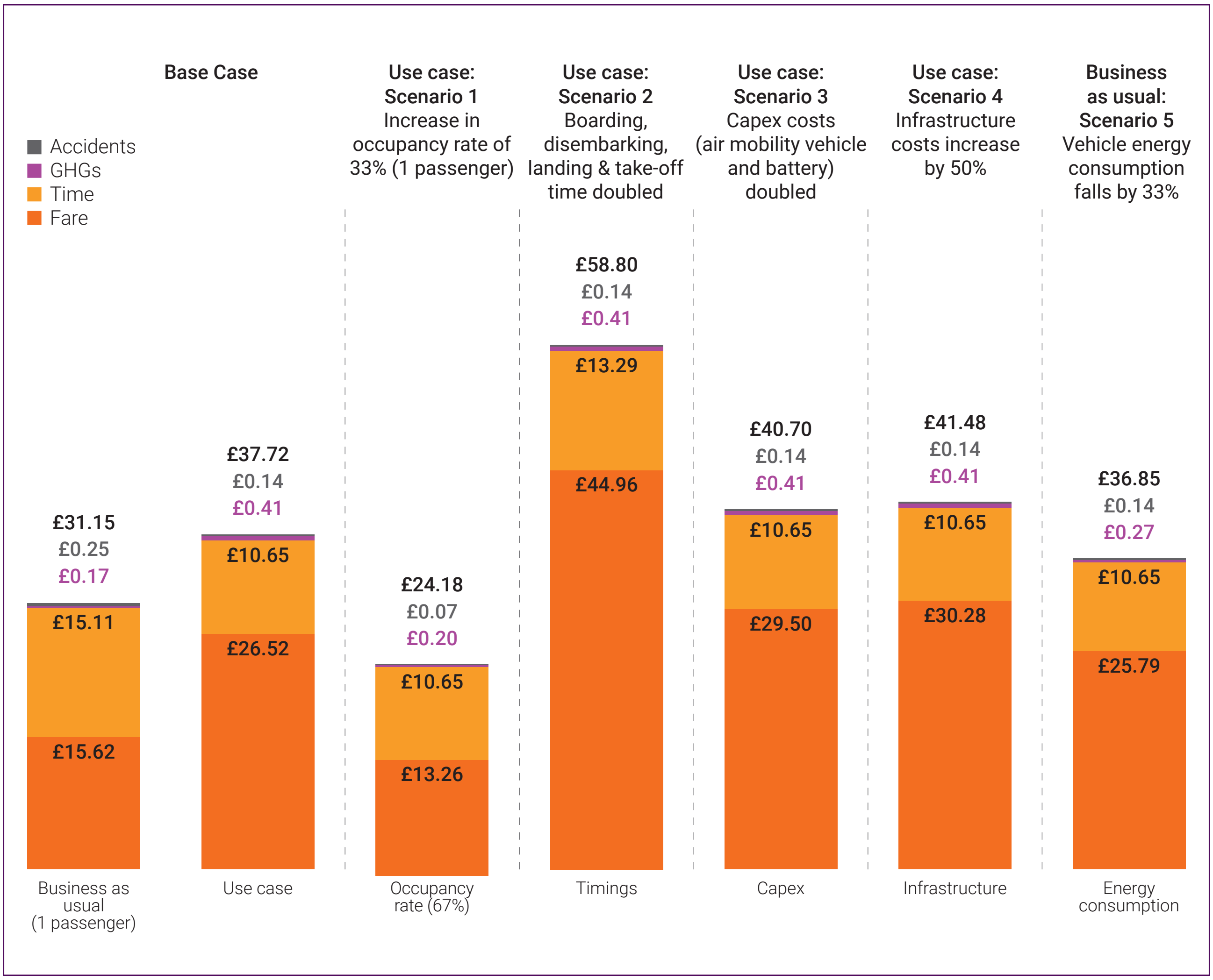
3. **Capex:** We assume the "near-term" costs where the costs of the air mobility vehicles are based on assumed (global) production of around 500 units a year: this enables some economies of scale and other advances in the technology and manufacturing process. As a sensitivity, we consider the impact of using the **"immediate term"** value for the vehicle and battery costs, which are **double** the "near term" costs. The assumption on the capital costs is dependant on how we assume the technology is likely to evolve over the next few years.

4. **Infrastructure costs:** Infrastructure costs are assumed to be £71k but, as we note, they depend on factors such as the quantity and quality of infrastructure as well as technological progress. As a sensitivity, we consider the potential impact if infrastructure costs per air mobility vehicle are **50%** higher.

5. **Energy consumption:** The cost of powering the air mobility vehicle depends on a range of factors including speed, weight, engine efficiency and load. As a sensitivity, we consider potential impact of **decreasing energy consumption by a third**.

Sensitivity analysis results

We set out below how changes to the key cost drivers impact the costs under the use case.



