Least Cost Paths for Participatory Network Design

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Summary

This research presents a novel PPGIS interface to facilitate the collaborative design of a route network (e.g. footpaths, cycle routes, roads). One of the key issues with conventional line-based PPGIS is the varied levels of generalisation in line digitisation. By using a browser-based A* routing algorithm to join each anchor point with a least cost path in real time, the level of generalisation between contributions is normalised and efficient are routes created based upon the heuristic in the algorithm. Path bundling will transform individual contributions from participants into conceptual 'desire lines' which will in turn be used to determine the resulting network layout. The benefits of this approach will be demonstrated by a case study on the isles of Barra and Vatersay in the Outer Hebrides, which are planning to develop a new network of footpaths, cycleways and roads in order to relieve the currently overloaded infrastructure.

KEYWORDS: PPGIS, Decision Making, A* Algorithm, Least Cost Path, Active Transport

1. Introduction

1.1 PPGIS in Decision Making

PPGIS encompasses a wide array of practices in which social groups and individuals can participate in GIS-based spatial analysis, planning, knowledge production and decision-making (Elwood, 2006). PPGIS tools can be used to compile and present data from a broad range of stakeholders in order to represent individual interests and priorities (Anderson et al., 2009). It is widely agreed that involving more views and ideas in decision making allows for a better understanding of the way people interact with the space around them (Huck et al., 2016; Carver et al., 2009; Montello et al., 2003; Evans and Waters, 2007 & Anderson et al., 2009), however there are numerous challenges.

The use of PPGIS has been driven by decision makers wanting to reduce dissatisfaction, produce better plans and form realistic expectations by accessing local skills and knowledge (Maquil et al., 2015). Spatial data collected from different stakeholders can benefit decision makers by gauging satisfaction and identifying concerns early in the decision making process, these can then reduce objections and maximise utility further down the line (Huck et al., 2014). Whilst there are clear advantages to including members of the public in the decision making process, it is not without issue. Barriers to effective PPGIS include (but are not limited to) digital divides (Gottwald et al., 2016), participation inequalities (Robinson et al., 2015), concerns over data quality/credibility and the effective representation of data produced (Huck et al., 2018).

This research focuses upon the production of lines in PPGIS. Conventional line digitisation interfaces, whereby the user clicks to create anchor points that are joined by straight edges, are poorly suited to applications such as the collaborative design of a path network. This is because the level of generalisation in the resulting lines varies depending upon the number of clicks that each participant

makes along their intended path. As such, similar routes can be difficult to compare, and generalised straight-line segments along selected routes (as shown in **Figure 1**) do not always accurately reflect the intention of the participant (in some cases even being unfeasible, such as crossing rivers or going over cliffs).

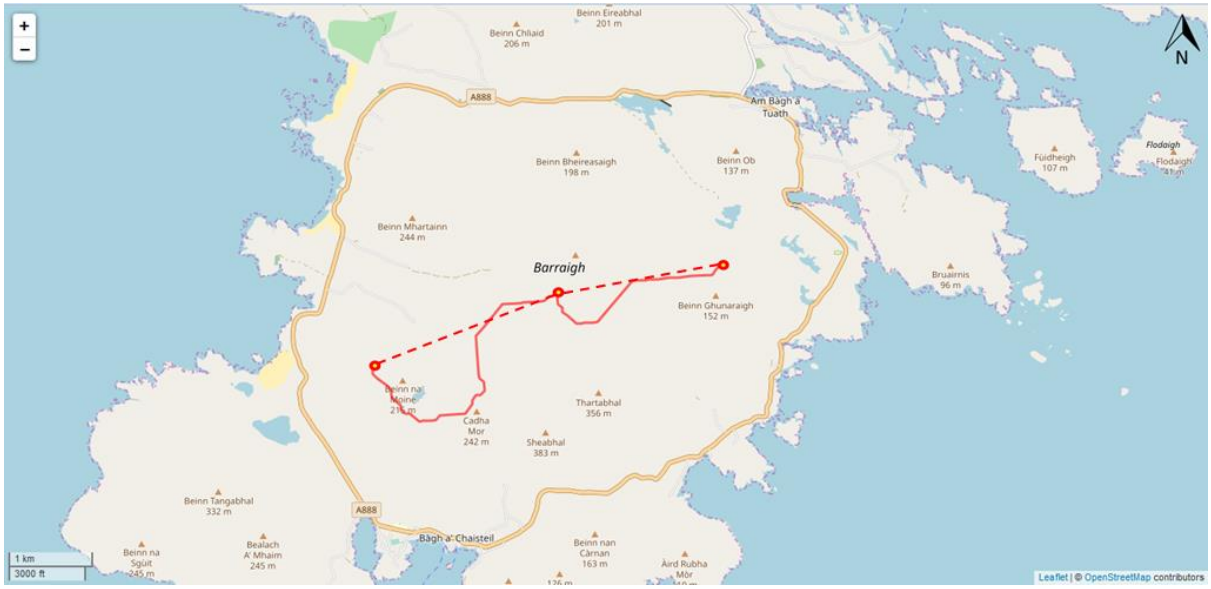

Figure 1 Comparison between A* algorithm network (shown in solid line) and conventional point-to-point line (shown as dashed line)

1.2 The isles of Barra and Vatersay

The isles of Barra and Vatersay in the Outer Hebrides provide a useful case study for this research. At approximately 23 square miles in size and with a tight-knit community (approximate population of 1,300) the isles provide an excellent opportunity to obtain high levels of participation in a sample area enforced by clear, geographical boundaries.

