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Can Mixed-Mode Logistics Fleets Including Drones Really Decarbonise Freight?: Grounding The Myths Using Case Study Modelling

Andy Oakey, **Tom Cherrett,** Matt Grote, Aliaksei Pilko, Alex Blakesley, Jakub Krol, Toni Martinez-Sykora, Bani Anvari

4th Dec 2023 – SRF Conference

CONTENTS

- Business-as-usual
- Introducing drones
- Exploring modelling challenge
  - Constraints, objectives
- Realistic modelling inputs
- Case Study Results
- Other challenges/opportunities

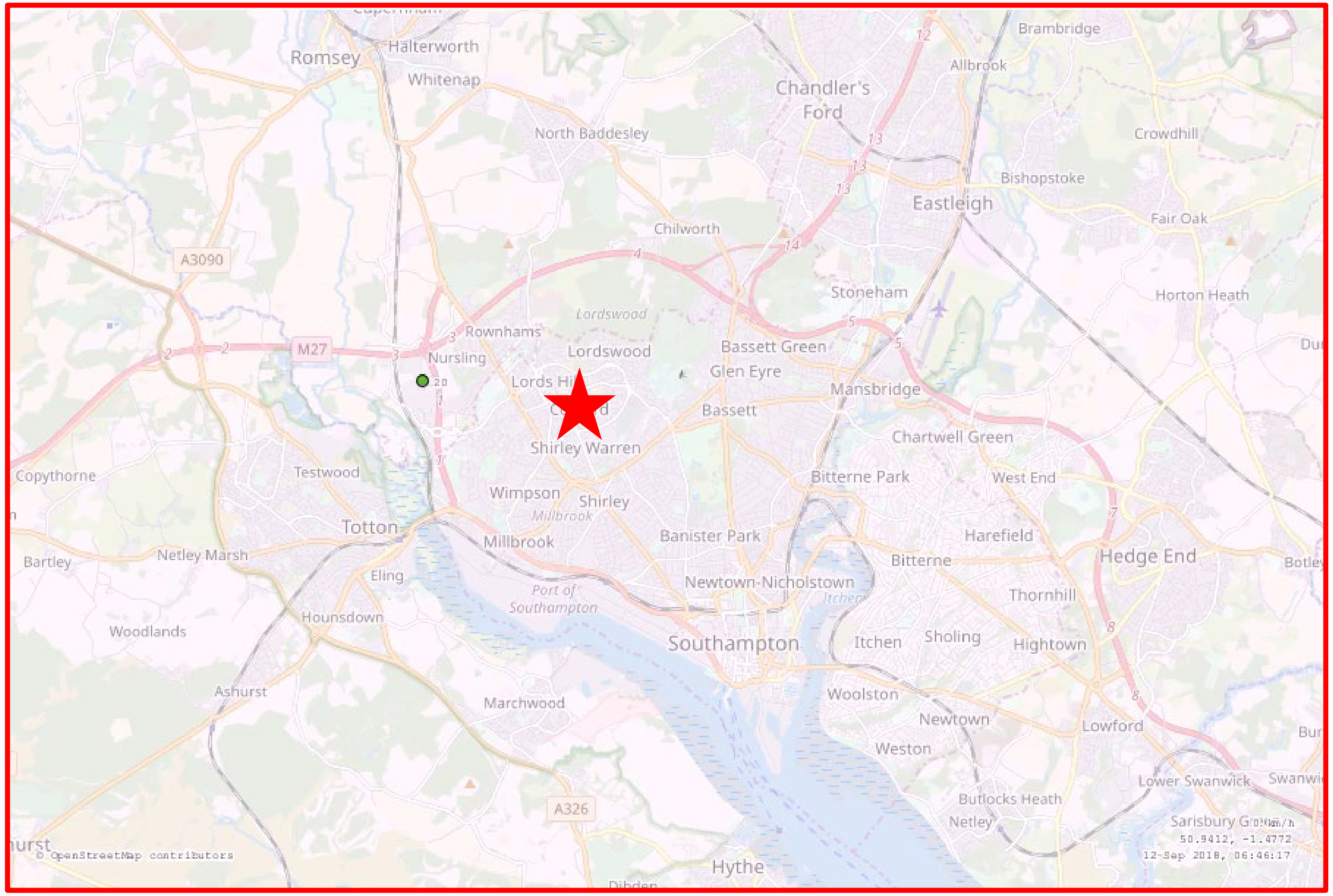
PROJECT BACKGORUND

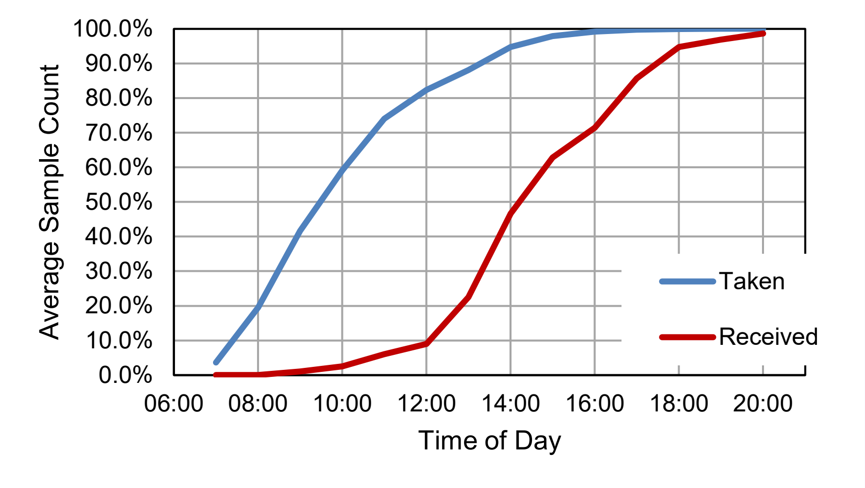
- **E-Drone (EPSRC), 1/1/21 – 31/12/23 (UoS, BU, UCL, Leeds)**
  - https://www.e-drone.org/
  - How to integrate drones into mixed-fleet logistics
  - The energy and cost implications of NHS drone logistics
  - Public perceptions of wide spread drone deployments
- **Future Transport Zone, (DfT), 1/4/21 – 30/6/25 (ST, UoS, UoP)**
  - Developing a UTM for managing drones in the Solent region
  - Developing drone corridors between the Solent NHS sites
  - Developing safe systems for dangerous goods transport
  - Understanding human factors issues in drone management

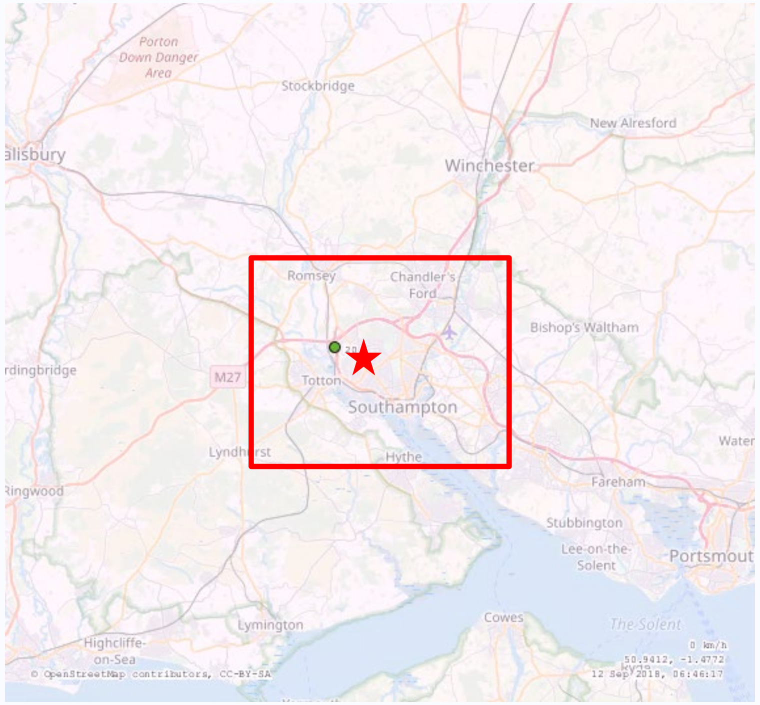
DIAGNOSTIC SPECIMENS – USE CASE

- Movement of patient specimens to a hospital laboratory for analysis
- Delivered “on-time”
- Without incurring significant costs
- Carriage in industry standard ‘Versapak’ medical carriers

FOCUS AREA: PATIENT SAMPLES

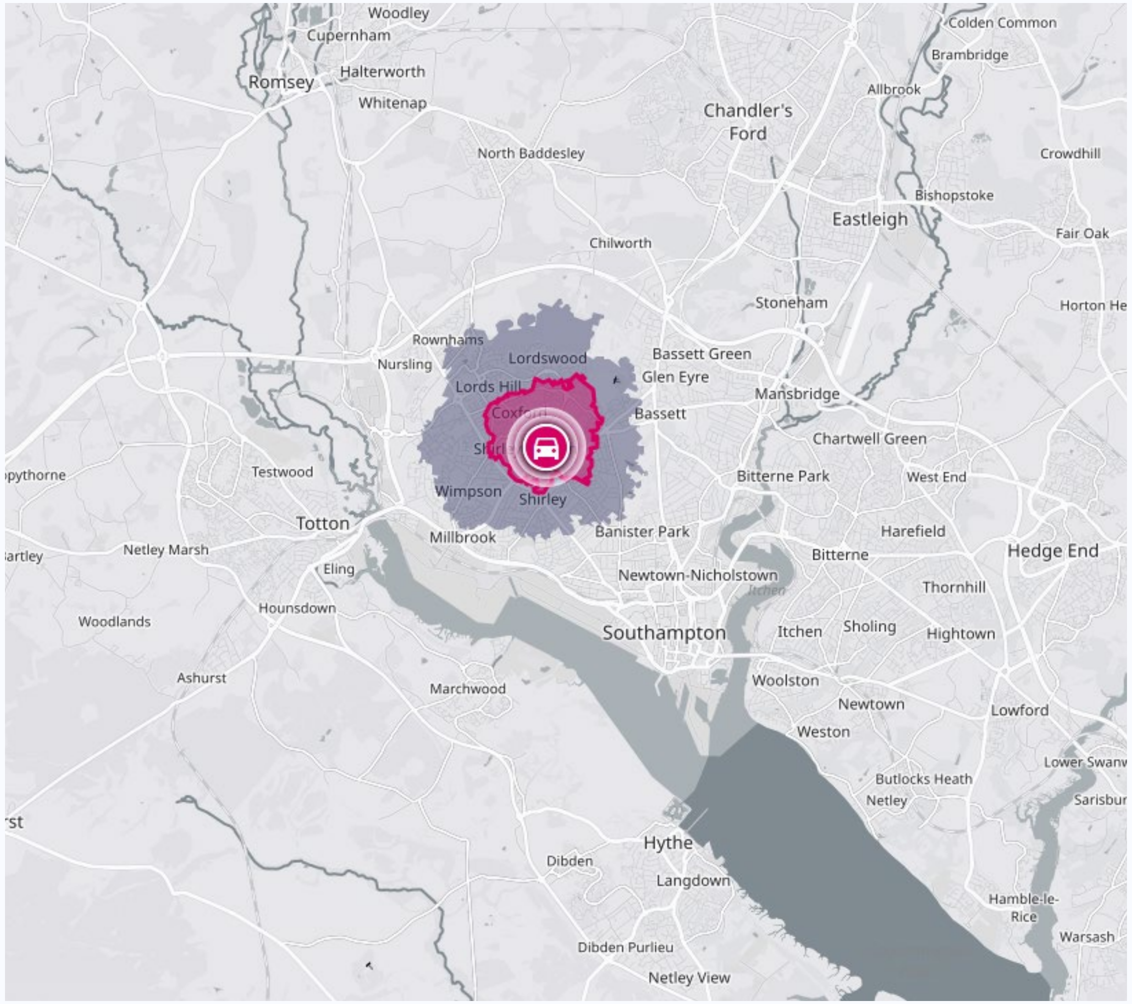


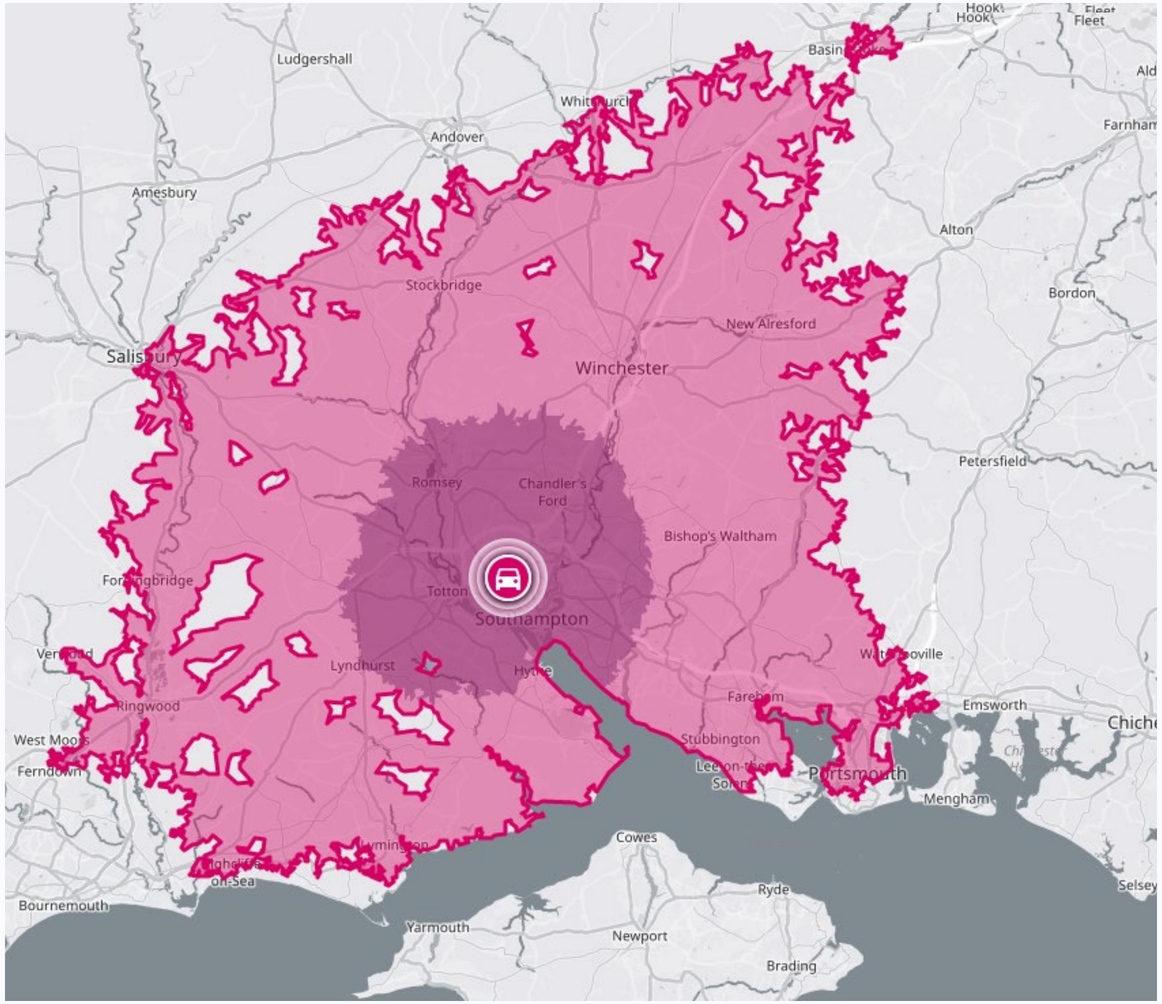




Base Map© OpenStreetMap Contributors

MULTI-MODAL: THE SOLUTION?





