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Using Spatial Network Analysis to Recover England's and Wales' Lost Footpaths and Rights of Way

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Abstract: Political action in contemporary society is often fuelled by a combination of large dataset analysis (big data) in conjunction with efforts to mobilize armies of volunteers (VGI – Volunteered Geographic Information). Those seeking to influence landscape decisions, which are inherently political in nature must also find new ways to combine insights gained from big data mining with technologies of social engagement. This research outline gives an overview of the pilot phase of a data analysis project intended to inform efforts by volunteers to recover 'lost' rights of way in England's footpath network in the face of a pending policy change in 2025. The research explores the feasibility of several methods of analysing the properties of spatial networks to find inconsistencies in how England's footpath network may have been recorded. By highlighting problem areas in the network, the efforts of volunteers tasked with much more time intensive methods of confirming and reaffirming lost rights of way may be better directed. Finally, the study seeks to give recommendations on how the network can be maintained and improved for future generations of walkers, especially in those parts of England characterized by high levels of economic deprivation or where regular walking is not an established pastime and fitness activity. The results of this first phase of research are intended to inform a broader research proposal covering all of England's footpaths.

Keywords: Landscape infrastructure, network analysis, big data

1 Introduction

An invaluable part of England's cultural heritage and sense of identity is its rural landscape, made accessible through an extensive network of protected footpaths and bridleways. These 'public rights of way' (PROW) are maintained at some cost to local authorities and private landowners, but the economic, health, and social benefits derived from upholding the permeability of the rural landscape arguably justifies the cost of maintaining the network, with income generated from walkers supporting between 180,000 – 250,000 full-time jobs (CHRISTIE & MATTHEWS 2003), and with walking for leisure far outpacing other forms of exercise in maintaining overall physical fitness (SPORT ENGLAND 2019).

Ancient rights of way, including simple footpaths, were essential to the development of rural life over much of England's history, but were only protected by law with the 1949 National Parks and Access to the Countryside Act, when it became a legal requirement for all civil authorities to record rights of way on a 'definitive map' under the legal principle 'once a highway, always a highway.' Since 1949, over 117,000 miles of PROW have been thus recorded and protected (NATURAL ENGLAND 2008). These PROWs can only be extinguished through specific legal processes or Acts of Parliament. Under current provisions, PROWs which have been 'lost' through failure to diligently record them on each council's definitive map can be reinstated for public use if it can be demonstrated that the path existed historically, usually through identification on an historic map, and for which no evidence exists of it having been extinguished through due process. To provide more certainty to landowners, however, this right to recover ancient rights of way from historic evidence will be eliminated

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on January 1, 2026, when all rights of way not recorded on each jurisdiction's definitive map will be extinguished (DEREGULATION ACT 2015).

In light of the possibility of losing public access to historic PROWs – an estimated 10,000 miles or more – The Ramblers walkers association has started the 'Don't Lose Your Way' campaign to engage volunteers in a project to identify lost rights of ways and to petition local authorities to record these on their definitive maps (RAMBLERS 2018). Much as local councils have been inconsistent in recording pathways, however, this project too suffers from the bias that areas with an already high density of walkers will be well represented in filing claims, but rights of ways in economically deprived areas or parts of the country with unremarkable or average scenery, where the footpath network is already often neglected, risk losing the most. It is precisely in these areas where the redevelopment of a well-maintained and coherent network could possibly bring the most social and health benefit (SPORT ENGLAND 2018).

To combat these biases and to focus efforts in light of the pending deadline called for by the Deregulation Act, this study investigates several methods whereby computational analysis of existing datasets can highlight areas where the recording of the footpath and bridleway network may have been negligent. These areas can then be the focus of further efforts to restore the overall coherence and connectivity of the network through the reinstatement of lost PROWs and other legal measures.

