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To cite this article: Snow, B., Dickinson, J., Smith, A., Chang, J., Nadeem, T., Pilko, A., Cherret, T., Oakey, A., & Blakesley, A. (2023). Navigating the Skies: A Serious Game for Exploring Drone Energy Consumption, Flight Risk, and Societal Impact in Logistics. In *Serious Games: 9th Joint International Conference, JCSG 2023, Dublin, Ireland, October 26–27, 2023, Proceedings* (pp. 342-349). Springer-Verlag. (doi:10.1007/978-3-031-44751-8_27)

Navigating the Skies: A Serious Game for Exploring Drone Energy Consumption, Flight Risk, and Societal Impact in Logistics

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Abstract. A logistics drone routing game utilising modelled flight risk and energy consumption data is presented, and its design elements are discussed. The game has been developed as part of a multi-disciplinary research project tasked with generating new understanding of the energy use and risks associated with drone use in logistics alongside the wider implications for society. The game aims to engage with a non-specialist, adult audience on the risk and energy implications associated with where logistics drones may fly. People's views of this new transport mode are gathered to support the wider research project. Use of the Unity3D engine and tilemap system are explored to provide an engaging context for users to build their own flight paths to solve drone delivery problems. The integration of modelled drone flight risk and energy data into the game is examined, as well as the utilisation of satellite imagery and geographic data. This data allows for a realistic representation of the route planning problem and for the simulation of drone flights along user-defined paths. Preliminary findings from two pilot trials indicate the game's effectiveness in engaging audiences and stimulating discussions about drone deliveries. Conference attendees are invited to experience a demonstration of the game.

Keywords: Logistics drones, risk modeling, serious games

1 Introduction

Drones have been developed for logistics purposes with trials taking place in many countries, with some more established services in Africa [1]. As a new mode of transport in lower airspace, the introduction of logistics drones raises many questions on where they should fly. Direct routes use less energy but have implications for ground risk if they pass over densely populated areas. It is challenging to involve non-specialists in debate about where drones should fly as most people are unlikely to have knowledge or experience of logistics drones and are largely disinterested in a transport future that is, for the most part, yet to exist. To involve non-specialists in discussion about drone routes, the E-Drone project (<https://www.e-drone.org/>) has developed several tools to garner people's interest in logistics drones and to help them understand the implications. This includes the development of a digital game, 'Navigating the Skies,' which draws on the expertise of the multi-disciplinary project team including the modelling of energy use [2] and ground risk [3]. Navigating the Skies aims to engage with a non-specialist, adult audience on the risk and energy implications associated with where logistics drones may fly.

This demo paper begins with a brief overview of games research in the sustainability and logistics fields. It then sets out the game objective and scenario, before focusing on the game design, particularly the approach to integrating modelled data of flight risk and energy consumption. The paper finishes with an overview of the deployment settings and initial findings from two pilots that demonstrate the game's effectiveness in engaging audiences and stimulating discussions about drone deliveries.

2 Literature Overview

Game based approaches are increasingly used to bring stakeholders to a dialogue on complex sustainability topics [4] since they facilitate social learning that leads to practice change [5]. Most success is achieved with games linked to specific contexts and based on real-world data of immediate relevance to participants [6]. Within the transport field, serious games have been used to help stakeholders understand complex decisions in transport planning [7], with more general audiences to educate people on use of new transport modes [8] and Freese et al. [9] have analysed the use of serious games as a research instrument in the transport field. Several studies have used serious games in the logistics field [10, 11]. Transport games focus on transport systems that already exist and typically facilitate better use of transport by the public or experts with the overarching aim of achieving cost savings or environmental benefits. Navigating the Skies is about a transport technology that has not been implemented beyond discrete trials and the focus is on helping players reflect on decisions that will impact future regulation and governance. We use the game as a research tool to engage players in drone routing decisions involving risk and energy trade-offs. To the best of our knowledge 'Navigating the Skies' is the first serious game focused on logistics drones or future flight transport technologies more broadly and has some similarities to flight planning tools.