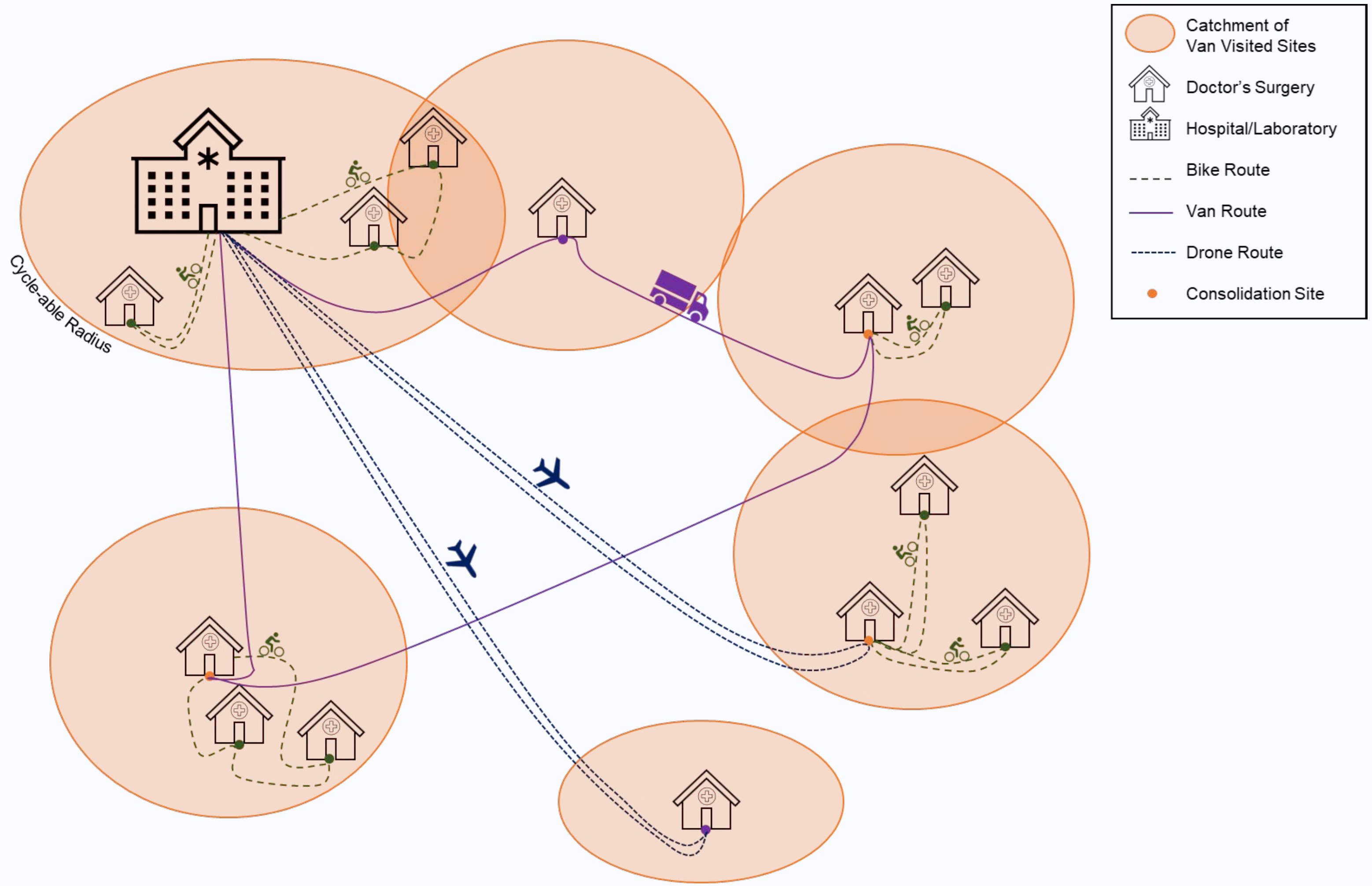
Base Map© OpenStreetMap Contributors

INTRODUCING DRONES

Wing
https://wing.com/

https://bsm-highlights.com/issue1_2021/autonomous-operations-in-the-marine-industry-how-drones-can-revolutionise-shore-to-ship-deliveries/

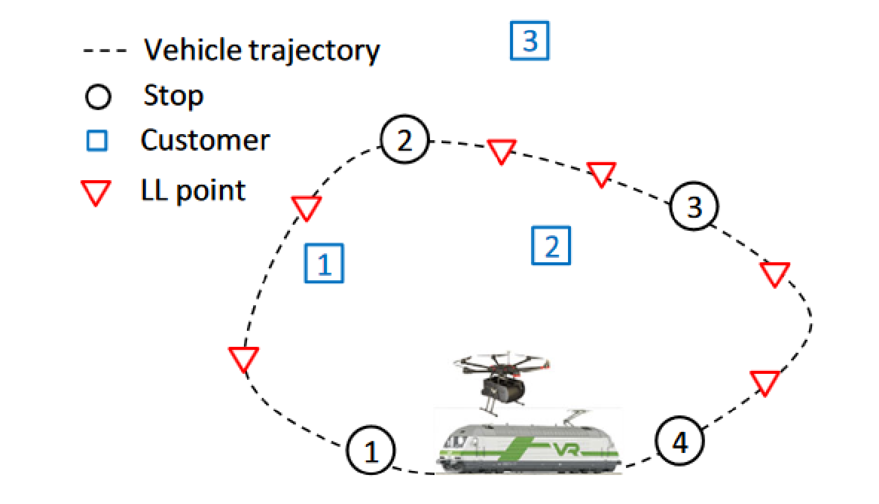
INTRODUCING DRONES – HOW?



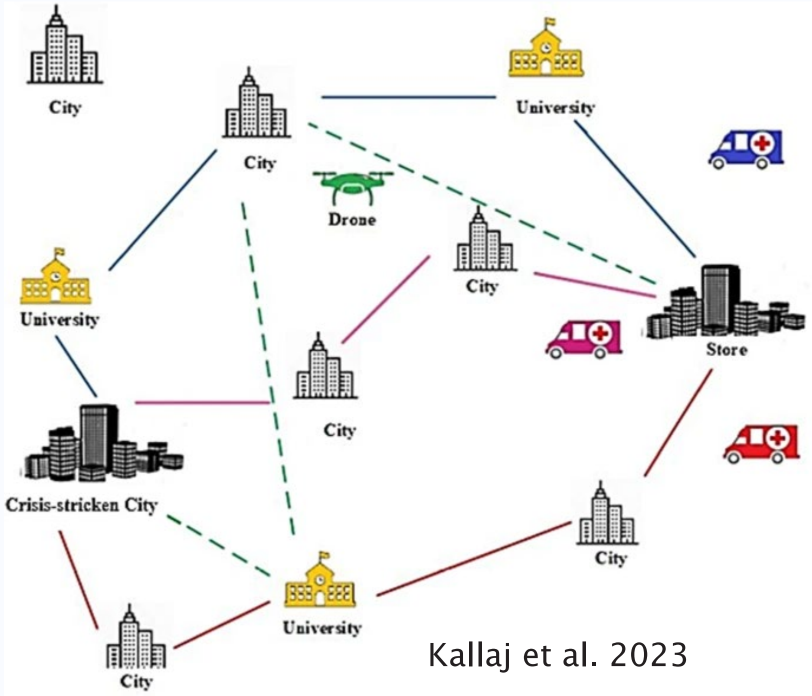
RELATED CONCEPTS

- Flying Sidekick
- Competing Modes
- Disaster Relief

https://anthropocenemagazine.org/wp-content/uploads/2020/05/generic-drone-and-van-delivery.jpg



Huang et al. 2020



Kallaj et al. 2023

RESEARCH QUESTIONS

- In what areas and what circumstances could drones contribute effectively to NHS logistics?
- What types of drones are most suited to these NHS areas and what would their operating criteria have to be?
- How would their operating performance be affected by routing constraints which may be dynamic in nature?
- How would they be used on a daily basis given weather conditions and routing constraints?
- What contingency options would be needed for no-fly events?

CHALLENGES MODELLING DRONES: COST

INSIDER

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Premium HOME > TECH

Amazon will pay a whopping $63 per package for drone delivery in 2025 and it shows just how the company is still grappling with cost issues for last-mile delivery

Eugene Kim and Katherine Long Apr 7, 2022, 10:00 AM

https://www.businessinsider.com/amazon-prime-air-drone-delivery-cost-63-per-package-2025-2022-4?r=US&IR=T

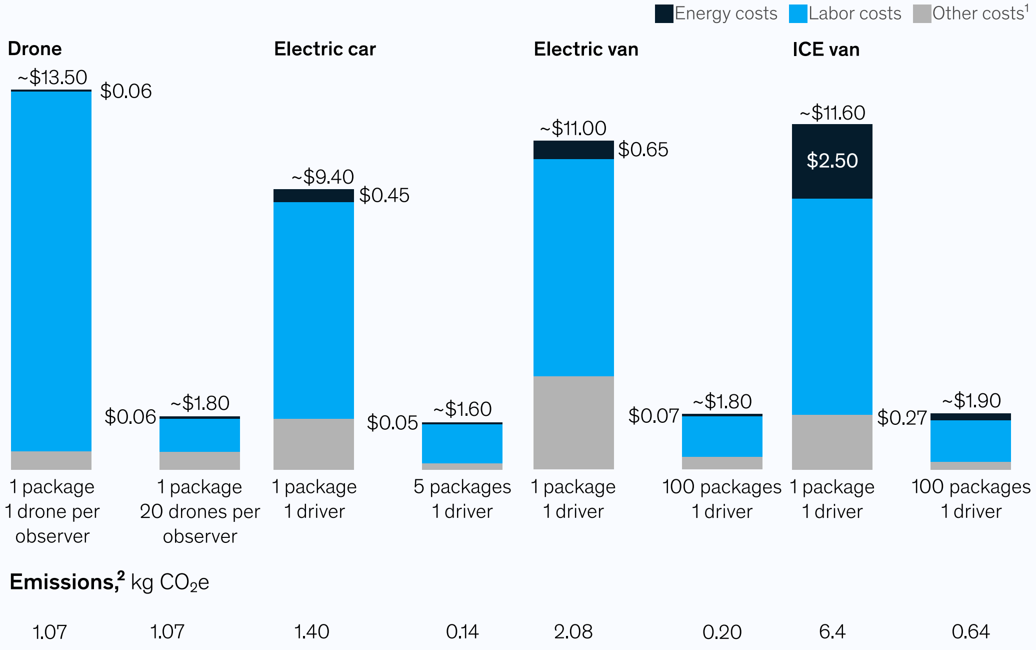
SWISS POST

> Operations demonstrated that drones are well suited to urgent transportation of special items and that there is a clear interest in the service. However, drones are cost-intensive for Swiss Post and cannot be operated profitably in the medium term.

https://www.post.ch/en/about-us/innovation/innovations-in-development/drones?shortcut=opp-en-about-us-company-innovation-swiss-post-s-innovations-for-you-drones

Drones could become cost competitive with other transport modes.

