THE SCOPE FOR INTEGRATING UNCREWED AERIAL VEHICLES INTO HEALTHCARE LOGISTICS SYSTEMS – A CASE STUDY OF PATHOLOGY SPECIMEN TRANSPORT

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Background

- Commercial operations using Uncrewed Aerial Vehicles (UAVs, commonly known as drones) have been expanding across a number of different applications (e.g., aerial photography, surveillance, monitoring, inspection, surveying, and support of emergency services).
- Drones could also have scope for payload delivery offering reduced energy consumption, emissions and costs, and faster delivery times and improved access to locations that are hard to reach via existing surface infrastructure.
- However, examples of large-scale, successful commercial implementations of routine drone logistics operations remain scarce.

Research Aim

The aim of this research was two-fold:

1. To assess the influence on sustainability of integrating drones alongside traditional modes in a multi-modal logistics system, based on a live case study in a healthcare setting; and
2. To quantify the scale of that influence, providing guidance to the drone and logistics industries on the potential effects of drone up-take.

FIGURE 1. Patient pathology specimen (left) and standard medical container (right). The medical container (brand name Versapak) has empty mass 2.2 kg, mass with a full load of specimens ~5 kg, and dimensions 460×255×305 mm.

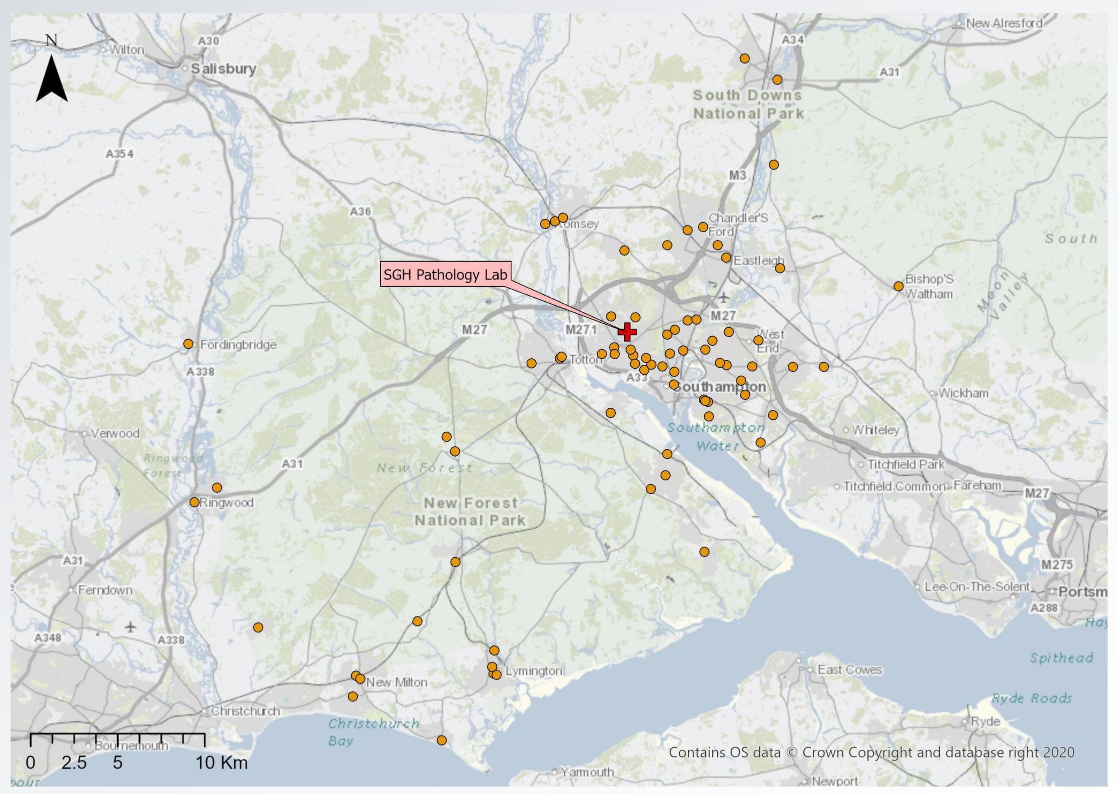

FIGURE 2. Southampton case study region. Orange circles indicate community clinics. SGH is Southampton General Hospital.