3 Game Objective and Scenario

The objectives of the game for the research were to:

- Engage stakeholders and public in drone delivery risk-energy trade-offs.
- Collect data about decisions made by users to gain insight into their choices.
- Evaluate and quantify post-game data on user reflections about drone logistics.

This required a game that captures the audience's interest, is fun to play, and includes multiple layers of complexity. The mission is to deliver a package from point A to point B using a drone by constructing a route whilst considering the drone's battery life (energy consumption) and ground risk. To achieve this, the game utilises satellite imagery to allow players to explore drone flight paths in their own area. The game design focused on Southampton, UK, and its surroundings as the project team were modelling drone delivery scenarios in this area, however, the modelled data and game can be transposed to other places.

Users can build a route from an origin location to a destination by selecting squares, also known as tiles, on a rectangular grid superimposed atop a satellite image (see Fig. 1 left). Constructed routes are continuous, self-avoiding, and have a fixed maximum length constrained by the battery limitations of real delivery drones. Modelled energy usage data is used to calculate the energy expenditure of a drone flying an equivalent distance on the underlying satellite image. A battery indicator displays the remaining energy available to select more squares. Selecting a tile on the grid reduces the amount of energy remaining to select additional grid tiles. Squares on the grid store modelled drone ground risk data which is shown to the user with a number and a colour to indicate the severity of risk for various locations. This gives users a reflection of the challenges faced by researchers when creating delivery routes in the real world. As a route is constructed, the ground risk along the path is accumulated and shown on a graph to the user. Users are encouraged to investigate the tradeoffs between risk and energy when constructing their routes. Once a complete route from the origin to the destination is created, the user can submit the route and be shown a 3D flyover of a drone following their constructed route (see Fig. 1 right).

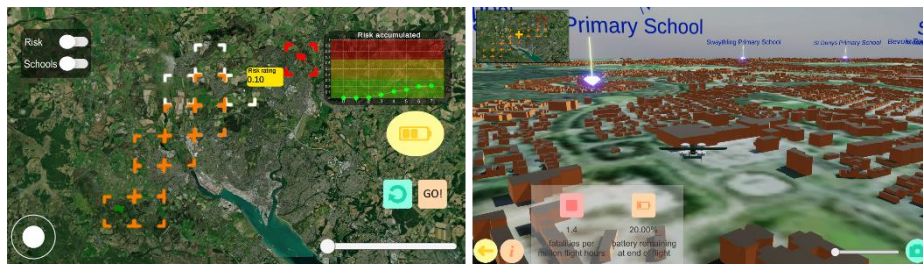


Fig. 1. Left: Selection scene in the digital game. Green and red flags indicate origin and destination locations. An orange delivery route is being constructed on the square grid. White tiles show possible next selections. A tooltip shows the risk rating numerically and changes colour, from green to red, based on the relative risk of the square beneath it. Toggle switches to show the risk map and local school locations are in the top left. A risk accumulation graph, battery indicator, undo and submit route buttons are to the right. Camera controls are to the bottom of the

figure. Right: 3D flyover scene with Open Street data. Animated drone in the centre with a minimap showing the drone location in the top left. Camera view toggle and animation speed slider in the bottom right. Return to selection scene and flight statistics in the bottom left.