Example breakdown: unit delivery costs and emissions for a five-mile delivery of a 216-cubic inch package (six inches per side)



[1]Other costs include asset, maintenance, and insurance costs.
[2]Scope 2 and Scope 3.

https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/future-air-mobility-blog/drones-take-to-the-sky-potentially-disrupting-last-mile-delivery

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CHALLENGES INTEGRATING INTO EXISTING SYSTEMS

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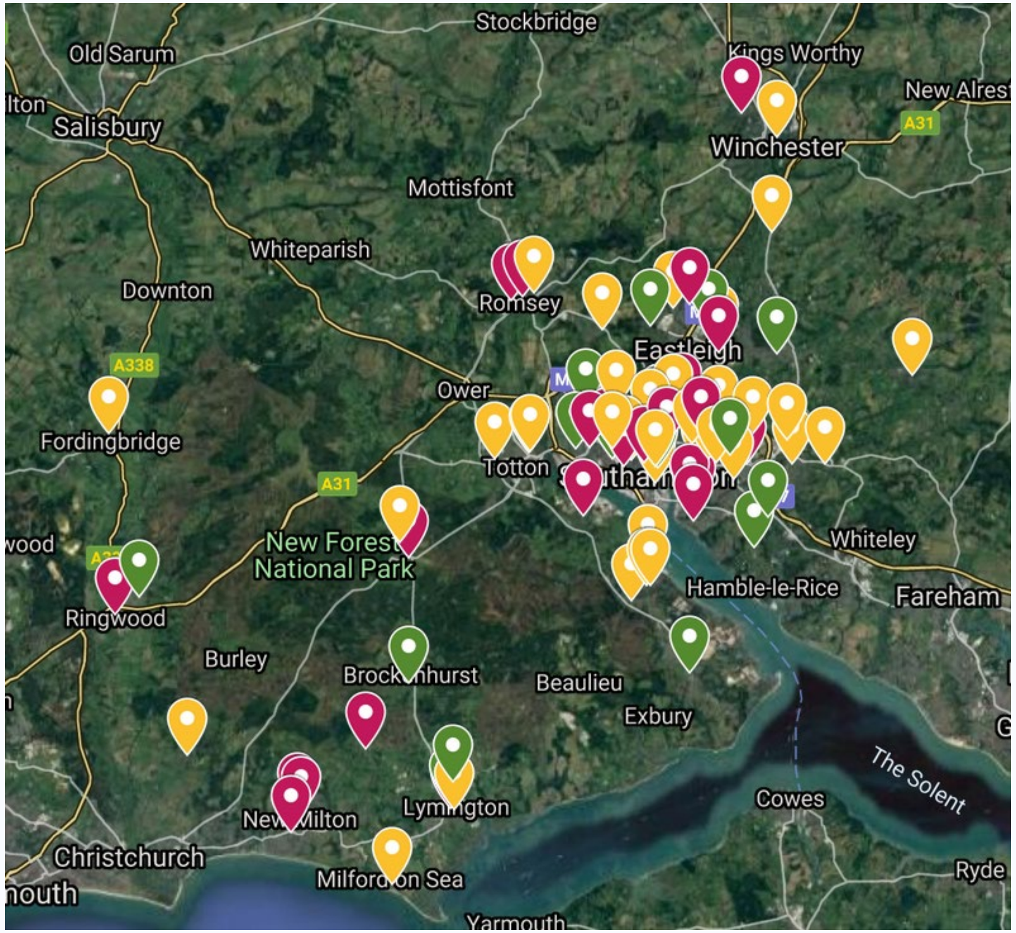
PRACTICAL CONSTRAINTS – LANDING SPACE



Small

NO

OK

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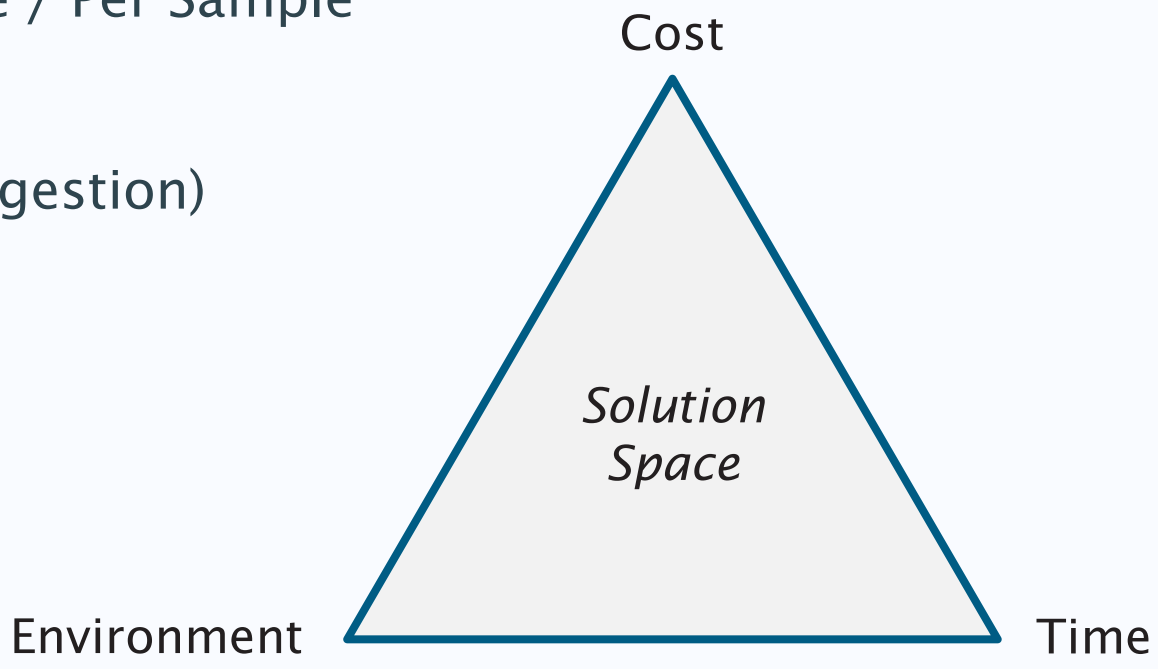
DEFINING THE PROBLEM - POTENTIAL OBJECTIVES

- **Patient Care** – Transit Time / Bleed to Receipt / Useful GP Hours / Staff Utilisation
- **Energy & Emissions** – Overall / Per Vehicle / Per Sample
- **Costs** – Overall / Per Vehicle / Per Sample
- (Assets – % Utilisation / Active Hours / Congestion)
- (Safety – Overall (fatalities/hr))



ASSUMED COST STRUCTURE

- Vans
  - Vehicle cost per DAY (insurance, etc.) and per MILE (fuel, etc.)
  - Driver cost per HOUR for a FIXED PERIOD (i.e. guaranteed pay)
- Bikes
  - Gig economy style model – on demand. Low utilisation outside of peak mealtimes.
  - Pay per JOB up to a given distance where a DISTANCE PREMIUM APPLIES, also BONUS PER STOP
- Drones
  - Aircraft cost per FLIGHT HR. – maintained using a usage based service schedule
  - Operator cost per HOUR for a FIXED PERIOD. Operator can oversee MULTIPLE DRONES.

MULTI-OBJECTIVE PROBLEM

Variable (Route) Operating Costs

Emissions

$$\min : \sum_{\bar{r}_k \in \bar{R}} \left(x_{\bar{r}_k} \left(\sum_{r_{v,k} \in \bar{r}_k \cap R^V} \theta_1 p_{r_{v,k}} + \sum_{r_{e,k} \in \bar{r}_k \cap R^E} \theta_1 p_{r_{e,k}} + \sum_{r_{d,k} \in \bar{r}_k \cap R^D} \theta_2 p_{r_{d,k}} + \sum_{r_{c,k} \in \bar{r}_k \cap R^C} \theta_3 p_{r_{c,k}} + \theta_4 \epsilon_{\bar{r}_k} \gamma \right) \right)$$

$$+ \theta_1 W^V A^V_{max}$$

$$+ \theta_2 (W^D A^D_{max} + W^O A^O_{max})$$

$$+ \theta_5 u$$

Fixed (Vehicle/Staff) Operating Costs

Maximum In Transit Time

KEY CONSTRAINTS

- 90 minutes In Transit Time
- 4 Hour Shift Periods
  - Guides payment structure – e.g. paid for 4 hours even if only active for 0.5 hours
- Cyclists can only visit 4 sites
- Drones only permitted to serve certain sites
- Drone range

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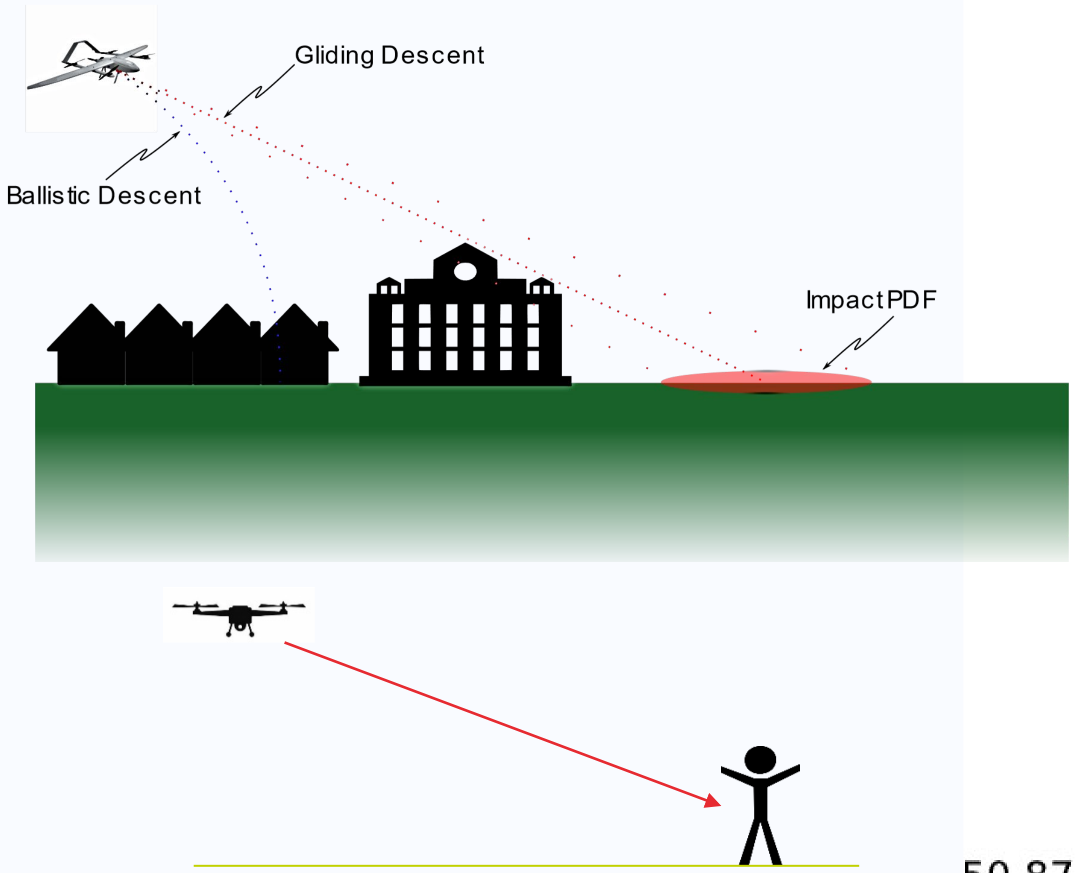
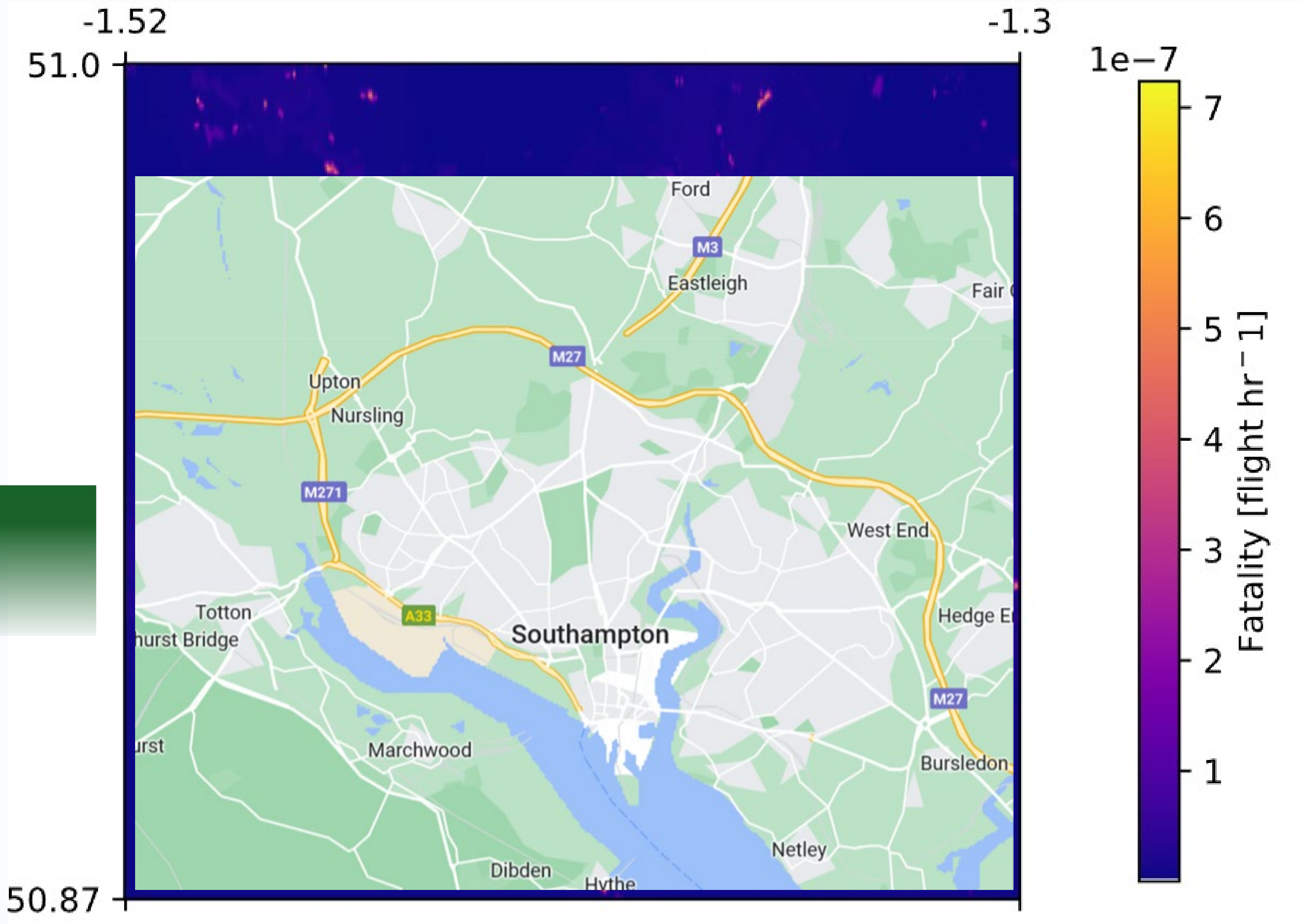
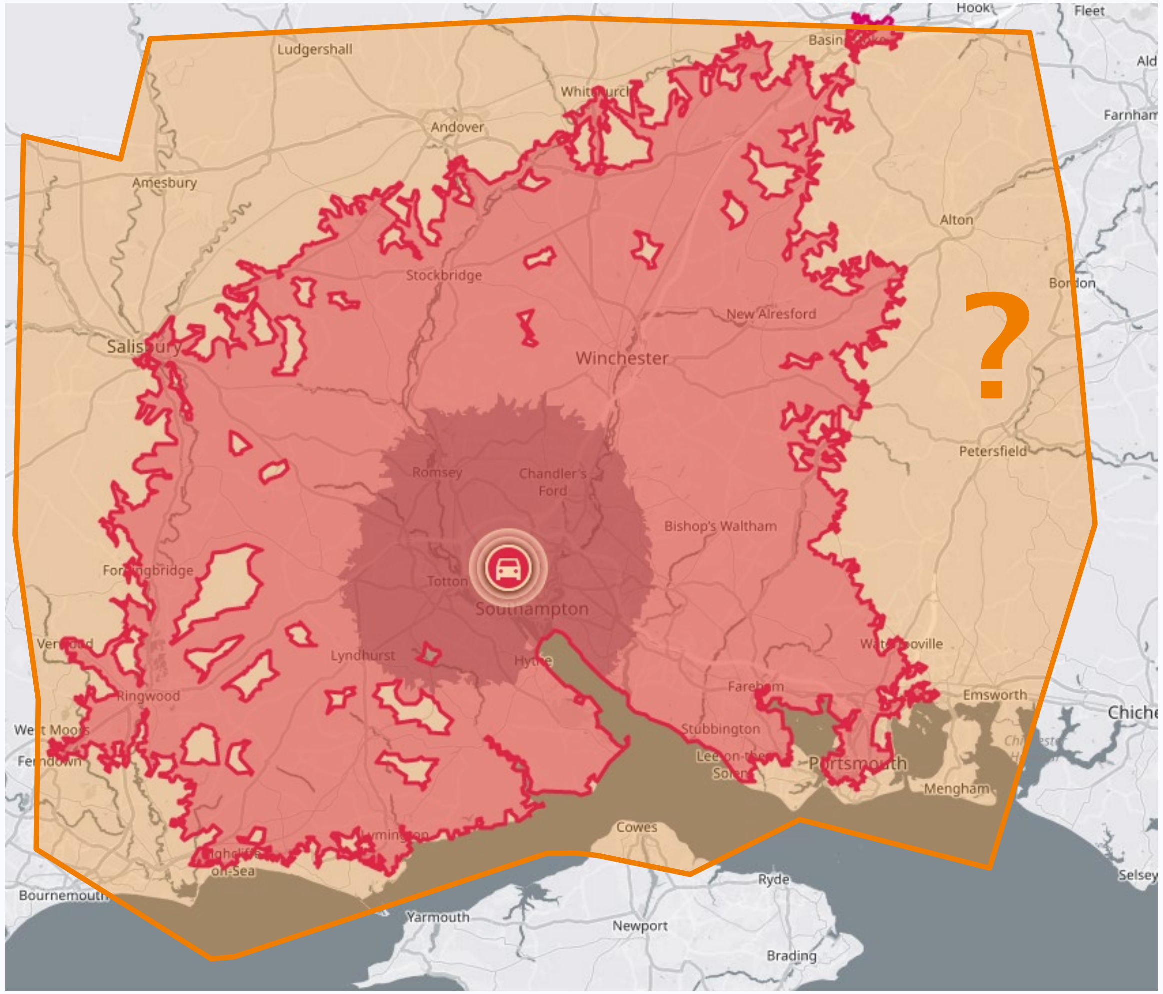
PRACTICAL CONSTRAINTS – GROUND RISK