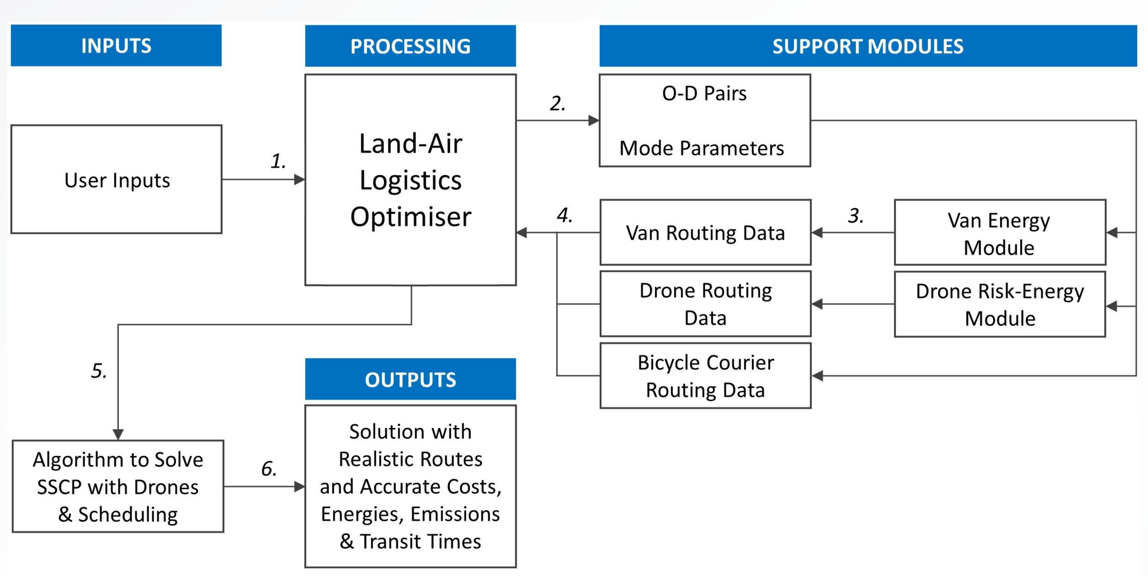

FIGURE 3. Flowchart of FORSETI processes. Numbers indicate the sequence of steps within FORSETI. SSCP is Sustainable Specimen Collection Problem.

Methodology

Case Study Area

- Over 300,000 routine pathology specimens are taken from patients at community clinics (i.e., doctor's offices) daily across the UK.
- These specimens are packed into standard medical containers (Figure 1) by clinic staff, and then collected via networks of vans for delivery to pathology laboratories, usually located at large hospitals, for analysis.
- The case study focused on the network of 76 community clinics located in and around Southampton (a city on the South coast of the UK with a population of ~250,000), sending specimens to Southampton General Hospital (SGH) (Figure 2). Two scenarios were investigated:
  i. The benchmark scenario represented the business-as-usual (BAU) situation where all clinics were serviced by electric van (i.e., e-van-only solution).
  ii. The intervention scenario introduced drones and bicycle couriers as potential alternatives to servicing clinics by e-van.
- Both scenarios covered a four-hour morning shift period (09:00-13:00), where each clinic had to be visited once to collect a container of specimens.
- Whenever a vehicle collected a container of specimens, it was assumed to drop-off an empty replacement along with fresh specimen tubes at the same time.