Following the production of a community energy plan (Local Energy Scotland, 2018), islanders highlighted transport as a key area of concern. With just one, single track road circumnavigating the island of Barra, an absence of footpaths and pavements, and high levels of cycle tourism the transport systems on the isles are overwhelmed. At present, 36% of imported fuel on the isles is used for transport (with 36% going towards heating and 28% electricity). Consequently, there are high levels of fuel poverty within the population, an over-reliance upon motorised transport and concerns around obesity which places pressure on the limited healthcare available (Local Energy Scotland, 2018).

Through consultation with the Project Officer of Barra and Vatersay Community Ltd it was agreed that policy surrounding active transport on the isles could be informed by the use PPGIS in order to facilitate the collaborative design of a new network of footpaths, cycleways and roads based upon community views and needs. By adding such infrastructure to encourage active transport, pressure on fuel supplies will reduce and enable an easier transition to low carbon futures as well as improve community health.

2. Methods

2.1 A* Routing Algorithm

This research addresses these issues by replacing the traditional line digitisation model with one in which user-generated anchor points are joined not with straight edges, but rather with least cost paths, calculated in real-time using an implementation of the A* algorithm. The use of these paths means that the level of generalisation of each line is normalised (based upon the resolution of the underlying

elevation data) and the routes are ensured to be physically feasible (avoiding obstacles such as water, steep slopes and other impassable obstacles). Accordingly, the resulting paths avoid issues around comparability and representation, whilst permitting the user to maintain full control over the final route by the addition of a greater or fewer number of 'anchor points' if they so wish (as shown in **Figure 2).**

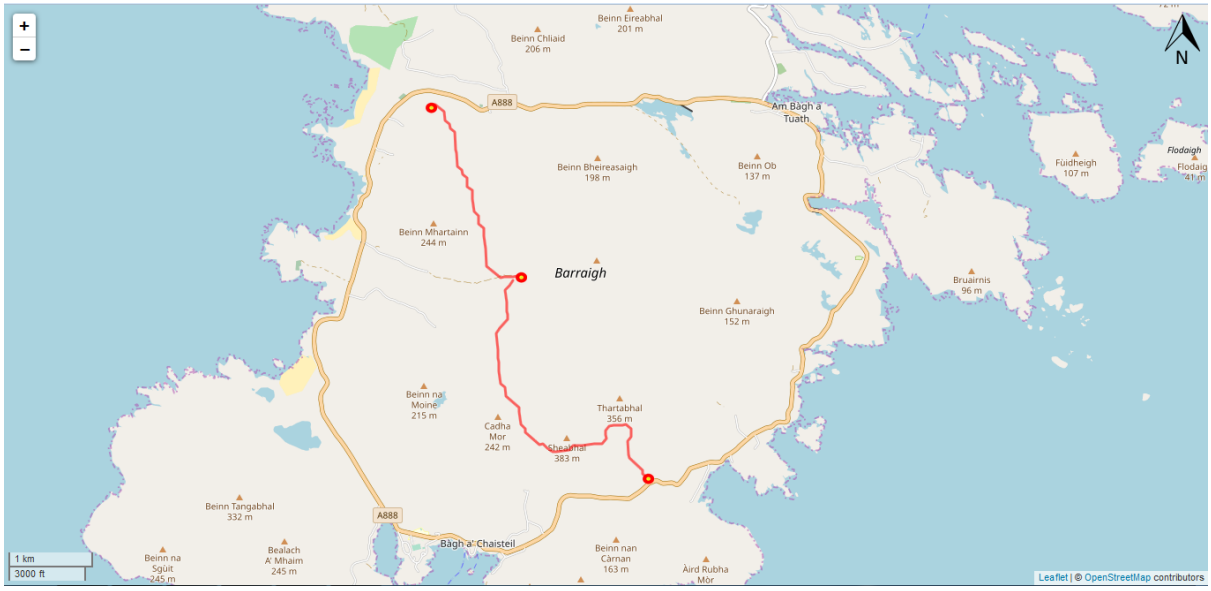

Figure 2 Least cost path network between multiple anchor points on the isles of Barra and Vatersay

The most substantial technical challenge in the implementation of this interface is the real-time calculation of least cost paths in-browser, as the continuous sorting of the underlying dataset is computationally expensive. This was addressed by the use of 'binary heaps' to process elevation data, allowing a digital elevation model at a resolution of 50m to be used for the analysis (Grinstead, 2010).

Once the data have been collected, path bundling will be used in order to then transform individual contributions from participants into conceptual 'desire lines', which will in turn be used to determine the design of the resulting network layout.

The interface normalises generalisation and accuracy in the resulting paths, taking the onus for data quality away from the participant's individual mapping effort and placing it instead on the resolution of the dataset. This removes the requirement for mapping effort to be used as in indicator for validity, and enables collective knowledge to be presented in a clear and uniform manner to decision makers.

3. Conclusion

As there are three main settlements on the isles (Castlebay, Northbay and Vatersay), a minimum of three workshops will be conducted in early 2019 with the intention of designing a new transport network. Additional workshops will then be held in order to feedback results and present findings to participants and relevant stakeholders.

This research has presented a solution to the issue of variation in generalisation in collaborative line digitisation, and a number of identified issues arising from that variation including the comparability, feasibility and representivity of results. By using an novel, algorithm-based PPGIS interface in order to allow participants to propose routes for new segments of pavement, footpath, cycleway and road, it is intended that this study will demonstrate how local knowledge can be effectively integrated into the decision making process.

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Biographies

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