PRACTICAL CONSTRAINTS – DRONE ENERGY/RANGE

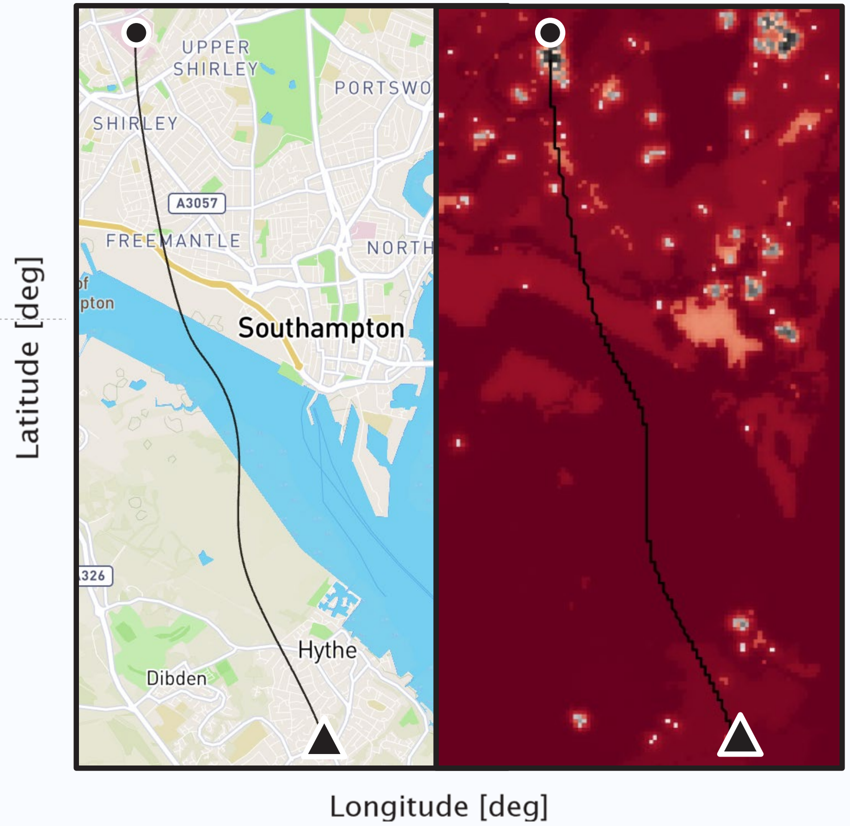


RISK AND ENERGY TRAJECTORY OPTIMISATION (Pilko, Blakesley, Krol)

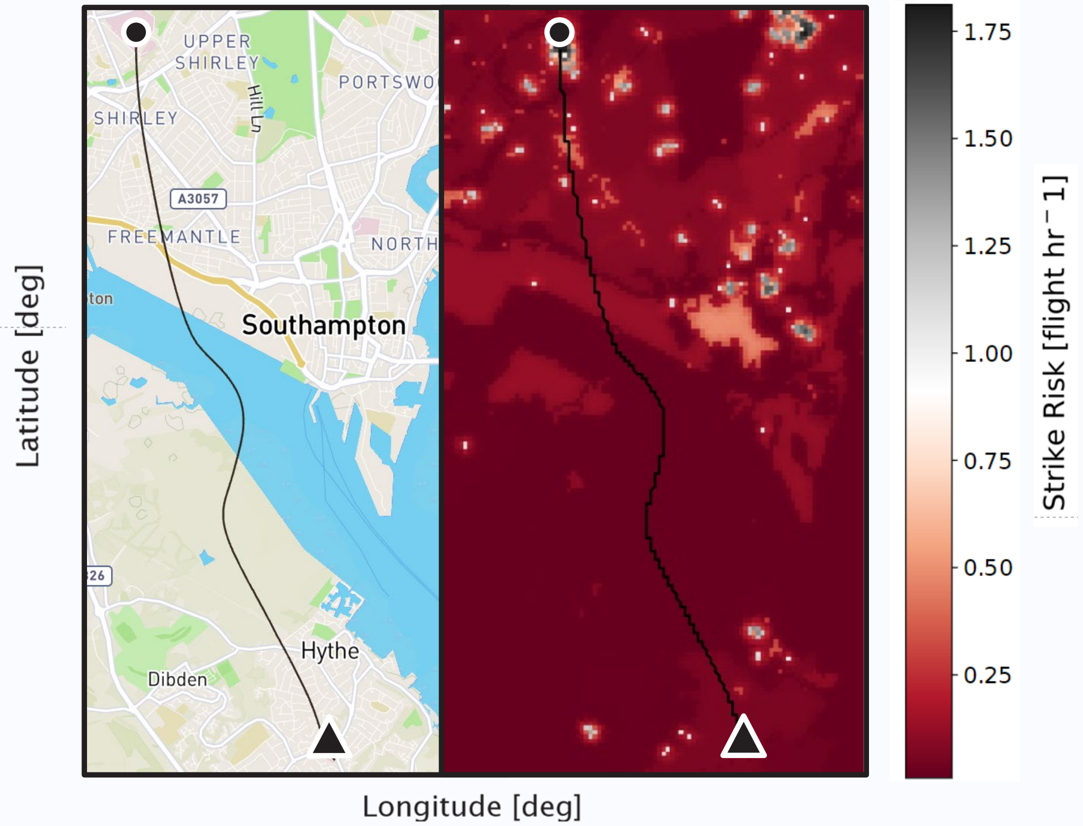
$$\min_{\omega_i} \sum_{i=1}^{4} \int_{t_0}^{t_f} E_i + \frac{\alpha}{4}(R + \gamma \log R)\, dt$$

- ● starting location = $[-1.434°, 50.933°, 0]^\top$
- ▲ destination = $[-1.403°, 50.859°, 0]^\top$

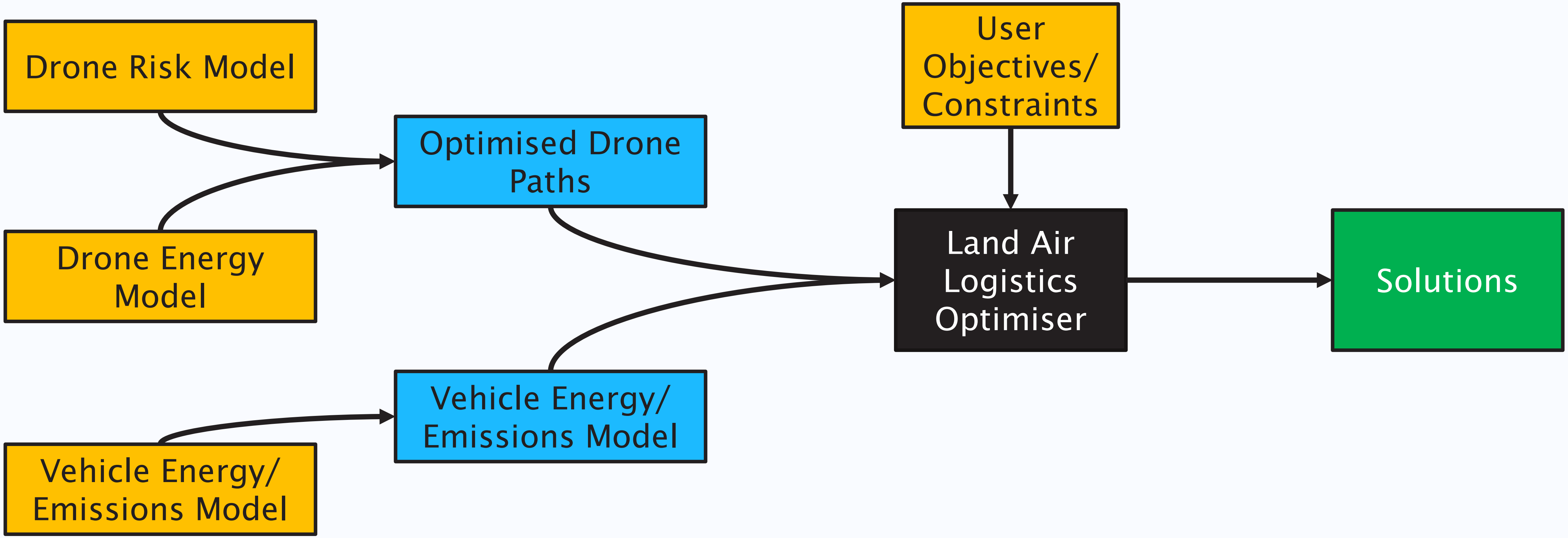
$\alpha = 5 \times 10^8$ Heatmap of fatality risk