2 Pilot Study Scope and Method

2.1 Area of Pilot Study

Much like the footpath network itself, the political divisions of England are the product of the country's long political evolution and incremental and sometimes piecemeal efforts at political reform. While current councils may be diligent in their efforts at recording rights-of-way, many have only recently been constituted in their current form and the legacy of recording the PROW network over the last 70 years – even within current jurisdictional boundaries – may as a result be inconsistent. To inform a broader study of the consistency of the PROW network in relation to political jurisdictions across England, this initial phase of research looks more closely at the networks in a study area in central England consisting of the councils in the historic counties of South Yorkshire and Derbyshire (Figure 1).

The ceremonial county of South Yorkshire is politically organized into four unitary authorities or 'Metropolitan Boroughs' of a similar geographic size – Sheffield, Barnsley, Rotherham, and Doncaster. The county is characterized by a variety of landscape types ranging from low-lying bogs and agricultural land to the east in Doncaster, to the high moorlands of the Peak District National Park in the west. Much of the central area is hilly countryside with significant urbanized areas. Both Barnsley and Doncaster – among the most economically deprived councils in England – scored in the bottom half of a nationwide study of 'path ease of use' conducted in 2003 with relatively affluent but socially divided Sheffield scoring in the top third. Despite also having high levels of social deprivation, however, the council of Rotherham surprisingly scored the highest in the survey (CHRISTIE & MATTHEWS 2003).

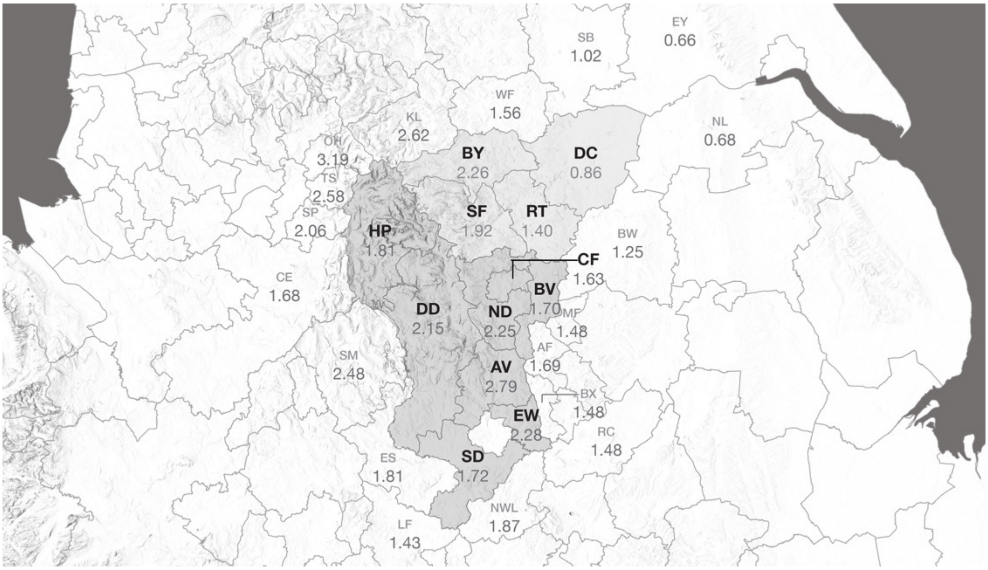

Fig. 1: The councils of South Yorkshire (Light Grey) include Barnsley (BY), Doncaster (DC), Rotherham (RT), and Sheffield (SF). The County of Derbyshire includes the councils of High Peak (HP), Derbyshire Dales (DD), North Derbyshire (ND), Chesterfield (CF), Bolsover (BV), Amber Valley (AV), Erewash (EW), and South Derbyshire (SD). The density of the Public Right of Way Network (total km of PROW / council area km^2) is shown for the councils in the study area and for the adjoining councils.

In contrast to South Yorkshire, Derbyshire, is governed by a county council which shares power with several smaller civil parishes, while the city of Derby itself (not included in the study) constitutes its own unitary authority. Despite much of its area being in the Peak District National Park, Derbyshire received one of the lowest scores for 'path ease of use' (CHRISTIE & MATTHEWS 2003) which makes it a good candidate for further study of its path network characteristics.