4 Game Design and Development

A game environment was constructed in the Unity3D game engine and formation of an interaction space was achieved with the Unity Tilemap system. Upon the beginning of play, a procedure commences whereby a series of tilemaps are spawned. These hold the satellite imagery, start and end points, selected route tiles, and surrounding tiles. An in-game camera is positioned to frame the area of player interaction and User Interface elements, such as the risk accumulation graph, are placed in the viewport. Unity's Tilemap system brings with it a GridInformation data structure component. This component allows data to be assigned to tile positions with associated keywords. As such, both relative and absolute risk are stored in the GridInformation, see section 4.1, and are accessible during game play. A GameManager component is used to handle the game state, facilitates the loading of levels and menus, and storage of user data during play. A MainManager allows data persistence between levels and communication between game scripts. Two levels, the selection and 3D flyover scenes, are present in the game. The user is first shown the selection scene in which they are tasked with constructing a route. After successfully building their route, users are asked to submit the route with the "GO!" button and watch a drone fly over a 3D reconstruction of the proposed path. Data from Open Street Map and Mapbox have been used to create a 3D environment of the Southampton area and a CAD model of a delivery drone is animated to fly along the proposed route.

In the event of a drone malfunction during flight, there is a probability that the craft will plummet towards the ground, colliding with an impact kinetic energy. The likelihood of an individual suffering a fatal injury in such an incident is determined for a particular location [3]. The risk that the falling drone causes a fatality is known as the ground risk. To model ground risk, a variety of factors must be considered, including drone failure data, simulated falling trajectories, wind conditions, drone parameters (e.g., weight and airspeed), time-of-day population density maps, road traffic information, shelter availability, and other relevant variables. A United Kingdom wide dataset of ground risk used to incorporate risk for the Southampton area in the game.

Data pre-processing is conducted to ensure suitability for the needs of the digital game. Using four coordinates of longitude and latitude, a region enclosing Southampton is established, and satellite imagery is aggregated using the Mapbox platform. A risk map is generated for 1pm GMT with fixed environmental conditions [12]. Further processing involves padding the dimensions of the risk map before a block-reduce algorithm is applied to average the risk values of neighbouring grid cells and reduce the resolution of the grid from 456x593 to 8x10, the resolution of the selection scene grid. Finally, two risk maps are produced, one absolute and one relative. Absolute risk refers to the probability of fatality per hour of drone flight time, and relative risk is normalized to represent the relative difference between tiles. Relative risk provides a more intuitive

understanding for users allowing for easy comparison between tiles. An absolute risk map, however, would exhibit an almost binary nature concentrated on the significantly higher risk in the city centre area compared to very low risk rural areas surrounding Southampton. The absolute risk values are stored to calculate the overall absolute risk of a user generated route in the problem scenario to give as feedback to the player.

Similar to the risk data, energy consumption of drone usage has been modelled and data generated is incorporated into the game mechanics. An implementation of the energy modelling formula is used to calculate the expected energy expenditure over a given distance with set operating parameters. This function can be used to calculate the energy usage for arbitrary conditions and distances. When a player appends a tile to their constructed route, the distance between the selected tile and the previously selected tile is calculated and then fed to the energy model to return the consumption over that distance. This is then deducted from a pre-computed maximum energy level available for flight. The number of squares a player can use to construct a route is constrained by this maximum available energy level. An undo button is featured to allow, and encourage, players to amend their routes in the selection stage and investigate how different routes affect risk and energy usage.

A command pattern is used to facilitate the route building mechanism. As the user selects a tile to add to their route, a command is sent to a command handler that stores the co-ordinates of the selected tile, the absolute ground risk, and energy expenditure. This information is then processed to add a data point to the accumulated risk graph and alter the battery level indicator. Commands can be removed from the command handler by use of the undo button allowing the user to reassess their selection decisions. When a request to add a tile to the route is made with a touch or click from the user, a check is performed to ensure the tile is immediately surrounding the previously selected tile. Only the nearest neighbour tiles are allowed to be selected (white tiles in Fig. 1). A check for self-avoidance is performed to ensure the route does not intersect with itself. Energy is removed from the remaining battery level and selections are disallowed when the battery is empty. When a valid tile is selected, an orange selection tile is placed at its location and the surrounding tile locations are updated. When a route is constructed that reaches the destination location, a termination condition is satisfied whereby the user can no longer add to their route (but undoes are possible) but can submit their route to visit the 3D flyover scene. A data collection procedure is in place that allows the evolution of the user's commands to be stored. From this data, a full reconstruction of a given user's actions can be made and routes plotted within the game can be collected.