$\alpha = 5 \times 10^9$ Heatmap of fatality risk



OPTIMISING WITH RISK/ENERGY/EMISSION AWARENESS

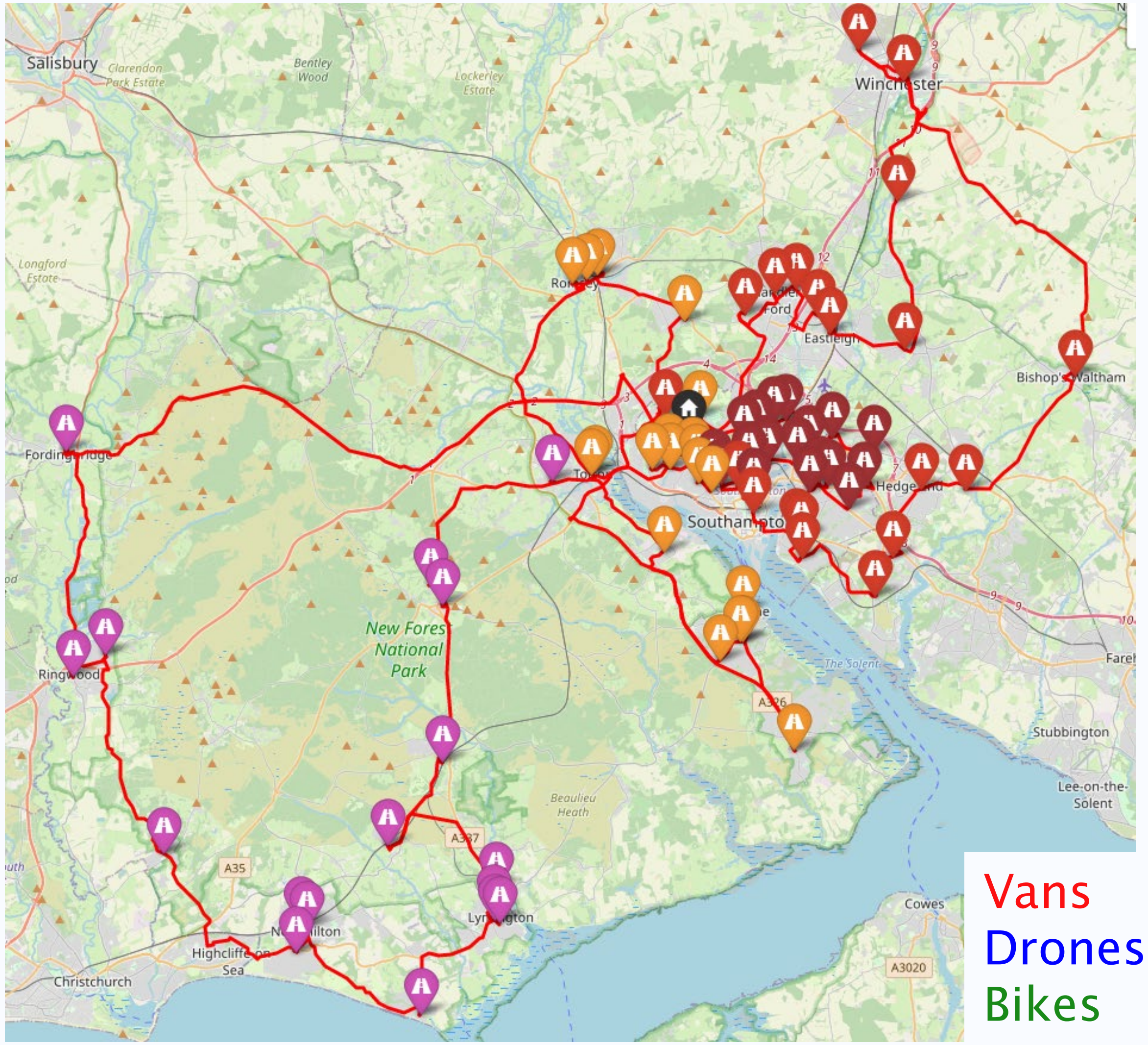


Results – Costs

HOW DOES THIS LOOK IN REAL LIFE?: CASE STUDY RESULTS

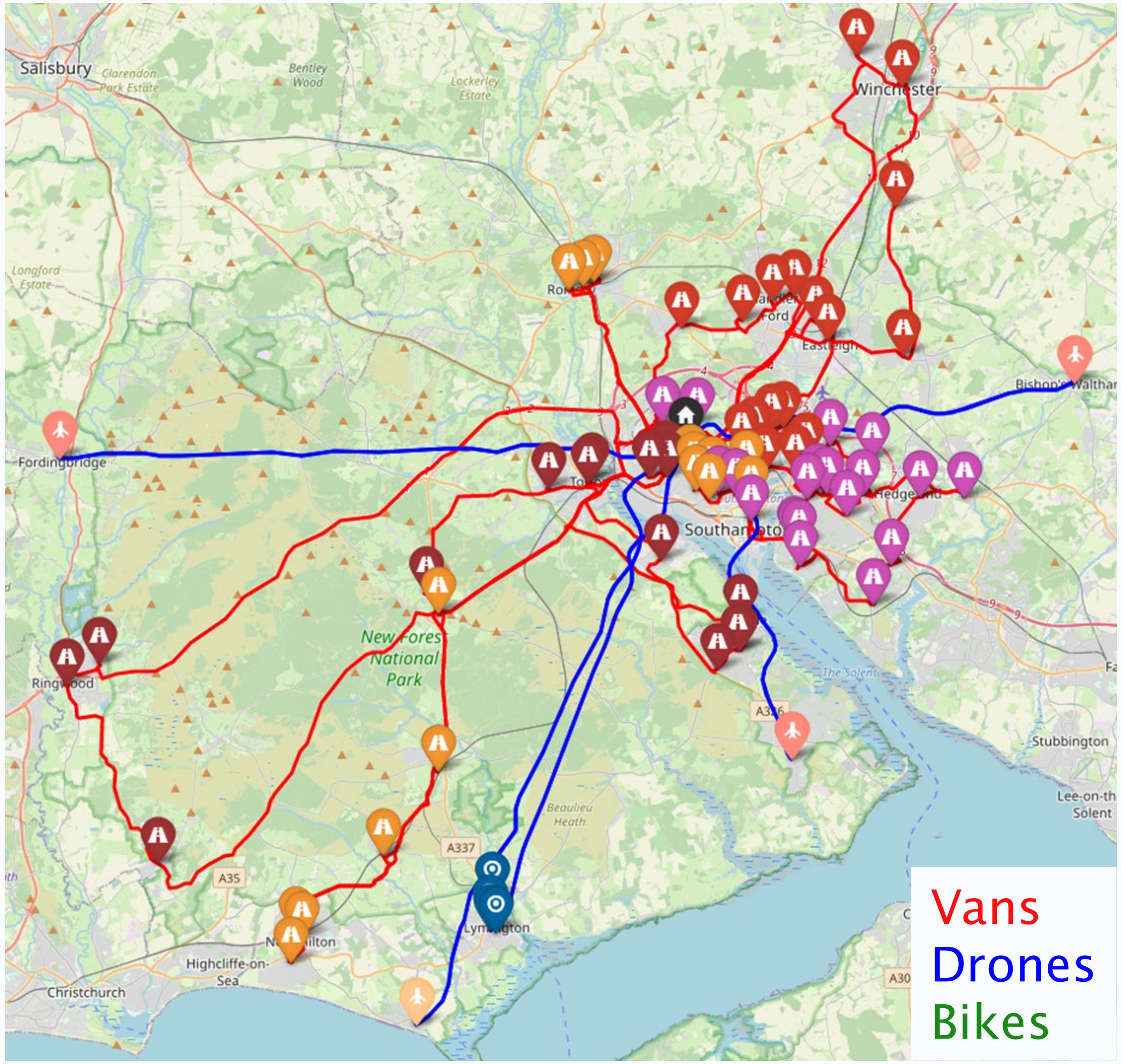
- Optimising to **Cost**
  Equal Component Cost Weights
- *Present day costs*

- All sites served by van…
  effectively business-as-usual



HOW DOES THIS LOOK IN REAL LIFE?: CASE STUDY RESULTS

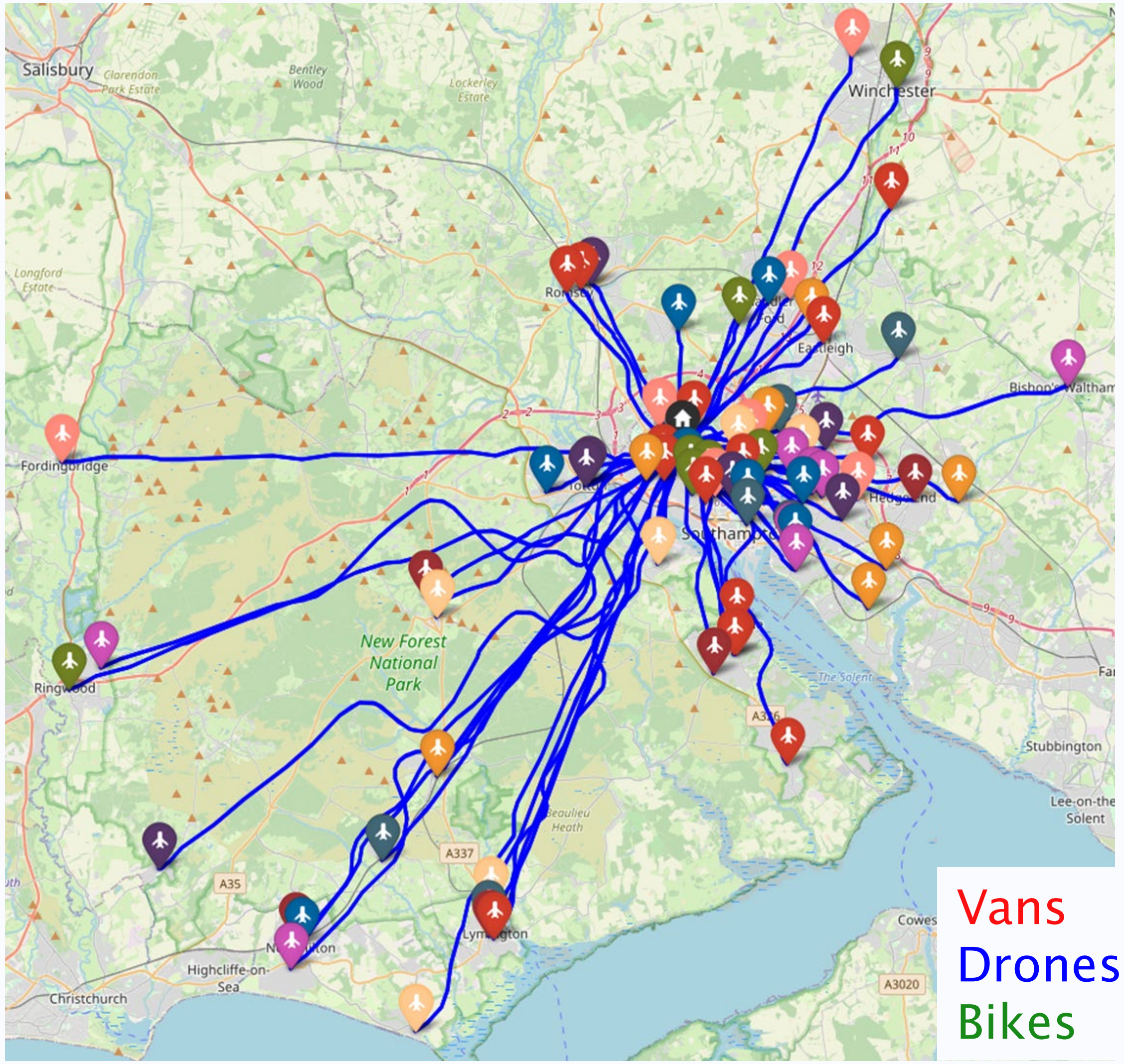
- Optimising to **Cost**
  Reducing Drone Component Cost Weight
- *Effectively reducing drone costs*
- *Partial uptake of drone service*



HOW DOES THIS LOOK IN REAL LIFE?: CASE STUDY RESULTS

- Optimising to **Cost**
  Reducing Drone Component Cost
  Weight (MAX)
- *Effectively reducing drone costs*
- *Full drone uptake – when all sites permitted for drone service*

40 aircraft movements per hour!



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HOW DOES THIS LOOK IN REAL LIFE?: CASE STUDY RESULTS

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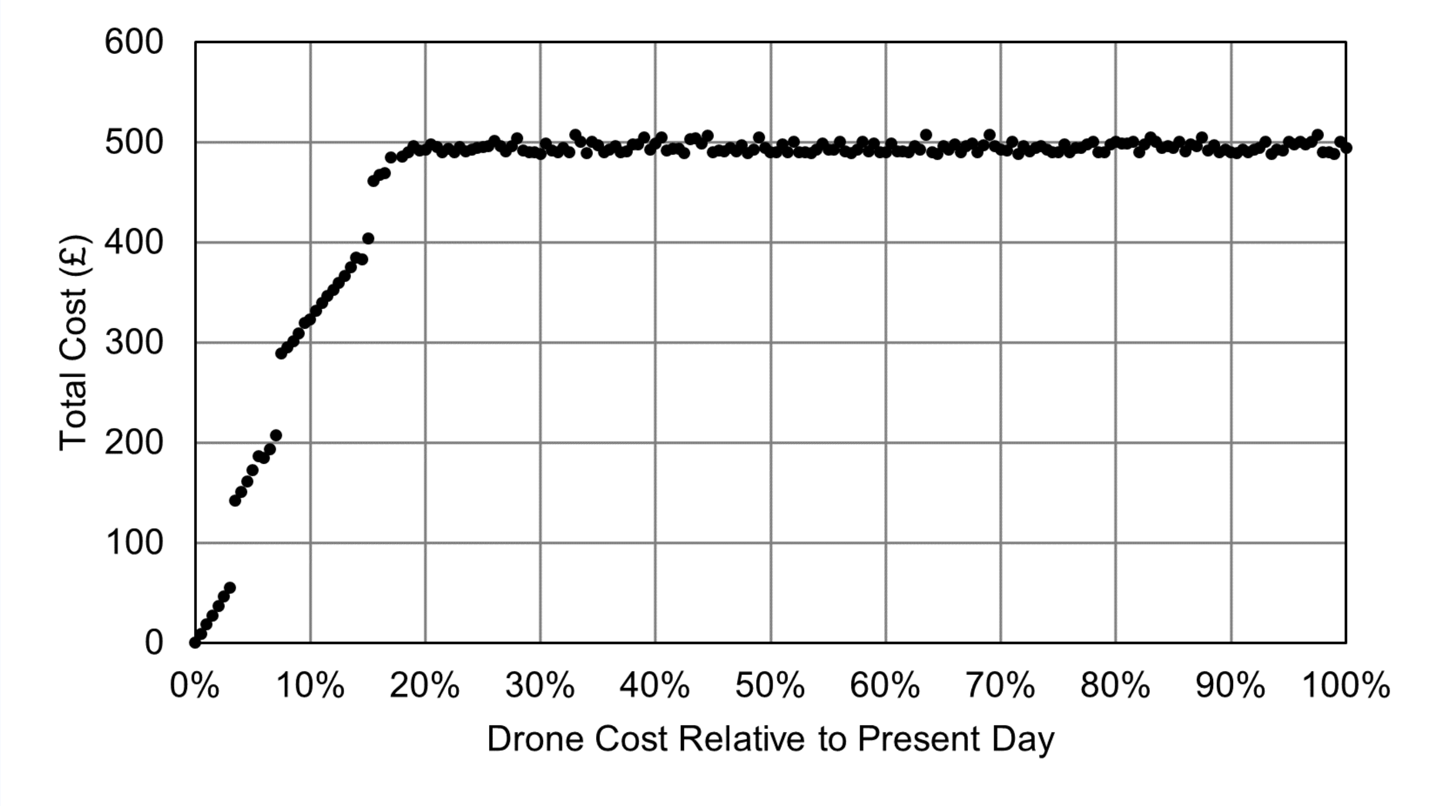