Conclusions and next steps

Attractiveness of the use case

- Our analysis suggests the total costs of using an air taxi in an urban area are around 21% higher than the use of a ridesharing service (business as usual). This is primarily driven by higher fare costs as we assume the four-seater air taxi only carries one passenger in addition to the pilot. Increasing the number of passengers to two lowers the fare per passenger so that total costs in the use case are around 22% lower than business as usual. Our results suggest that the use case could be attractive in urban areas provided that they offer convenience and shorter journey duration (including the time waiting for an air taxi).
- Our analysis focuses on the use of air taxis by business users who are more likely to trade off fare costs for reduced journey time and better quality journeys.
- If - or as - the use of air mobility vehicles becomes more widespread, capital costs could fall due to economies of scale resulting in the air mobility vehicle becoming even more attractive, including for non-business users whose alternative model of transport is public transport.

Assessment of winners and losers

- The key stakeholder groups impacted by this use case are passengers, ridesharing companies (and their drivers) and air taxi operators:

  The winners are likely to be passengers who benefit from shorter journey duration and air taxi operators.

  The losers are likely to be ridesharing companies and their drivers as the air taxi starts to replace the use of ridesharing services.

Next steps / further analysis

- Going forward, further analysis could be undertaken to understand the differences in costs between the use case and business as usual which involves the use of public transport (e.g buses and underground). In addition, as the use of air mobility vehicles becomes more widespread, it is likely that other externalities (e.g. air quality, landscape, historical, environmental etc) become more material and would need to be assessed to capture the total costs in the use case and business as usual.

Summary – key results and their implications

9

Summary

9

The scope and purpose of analysis

Scope and purpose of analysis

This study has developed and tested a holistic framework that can be used to assess the potential costs and benefits of different applications of new aviation technologies compared to the alternatives currently in use.

Our report analyses six different use cases:

- Use of drones for powerline inspection
- Use of drones for cargo (mail) delivery
- Use of drones for last mile delivery of prescribed medicines
- Sub-regional air taxi transporting passengers from York to Preston
- Rural air taxi transporting passengers from village to village or village to town
- Urban air taxi transporting passengers in an urban area

These use cases were selected to provide illustrative applications of drones or air mobility technologies which are already well defined; they are not intended to be representative of all possible applications and, specifically, do not consider possible longer term developments in the technologies.

We develop a bottom up model to estimate the total costs for each use case and the business as usual scenario. We rely upon data in published sources, academic literature, government guidance and PwC proprietary analysis to support our analysis.

We establish a set of base case costs for each use case - often underpinned by some key assumptions - and identify the key cost drivers. We then undertake sensitivity analysis to assess how changes to key cost drivers influence the costs under the use case and the business as usual scenario.

Summary

Key findings

Our analysis suggests that in the majority of use cases there are significant potential benefits associated with the use of drone and air mobility technologies. The overall net cost of the use cases is between 20-48% lower than business as usual. The table below sets out the cost under the use case and business as usual and shows the difference between the two.

The two use cases where the cost of the use case is greater than the business as usual are: Rural and Urban air taxis. This is primarily driven by the higher "fare" element of the costs which, in turn, reflects the (assumed) single occupancy rate. Both use cases present time saving benefits and, therefore, have lower time related costs relative to business as usual.

Use case	Unit cost of business as usual	Unit cost of use case	Difference in unit cost
Powerline inspection	£193,141	£127,856	**-34%**
Cargo delivery – mail	£1,722	£1,117	**-35%**
Last mile delivery	£15	£12	**-20%**
Sub-regional air taxi	£126	£66	**-48%**
Rural air taxi	£24	£40	**67%**
Urban air taxi	£31	£38	**23%**

Summary

Interpretation of findings and next steps

Interpretation of findings

Our analysis shows the potential offered by drone and air mobility technologies across the sample of use cases.

In our sensitivity analysis, we flex various cost drivers to explore the impact that they have on the overall net costs. We find that, for the majority of sensitivities, the use cases continue to offer benefits relative to business as usual.

We note that our analysis is based on the initial uptake of the drone or air mobility technology and, therefore, captures the net costs at a particular point in time; our analysis does not consider how the costs and benefits could change as the technology becomes more pervasive.

Our analysis highlights the potential market opportunity that could be realised through application of the drones and air mobility technologies we have considered; further analysis is required to understand the scale of the opportunity.

In addition, our study does not consider the extent of societal acceptance of these technologies, the regulatory implications, nor the supporting infrastructure and technology ecosystem required for the use cases, which may have implications on their attractiveness.

Next steps

Looking ahead, further analysis is needed to consider:

- The potential size of the market opportunity for each use case and how sensitive this is to the potential evolution of the costs of the different technologies.
- How regulation and societal acceptance will affect each use case.
- The infrastructure and technology ecosystem required to support the use case, how this might be funded and the implication for the take up of the technologies.
- How the external costs and benefits associated with each use case could change if take up of the technologies becomes significant
- How similar the picture is for other potential use cases beyond those considered in this study.
- The impact of increased levels of renewable energy generation on the greenhouse gases (GHG) emitted in each use case.

FFC: **Kerissa Khan,** Innovation Lead, ISCF Future Flight Challenge, UK Research and Innovation
07395 376965
kerissa.khan@innovateuk.ukri.org

PwC: **Craig Roberts**, PwC Drones Technical Lead
07771 930482
craig.roberts@pwc.com

UK Research
and Innovation