5 Initial Game Deployment, Data Collection and Findings

To date the game has been deployed at two public outreach events (Hands on Humanities and Science Day at the University of Southampton on the 19/11/2022 and 18/3/2023 respectively) that provide a range of engagement activities to involve the public in research. Use of the game at these events aided the game development and captured initial data from the public to establish the value of the game in the research

project. At Hands on Humanities the game was available to play on tablet computers, while at Science Day the game was available on tablets and a larger touch table. Following a brief introduction, participants were invited to play the game and, where participants' time allowed, adults were invited to complete a brief post-game questionnaire (Hands on Humanities n=31, Science Day n=10, Bournemouth University ethics committee approval ID: 45834). Gender composition was 33% male and 67% female for n=41. The questionnaire included open and closed questions about participants' initial thoughts about delivery drones, where they should fly and the regulation of delivery drones. This was followed by a short section to provide feedback on the game and questions on participants' age and gender. The sample composition (Table 1) indicates participants included a variety of ages and genders. The data collected post-game demonstrates the game helped participants reflect on logistics drones. The data collected post-game demonstrates the game helped participants reflect on logistics drones. Participants provided nuanced and considered views, for example, "*Think about sustainability vs. Vans*" or "*Considering safety, impact, environmental factors.*"

Table 1. Sample composition.

Age	16-24	25-34	35-44	45-54	55-64	65-74	75-84	85+
(n=41) %	13	13	18	37	13	0	3	3

As well as picking up on energy and risk issues, participants reflected on other factors such as noise over residential areas, flight times, privacy and types of products delivered, for example, "*Interesting concept although have concerns about noise and number of flights overpopulated areas. Impact on wildlife (birds etc)*" and "*I wouldn't want the use to escalate to delivery of non-urgent items.*" Participants were asked about flight frequencies in a range of settings showing a wide spread of views (Table 2), though participants were more circumspect about flights over housing and their own homes. Feedback on the game indicated it was easy to understand and follow (92% agreed or strongly agreed). Comments included: "*Very helpful in translating the ideas into what they mean in practice,*" "*fun and user friendly*" and "*great for getting the message across.*" Users suggested developments that are informing the game's features: more detailed route mapping; adding more complexity; and embedding instructions at the start of the game.

Table 2. Which settings do you think it would be appropriate for delivery drones to fly over?

Flight over:	No drones flying over (%)	No more than four drone flights a day (%)	A drone flying over every hour (%)	A drone flying over every 30 minutes (%)	A drone flying over every 15 minutes (%)	<i>M¹</i>	<i>SD</i>
Housing	34	39	12	5	10	2.17	1.243
My home	24	46	17	2	10	2.27	1.162

¹ Scale from 1 to 5 where 1 is no drones flying over and 5 is a drone flying over every 15 minutes.

Urban park	25	25	30	8	13	2.58	1.299
Town/city centre	18	35	20	10	18	2.75	1.354
Countryside	12	32	20	15	22	3.02	1.369
Industrial area	2	10	32	17	39	3.8	1.145

6 Future Work

The game will be deployed this summer/autumn by the project team in a data collection activity. This will formalise a data collection protocol that will capture users' views of logistics drones, the distribution of risk accumulated, and the routes plotted. Data captured post-game will be linked to in-game choices on risk and routes. To further research initiatives, a data collection procedure to collect both user metadata and path selection data has been constructed. The game has been well received by other researchers and, given the game was designed to be readily adapted to specific places, it is now being developed for new locations as part of a second research project. The game and the local variants of the game will be available as digital artifacts to download and play through the project websites and the game code and instructions will be made available for reuse.

Acknowledgements

The research reported in this paper was carried out as part of the UK EPSRC-funded E-Drone project, EP/V002619/1 (www.e-drone.org).

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