Drone Current/Future Costs Comparison

- Current:
  - 1 High Skill Commander (£50/hr); 2x Safety Pilot (£50/hr); 2x Loader/Servicer (~£10/hr); 3% Profit
- Future:
  - 1 Commander (~£20/hr); 1x Loader/Servicer (~£10/hr); 3% Profit
  - Increased automation; Forecast discount in manufacture (new methods/processes)

Cost	Current	18.5% of Current	Future
Labour (£/h)	£175.64	£32.49	£31.44
Veh. Running (£/h)	£32.40	£5.99	£20.33
Veh. Daily (£/veh./day)	£8.99	£1.66	£8.99

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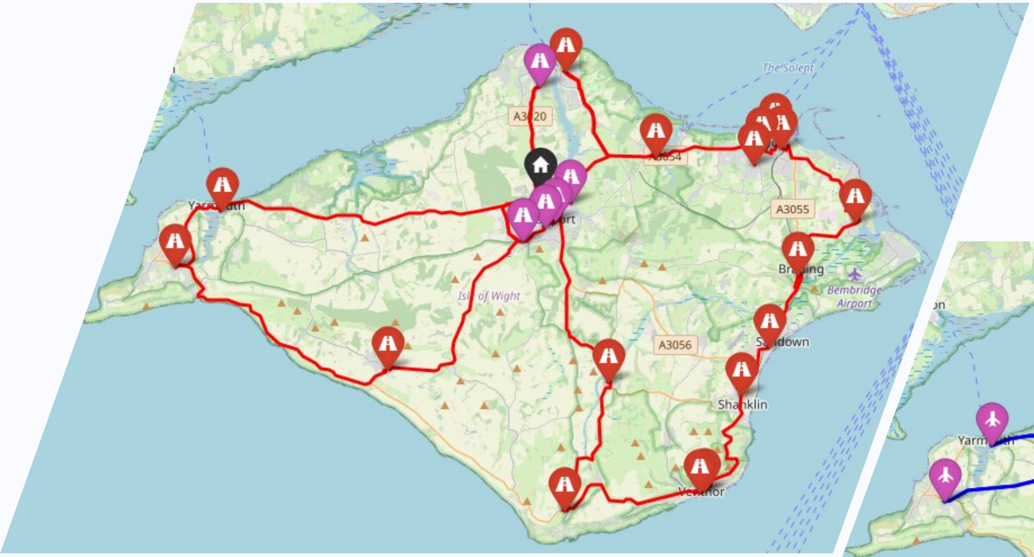
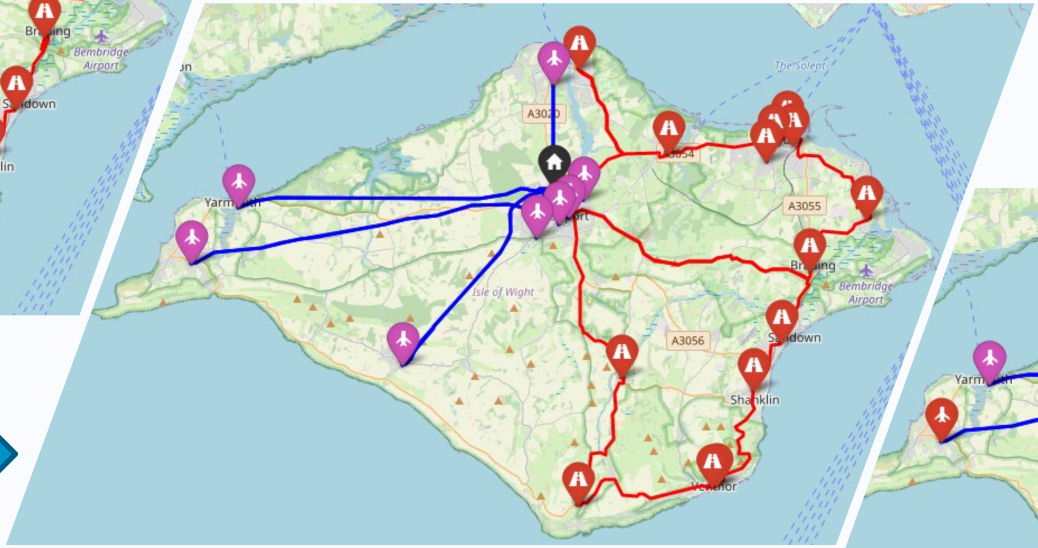
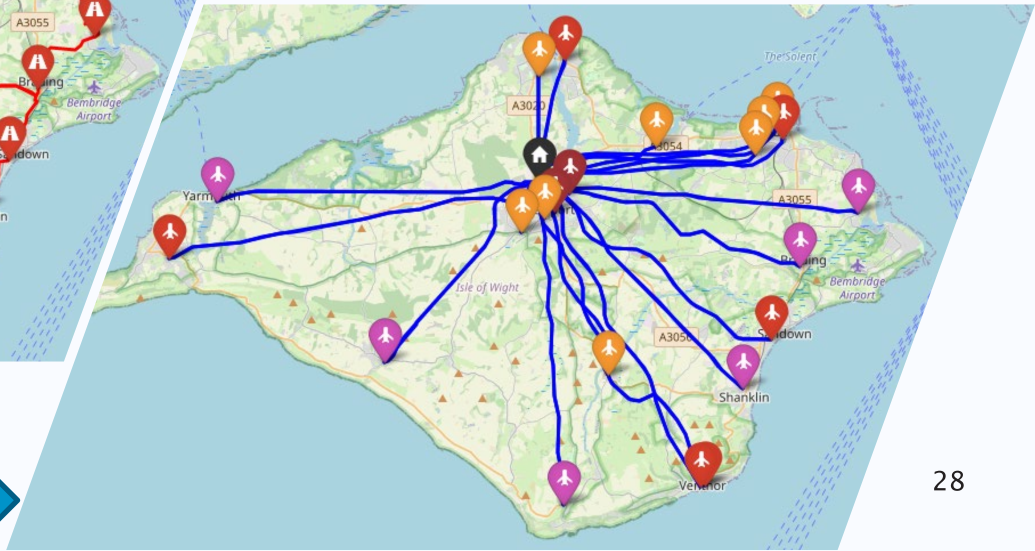
HOW DOES THIS LOOK IN REAL LIFE?: CASE STUDY RESULTS

- Optimising to **Cost**
  Reducing Drone Component Cost Weight
- *Effectively reducing drone costs*
- Similar behaviour in other case studies (Isle of Wight shown)





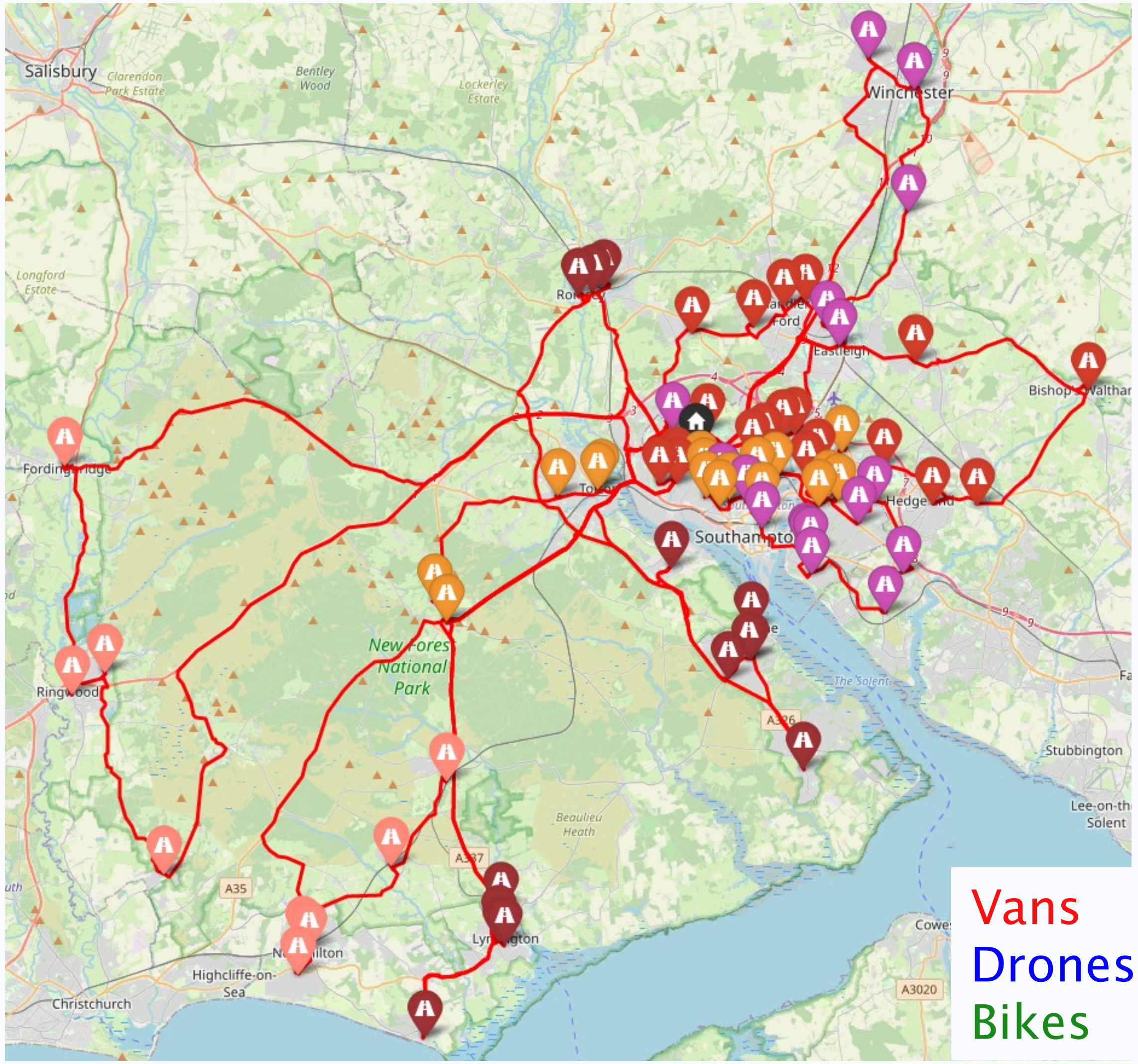


Vans
Drones
Bikes

Results – Time

HOW DOES THIS LOOK IN REAL LIFE?: CASE STUDY RESULTS

- Optimising to **Transit Time**
- *Theoretical future costs*
- When ONLY permitted sites can be served by drone
- Drone not used: minimise the MAX