2.2 Methodology

The research is based on an analysis of datasets describing the PROW network provided by each council in the study area and in adjoining councils (ROWMAPS 2019), together with road network data provided by England's mapping agency Ordnance Survey (OS 2019). While future phases of this research will aim to incorporate topographic data into the overall analysis, for the purposes of this phase of study, the data is only considered 2-dimensionally. The data is first curated in ArcGIS and then exported into Rhino/Grasshopper for the computational analysis. The analysis described could likely be performed wholly in the GIS environment, but owing to the author's personal skills, preferences, and future research plans, the Rhino/Grasshopper environment was chosen.

The methods chosen for this initial phase of the research are derived from recommendations put forward by the Ramblers in their 'Don't Lose Your Way Campaign.' The Ramblers recommend visual inspection of maps for dead ends in the network, especially at parish and council boundaries, as historically public paths would be expected to continue between distinct destinations and to not stop suddenly at administrative lines. The Ramblers also recommend comparing the abundance of rights of way in one administrative area to that of its neighbours, as jurisdictions sharing similar topographic characteristics should be expected to have similar densities in the path network. Based on these recommendations, three computational tests are employed.

Test One: Network Density: A comparison of the density of the footpath network from one jurisdiction to its immediate neighbours is a fairly straightforward task once data on administrative boundaries is compared with the path data from each council. For this test, the total length of the PROW network from the councils in the study area as well as of the adjoining councils is compared. A countrywide survey of the PROW network by the now defunct Countryside Agency in 2001 found the average density of the PROW network to range from 1.1 – 1.2 km/km^2 in the East and Southeast of England to 1.6 – 1.7 km/km^2 in the North and Northwest (COUNTRYSIDE AGENCY 2001). Within this range, however, individual jurisdictions can vary considerably, especially where urbanisation has erased historic rights of way. Once the actual network densities are derived for each council, they are compared to a hypothetical 'expected' network density for the council derived from a weighted average of each neighbour's network density as a proportion of their shared boundary. These results are then compared with 'found' footpaths from the next tests to determine if there is a correlation.

Test Two: Analysis for dead ends within administrative boundaries: In order to find dead ends within each of the councils, data from the PROW network (footpaths, bridleways, and sometimes byways) must be considered in conjunction with the network of highways, streets, roads and tracks open to vehicular traffic, known collectively in England and Wales as 'adopted highways' as these are part of the overall network of movement for walkers through the council. Care must be taken not to include private roads, drives, and tracks – which are closed to the public – in this analysis. Also not included here are so-called 'permissive paths' which are open to the public most of the time by agreement with the council, but which the landowner can close temporarily or permanently at will, and which are typically closed at least one day a year (typically Christmas Day) in order for the landowner to reassert their private ownership rights over the path (OS BLOG 2011).

Once the appropriate datasets are identified, finding dead ends computationally is a bit harder than it might seem intuitively. Paths and roads which have variable width in the real world are typically represented only as lines in the dataset, and the endpoints of one dataset do not neatly correspond with others. Proximity and connectivity then, can only be assumed within a degree of tolerance. For this study, a tolerance of 20m was used based on initial tests, although the optimal tolerance should be verified more rigorously through future research. Once the tolerance is determined, a set of points is drawn at a regular interval along each path line at a distance of half the tolerance factor (in this case 10m). The points in the various datasets are then cross compared for proximity. Where more than two points are found within a radius equal to 95 % of the tolerance range, this indicates a likely intersection or case of path connectivity.

Test Three: Analysis for dead ends at administrative boundaries: While the test for dead ends described above can identify most of the path connectivity issues *within* a council's purview, it is also essential to test the path data from adjoining councils to see if these unexplainably terminate at the council boundary. A path within Barnsley which terminates at its boundary with Rotherham, for example, indicates the fault is potentially not with Barnsley's network, but with its neighbour's. For this test, only the endpoints of the paths in each neighbouring council are compared with the path and road data within the council being analysed within the same tolerances as described above.