Analysis Tool

- A novel logistics planning tool (Freight Optimization with RiSk, Energy, and mixed-mode Transport Integration; FORSETI) was developed to analyze these scenarios.
- FORSETI analyzes the demand for logistics during a given shift period and produces the optimal deployment of available transport assets to satisfy that demand, based on a combination of user-weighted optimization objectives and user-defined input parameters (Figure 3, Table 1).
- E-vans were assumed because a transition to electric vehicle fleets is a committed change within the UK National Health Service (NHS).
- The drone-type was set as an electric Vertical Take-Off and Landing (VTOL) and Fixed-Wing (FW) hybrid drone (Figure 4) with sufficient payload capacity to carry one medical container.
- FORSETI uses flightpaths that consider ground risk (i.e., the risk of a fatality on the ground due to a drone crashing) by detouring around higher risk areas with higher population densities, accounting for land-use and the variation of population densities with time of day.
- Whilst there was nothing in principle to prevent them delivering direct to the hospital, bicycle couriers generally performed a consolidation function, collecting specimens from nearby clinics and consolidating them at a given clinic for onward transport to the laboratory by drone or e-van. Energy consumption (and therefore emissions) for bicycle couriers was assumed to be zero.

TABLE 1. Input parameter values.

Input Parameter	Value
Shift duration	4 hours (09:00 to 13:00)
Dwell time (consistent with logistics industry norms)	2.5 minutes
Additional dwell time for drones at the laboratory to allow for battery swaps and airworthiness checks	10 minutes
Maximum allowable in-transit time to maintain specimen viability for analysis	90 minutes
E-van payload capacity	5 m^3/800 kg
E-van range	200+ km
E-van labor cost (includes pay for overtime and productivity)	11.93 GBP/hour
E-van vehicle running cost (includes fuel, tires, maintenance)	0.34 GBP/mile
E-van vehicle standing cost (includes vehicle tax, insurance, depreciation, and overheads)	29.33 GBP/day
Drone payload capacity	1x medical container
Drone range	150+ km
Drone cruise speed	65 km/h
Drone operator-to-vehicle ratio (mission commanders were assumed to be able to monitor up to 20 drones simultaneously in accordance with recently reported real-world values)	1:20
Drone labor cost (includes 1x mission commander, 2x safety pilot, 2x specialist loader/technician)	175.64 GBP/hour
Drone vehicle running cost (includes drone platform based on component life expectancies, electricity)	32.40 GBP/flight-hour
Drone vehicle standing cost (includes insurance, airspace access fees to UAV Traffic Management (UTM) service providers)	8.99 GBP/day
Future drone labor cost (includes 1x mission commander, 1x specialist loader/technician)	31.44 GBP/hour
Future drone vehicle running cost	20.33 GBP/flight-hour
Future drone vehicle standing cost	8.99 GBP/day
Bicycle courier payload capacity	3x medical containers
Bicycle courier range	8 km
Bicycle courier task cost (includes one collection)	7.07 GBP/task
Bicycle courier distance cost (beyond a 0.5-mile threshold)	1.01 GBP/mile
Bicycle courier additional collection(s) cost	2.78 GBP/collection
Emission factor for electricity used in-vehicle	0.1934 kg CO_2-eq/kWh
Emission factor for processes associated with generating electricity used in-vehicle (includes extraction, refining and transport of primary fuels, and losses in electricity transmission and distribution)	0.0505 kg CO_2-eq/kWh