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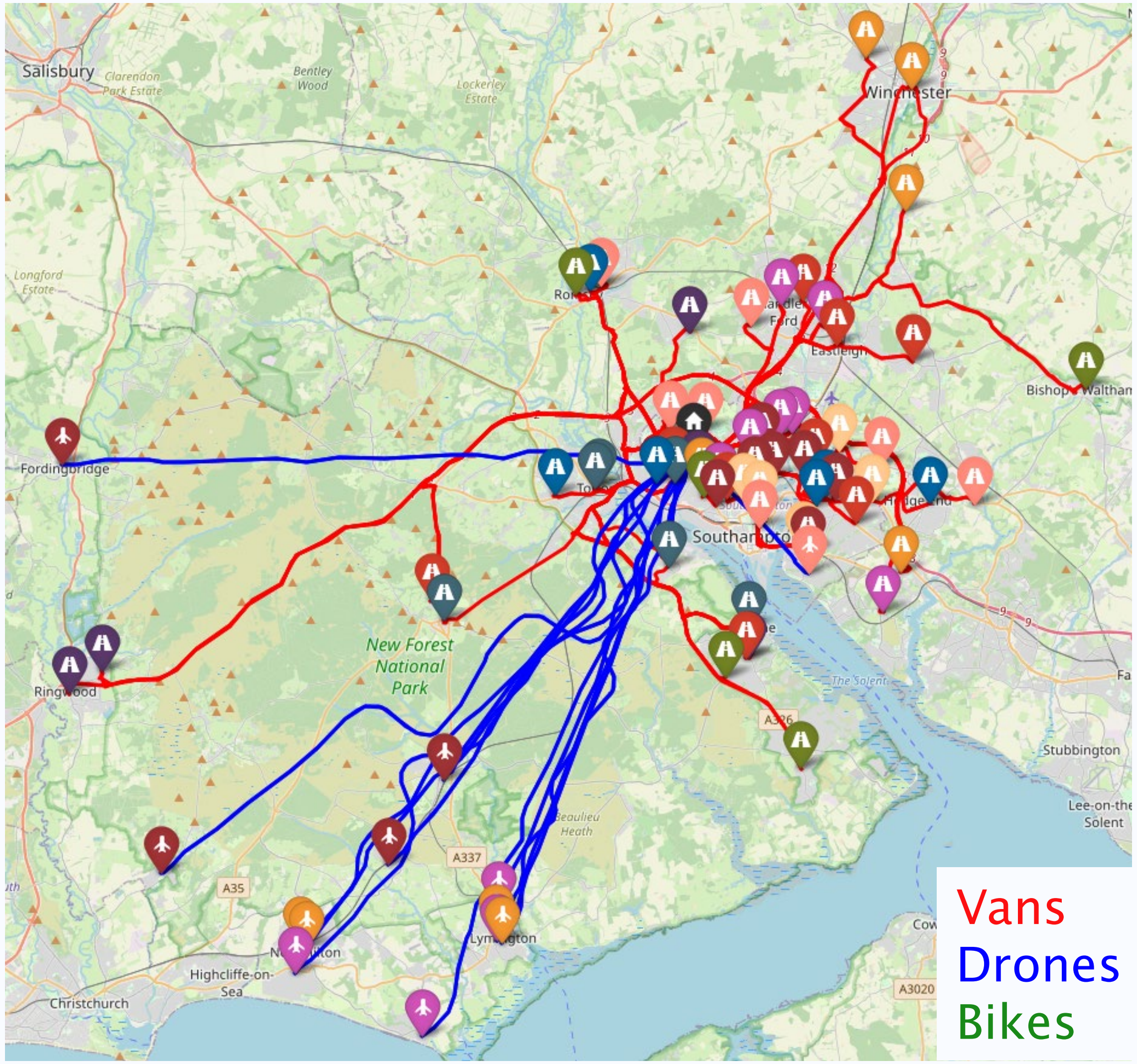
HOW DOES THIS LOOK IN REAL LIFE?: CASE STUDY RESULTS

- Optimising to **<u>Transit Time</u>**
- *Theoretical future costs*
- When ALL sites can be served by drone
- Drone used up to parity with van maximum

Maximum
84% reduction
209->33 mins

Cost Increase
£253k /yr!
£1.4k /min saved



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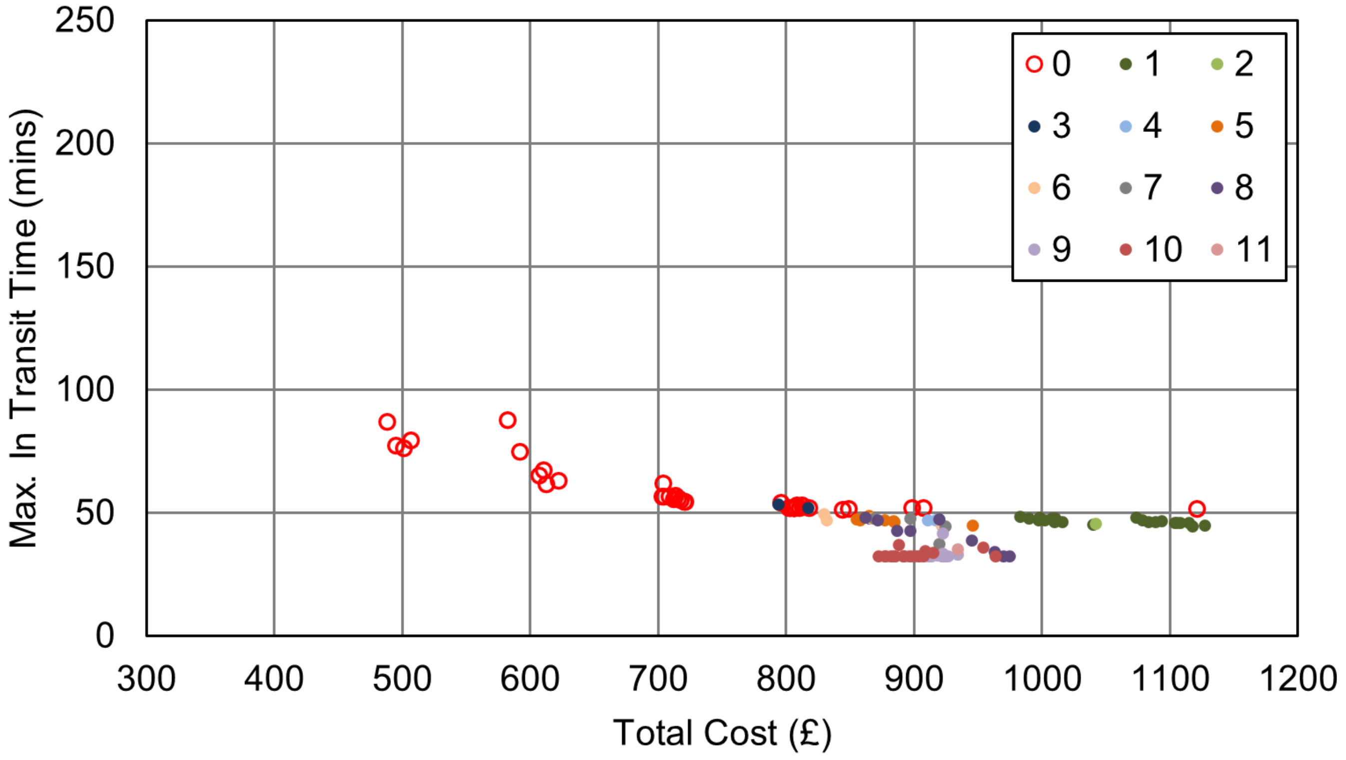
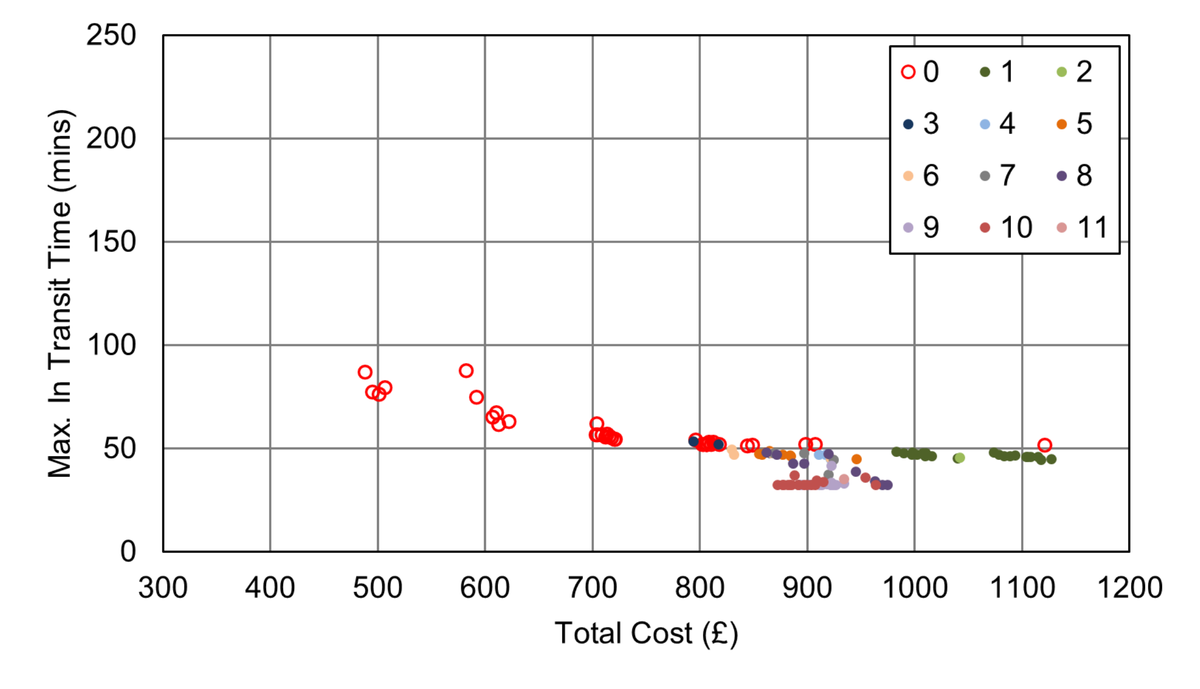
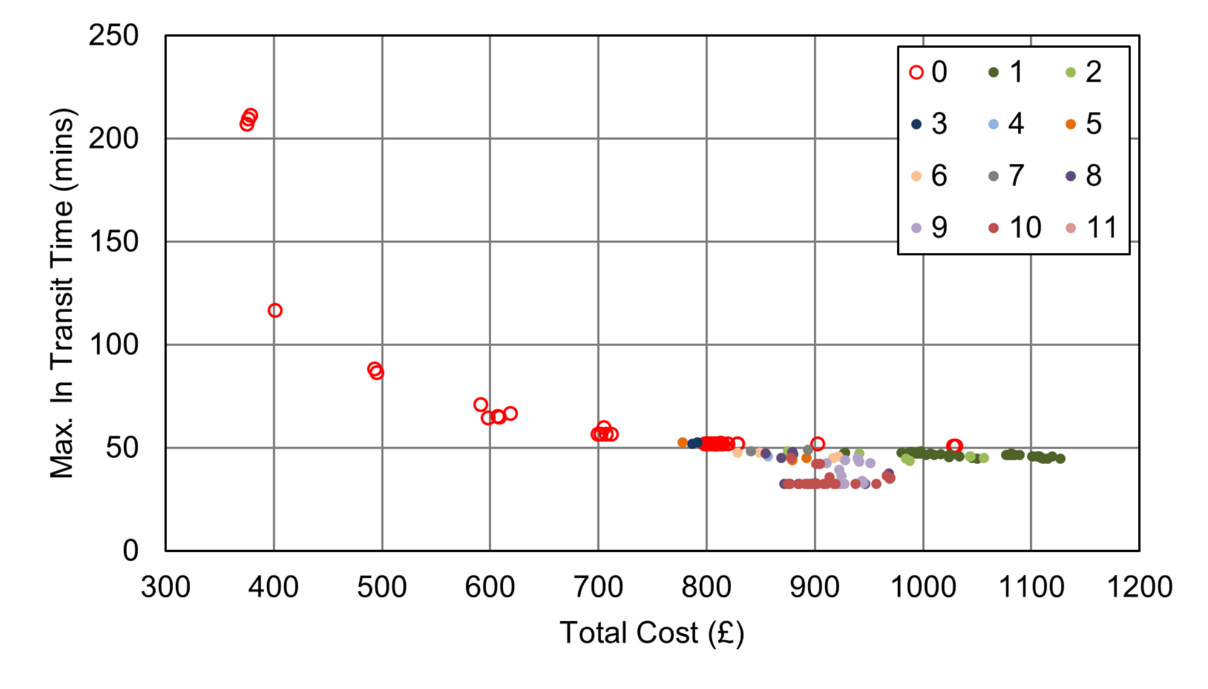


TRUE VALUE OF TIME?

- 90 minutes is the standard in literature, but 4 hours is typically the acceptable level in NHS tenders



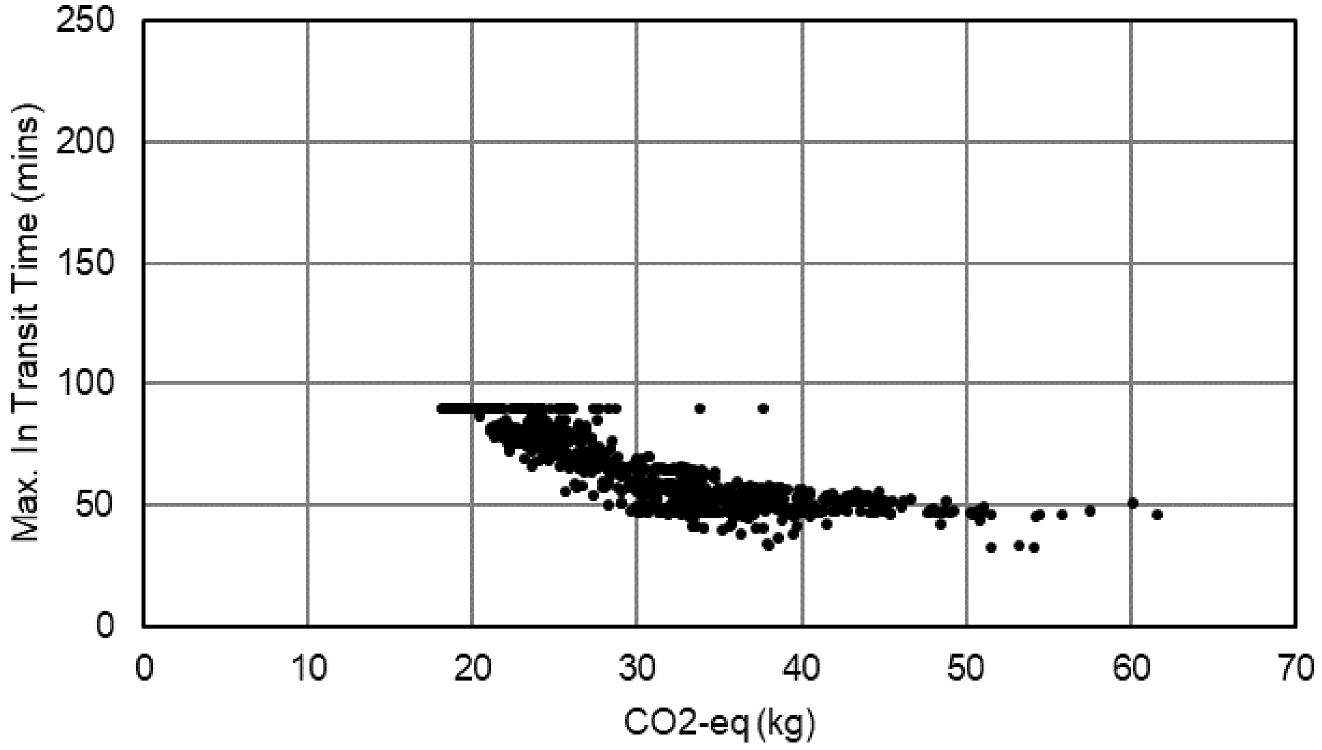


Soton: 90-minute limited No limit

- What is the TRUE value of faster transit time? :+£1.4k /min saved worth it? (per yr)