After the analysis of the footpath network for the two types of dead-end conditions is undertaken and possible markers of inconsistencies in the network are identified (Figure 2).

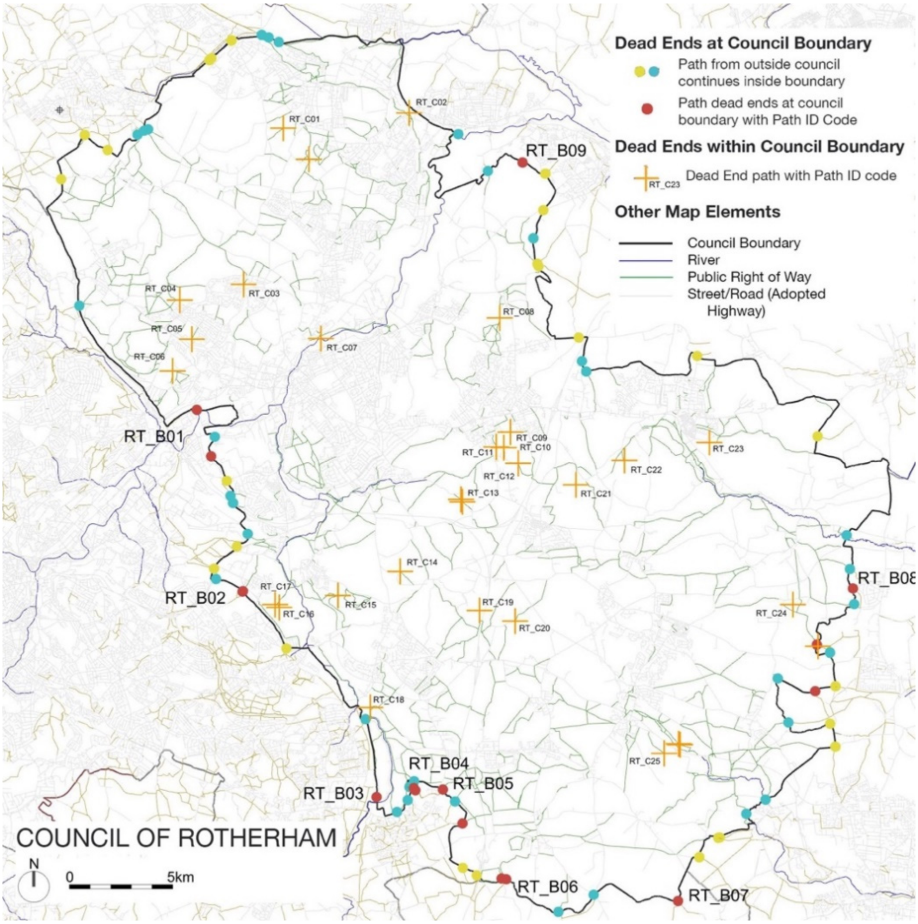

Fig. 2: Path dead ends computationally identified in the Council of Rotherham

historical maps are analysed to see if a lost PROW can be found associated with each potential dead end. A full archival search of non-OS maps is not possible within the scope of this research, but current OS Maps along with historic OS Maps from 1840s onward in digitised form could be consulted. Where a clear loss of an historic footpath at each potential dead-end is evident from the preliminary archival research, the feasibility of 'recovering' the path along with the total length of the 'recovered' path segment is tabulated. The aim at this stage of the research is not yet to build a case for recovering the lost footpaths themselves, but to find the correlation between the raw computational results and the potential for path recovery, in other words, the incidence of true vs. false positives. For this reason, when 'lost' footpaths were visually identified on the maps in the vicinity of the dead end but which were not clearly associated with the dead end itself, the 'found' footpath is not accounted for in the tabulation, since its recovery was coincidental or random. In such cases notes were made by the researcher and other algorithmic methods will be considered in future research which might be able to reliably flag such cases.