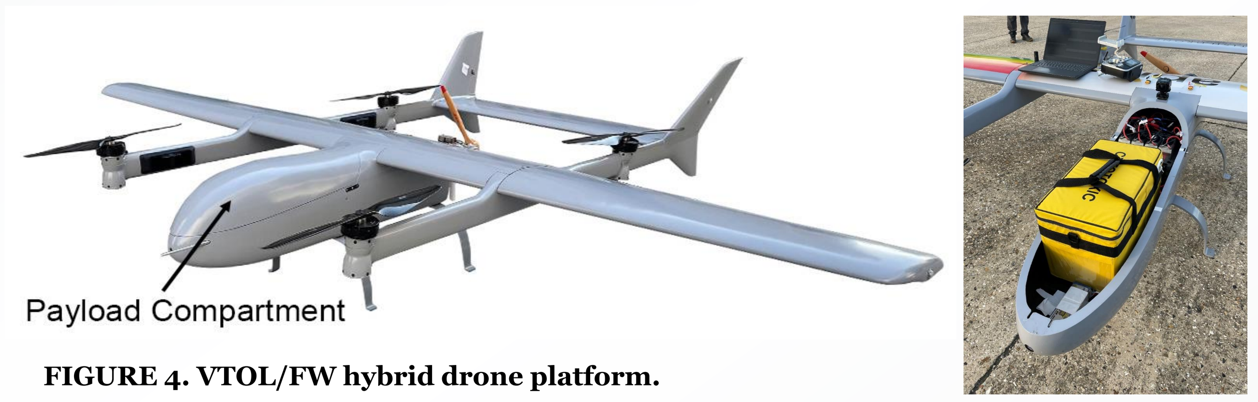

FIGURE 4. VTOL/FW hybrid drone platform.