HOW DOES THIS LOOK IN REAL LIFE?: CASE STUDY RESULTS

- Optimising to **Transit Time**
- *Theoretical future costs*
- When ALL sites can be served by drone
- Drone used up to parity with van maximum



+19.5T CO_2 (+211%) per year for an 84% reduction in transit time with uncertain practical value

Results – Emissions

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HOW DOES THIS LOOK IN REAL LIFE?: CASE STUDY RESULTS

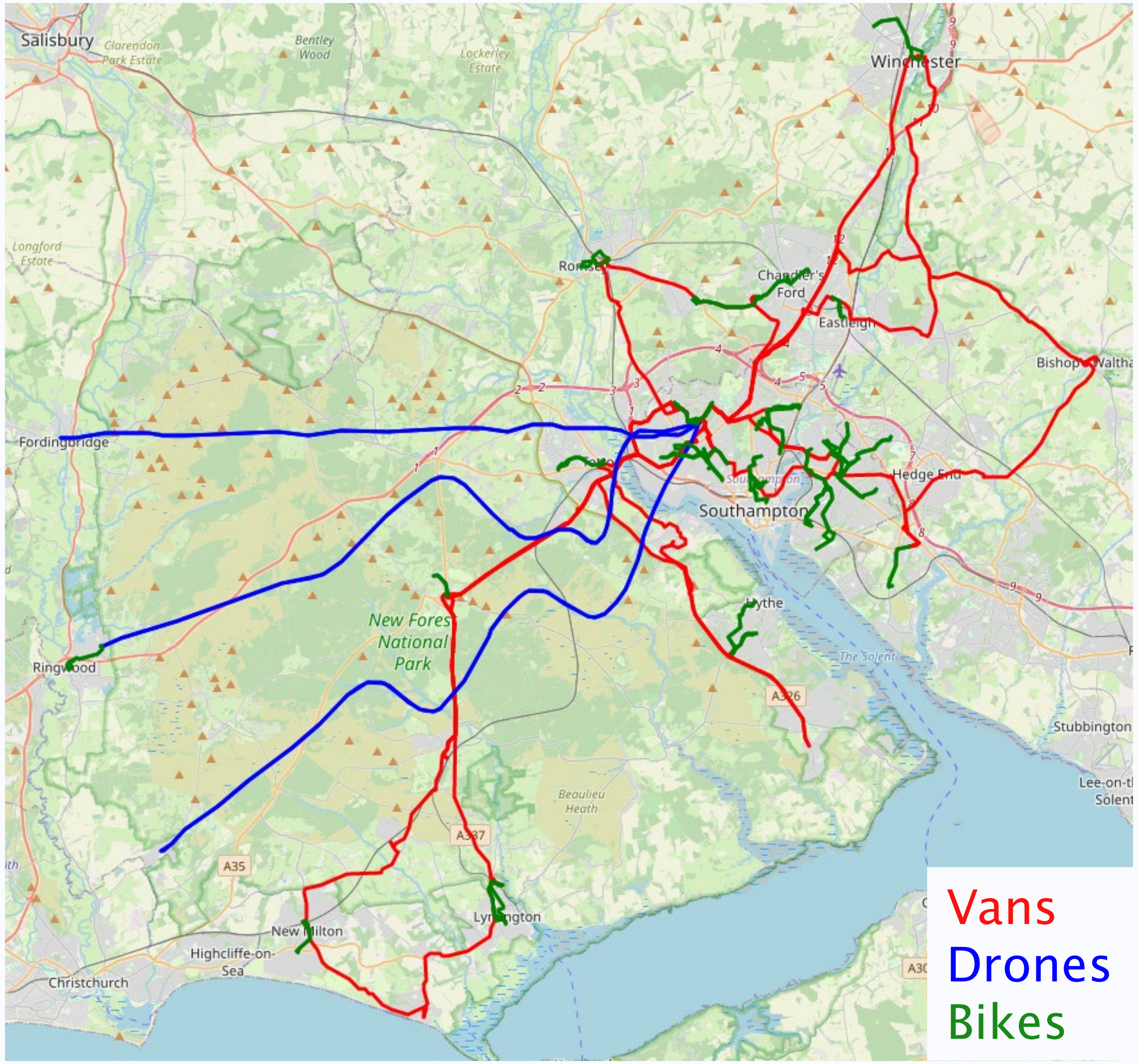
- Optimising to **<u>Emissions</u>**

- *Theoretical future costs*

- When ALL sites can be served by drone

- Bikes used in dense areas, drones to remote areas to avoid stem mileage

- 23% Emissions reduction possible, mostly from cycling (relaxing time even better!)



Other Considerations/ Future Developments

Oakey, A., Cherrett, T., 2023. Quantifying Weather Tolerance Criteria for Delivery Drones - A UK Case Study, in: 2023 International Conference on Unmanned Aircraft Systems (ICUAS) https://doi.org/10.1109/ICUAS57906.2023.10156144

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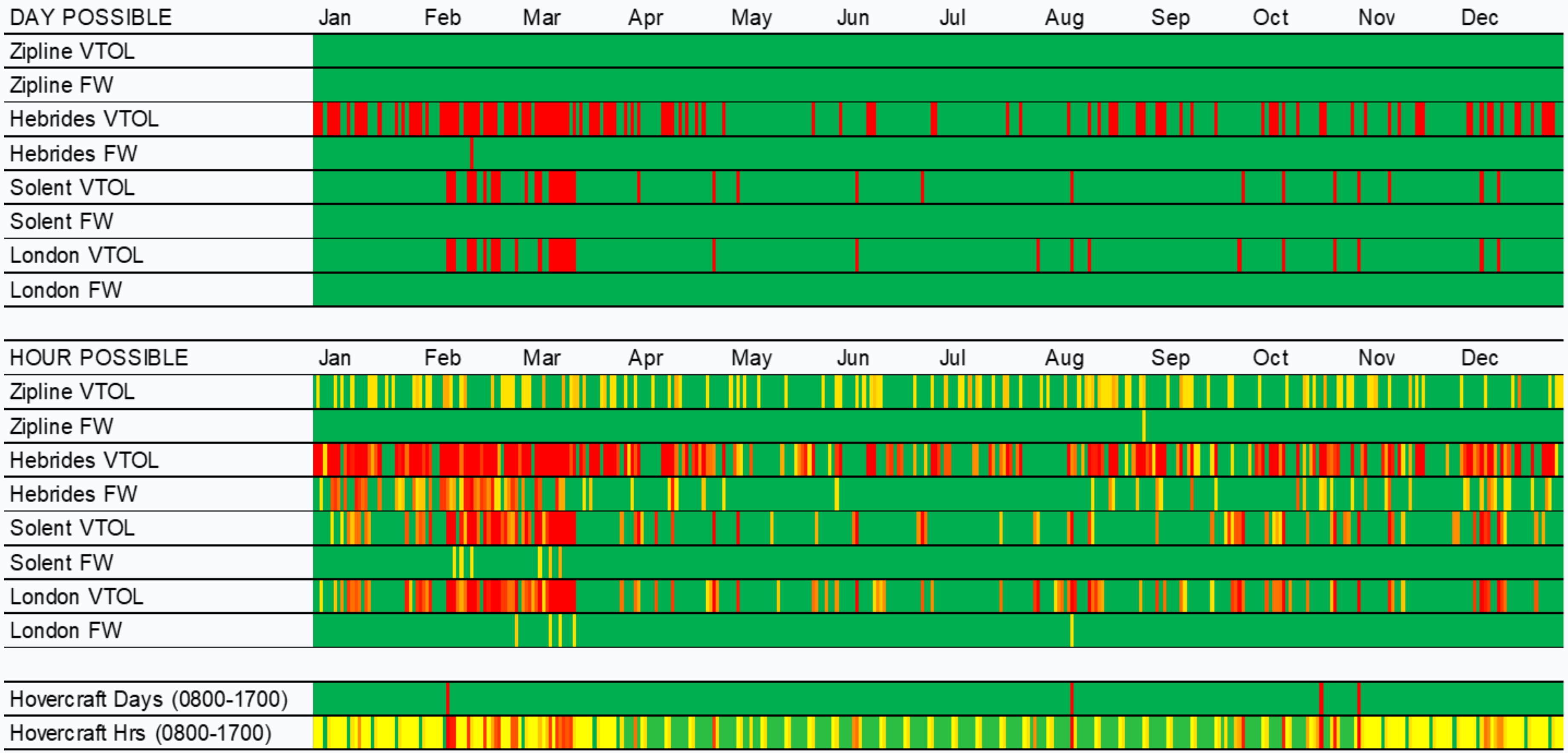
SEASONALITY?

- 10 m/s

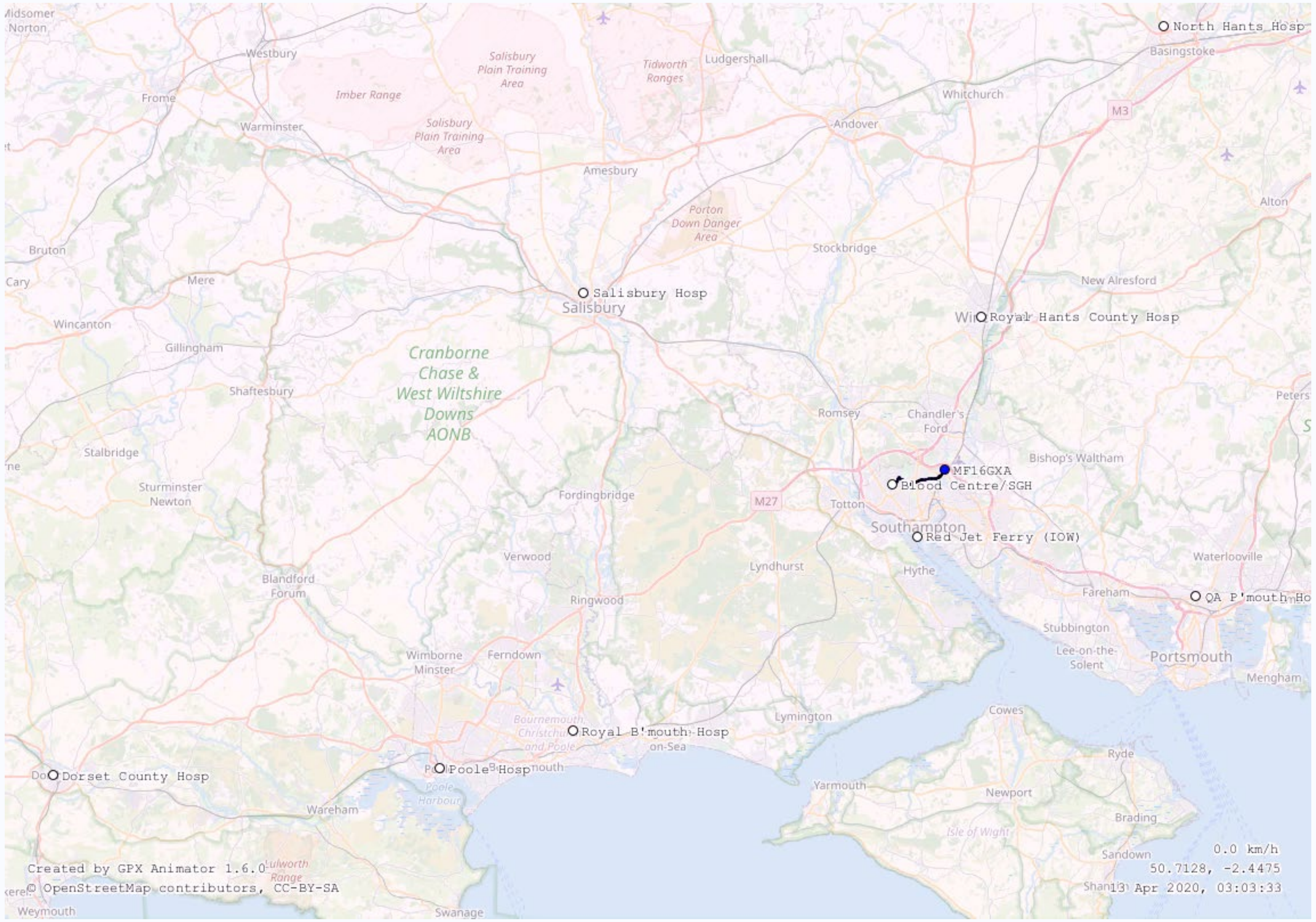
POSSIBLE? (ANY HOUR)

FLEXIBLE? (# HOURS)



SHARED FLEET?

- Existing Assets?
  - Include a wider range of tasks



https://nhsbtdbe.blob.core.windows.net/umbraco-assets-corp/22139/new-ford-fleet.jpg

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SUMMARY

- Drones previously modelled with very limited practical assumptions around costs and rarely modelled with other modes (mainly flying sidekick)
- Mode trade-off in a fully integrated system not widely explored
- Results demonstrate strengths of different modes towards supporting each objective
  - Target tipping points for cost?
  - True value of time?
- Weather effects may present risks, though encourage other potential options

YOUR QUESTIONS

Thanks for listening

Andy Oakey – a.oakey@soton.ac.uk
Tom Cherrett – t.j.cherrett@soton.ac.uk