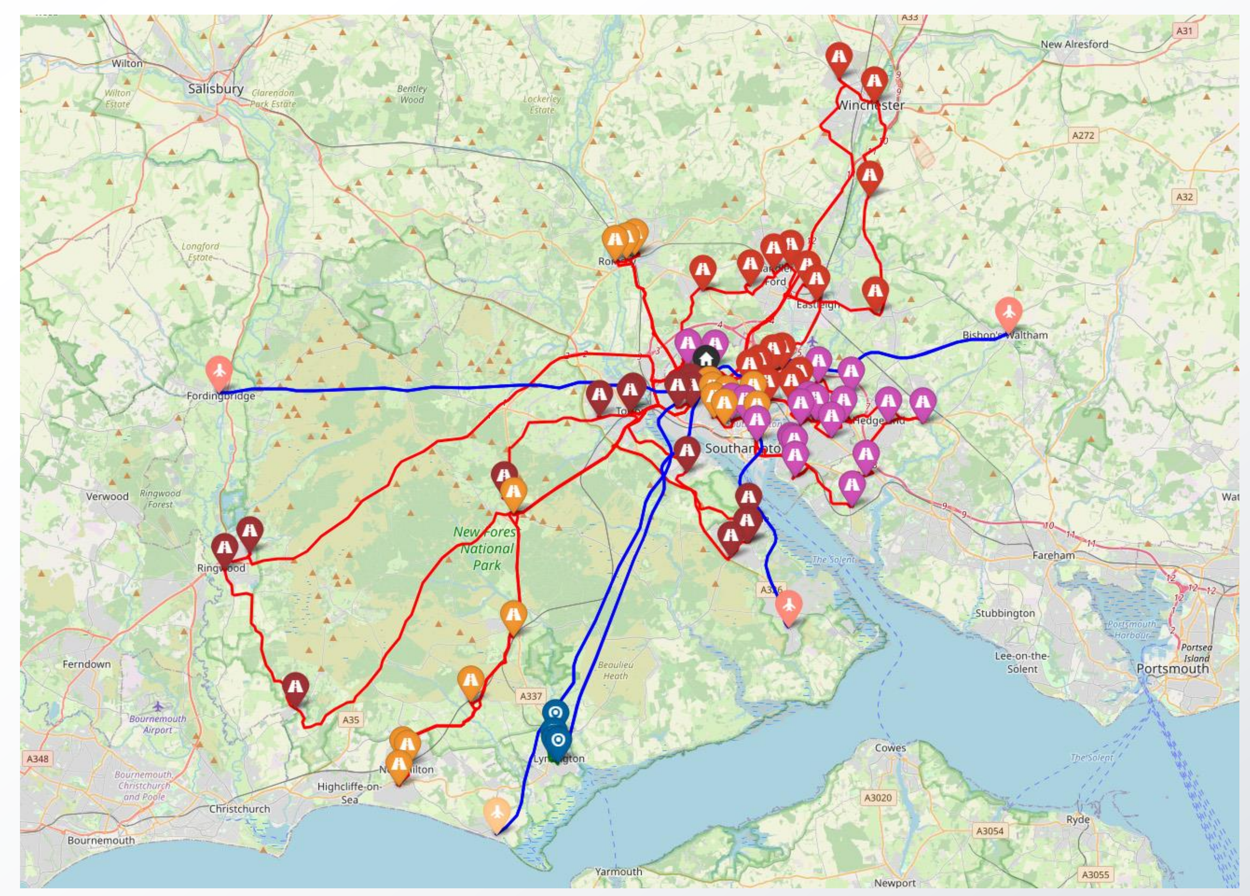

FIGURE 5. Map of vehicle routes showing partial uptake of drones as drone costs were reduced. Blue, red, and green lines indicate drone, e-van, and bicycle courier routes, respectively. Pins indicate clinics: aircraft symbol served by drone; road symbol, e-van; wheel symbol, bicycle courier. Black pin indicates Southampton General Hospital. Base map source: OpenStreetMap.

Results

- A reduction in drone operating costs of at least 82% from current values was likely to be necessary before drones would begin to be selected as a cost-viable alternative to e-vans or bicycle couriers in multi-modal logistics systems (Figure 5).
- Analysis comparing drone costs from FORSETI when input parameter values for drone costs were set to future values versus compared to current values (Table 1) suggested that a reduction in drone costs of ~55% might be achievable in the future through increased automation and economies of scale in manufacturing.
- Introducing drones into multi-modal logistics systems could reduce energy consumption and greenhouse gas (GHG) emissions by 53% compared to an e-van-only solution. However, most of the reduction in the intervention scenario was due to the increased use of bicycle couriers (Figure 6).
- These reductions in energy consumption and emissions were countered by a significant increase in cost of 88% (based on likely future drone costs, Table 1).
- Introducing drones into multi-modal logistics systems could reduce maximum In-Transit-Time (ITT) by 63% compared to an e-van-only solution (Figure 6).
- This reduction in maximum ITT incurred an 80% increase in costs (based on likely future drone costs, Table 1), questioning the true value of expedited delivery when the level of service demanded by the NHS for pathology transport (i.e., within 90 minutes of first collection) can be easily satisfied at lower costs using e-vans alone (i.e., the benchmark scenario).

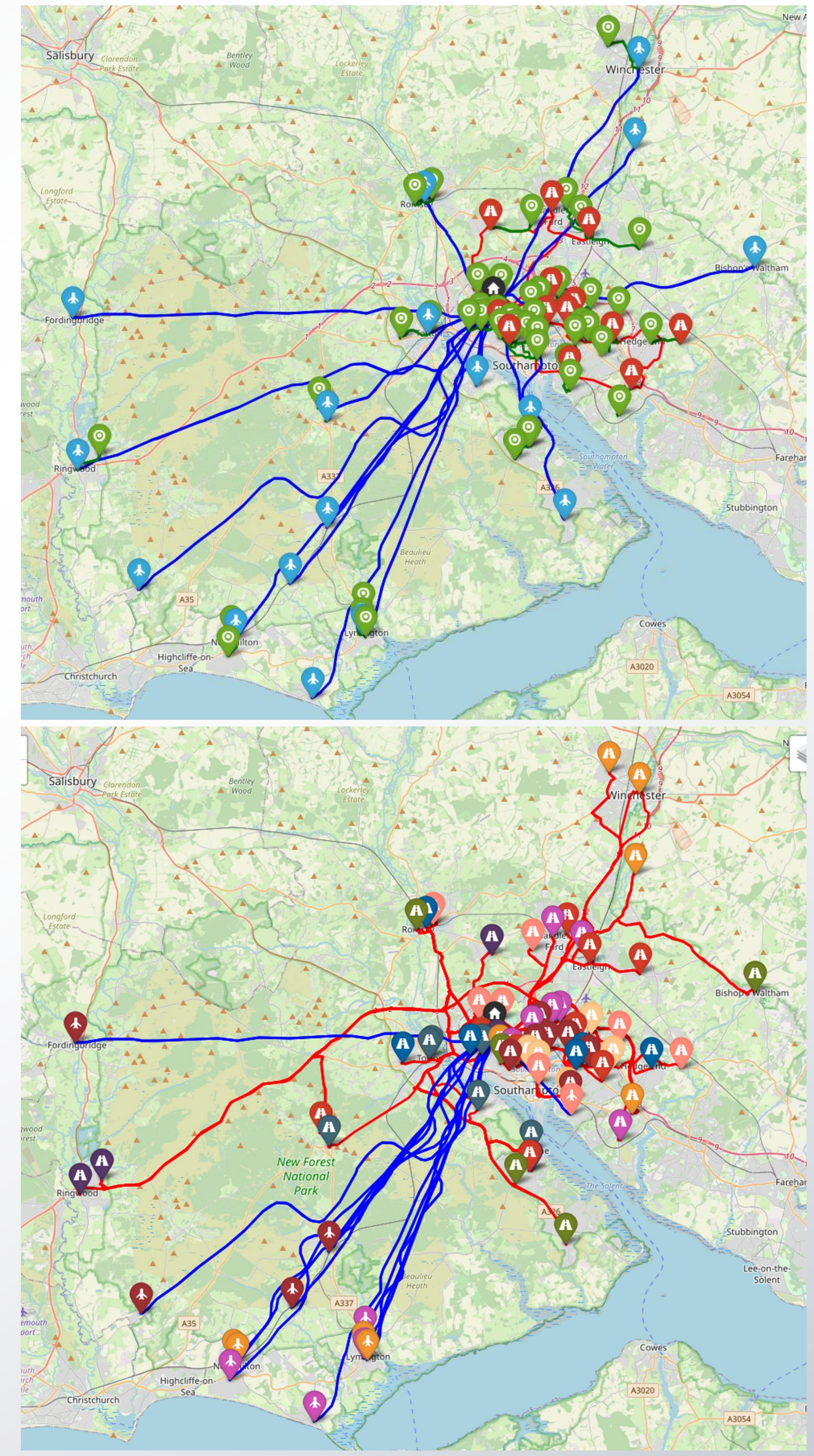

FIGURE 6. Maps of vehicle routes for intervention solutions optimized to minimize energy/emissions (top); and to minimize maximum in-transit time (bottom). Blue, red and green lines indicate drone, e-van and bicycle courier routes, respectively. Pins indicate clinics: aircraft symbol served by drone; road symbol served by e-van; wheel symbol served by bicycle courier. Black pin indicates Southampton General Hospital. Base map source: OpenStreetMap.

Discussion and Conclusions

- Drones offer the most potential (costs, energy/emissions, transit time) when used to service the more remote and/or isolated clinics.
- E-vans or bicycle couriers tended to be more efficient in urban areas, where clinic densities are higher, using their greater payload capacity to produce economies.
- The introduction of drones and bicycle couriers can produce reductions in energy consumption, GHG emissions and payload transit times compared to e-van-only solutions, but these benefits are usually at the detriment of increases in costs.
- Drones could improve the sustainability of multi-modal logistics systems in particular circumstances, such as when speed of delivery is highly valued (e.g., for urgent payloads like delivering defibrillators to cardiac arrests or naloxone to drug overdoses) or when serving remote and/or isolated locations.
- Practical realities may limit the ability of drones to realize their full potential such as service reliability, weather tolerance, landing site availability, payload capacity, and the ability to fly routinely beyond-visual-line-of-sight (BVLOS) of an operator and in shared airspace alongside existing crewed aircraft.

Acknowledgements

The research was supported by the UK EPSRC as part of the E-Drone project [grant number EP/V002619/1] (www.e-drone.org), and by the UK Department for Transport as part of Solent Transport's Future Transport Zones project (www.solent-transport.com/solent-future-transport-zone/).