3 Results

After running the three computational tests for overall path density, dead-end incidence *within* council boundaries, and dead-end incidence *at* council boundaries, some preliminary observations as to their usefulness and limitations could be gathered and recommendations for improving and expanding the methods for a broader ranging study can be made.

The test of overall path density showed overall network density to range from a low of 0.86 km/km^2 in Doncaster to a high of 2.79 km/km^2 in Amber Valley. Adjacent to the study area in adjoining councils an even wider range was found from a low of 0.66 km/km^2 in East Yorkshire to 3.19 km/km^2 in Oldham, Greater Manchester (Figure 1). In general, densities are higher in the study area than both the national average for England as a whole and northern England in particular. The network density is highly correlated first with topography, with flatter councils having relatively low densities, and hilly areas having high densities. The highest moorland plateaus, however, also have very low path densities. Another factor influencing path density in a council is the degree of urbanisation, with highly urbanised councils having lower densities of footpaths.

With these complex factors and others affecting network density, is a density comparison of adjacent councils with the goal of focusing efforts useful? To a point it seems to be. The results of the analysis of 'expected' versus 'actual' network densities in the councils did show a weak but significant correlation ($R^2 = 0.4126$) between the expected and actual network density and the length of 'lost' footpaths 'found' as a percentage of each council's total PROW (Table 1). This is not a very reliable test, however. When looking closely at the case of South Derbyshire, for example, whose network density was 11.22 % lower than expected putting it 4^{th} on the list of potential 'problem' councils, closer inspection reveals it to have the lowest ratio of 'lost' footpaths to existing network length in the study area. This is likely because South Derbyshire which is surrounded by rivers on most of its boundaries is considerably flatter topographically than its immediate neighbours, but this fact cannot be adequately accounted for with the simple method used. Perhaps the usefulness of this method could be enhanced with factors accounting for slope, elevation, and urbanisation, but even then, the problem is that this method while possibly informative, does little to deliver actionable data for finding lost PROWs.

Table 1: Percent deviation between actual and expected network density in relationship to 'lost paths' found. Expected network density derived from weighted average of neighbour's network density in relation to the length of the shared boundary.

Council	Expected Network Density	Actual Network Density	Percent Deviation	Actual 'Lost Paths' in Council	As % of Council's ∑-PROW
Doncaster (SY)	1.26	0.86	–31.60 %	22.94 km	4.68 %
Chesterfield (D)	2.17	1.63	–24.78 %	1.17 km	1.08 %
High Peak (D)	2.18	1.81	–16.94 %	10.09 km	1.03 %
South Derbyshire (D)	1.94	1.72	–11.22 %	1.22 km	0.21 %
Rotherham (SY)	1.53	1.40	–8.41 %	12.98 km	3.24 %
Sheffield (SY)	2.02	1.92	–4.98 %	4.82 km	0.68 %
Derbyshire Dales (D)	2.11	2.15	+1.70 %	12.86 km	1.03 %
Bolsover (D)	1.80	1.70	+5.50 %	2.50 km	0.92 %
Erewash (D)	1.99	2.28	+14.79 %	0.70 km	0.28 %
North Derbyshire (D)	1.89	2.25	+19.20 %	3.30 km	0.53 %
Barnsley (SY)	1.80	2.26	+25.29 %	6.45 km	0.87 %
Amber Valley (D)	2.06	2.79	+35.40 %	4.05 km	0.55 %

In contrast to the density test, the two dead end tests did deliver actionable results. A strong correlation ($R^2 = 0.7672$) was found between incidence of dead ends and the length of recoverable 'lost footpaths' as a proportion of the existing network length in each council, and with a few further refinements to the algorithms used, the reliability of this method could be increased even more. Over the whole study area, 53 % of the 'hits' returned by the raw computational analysis correspond with a potential lost PROW identified after the detailed historical map analysis. A human user can very quickly visually inspect the 'hits' to eliminate false positives and increase this incidence to around 67 %, and improvements to the algorithms used to process the datasets should allow the raw computational results to approach this number as well. The reasons for this and potential improvements to the computational process will be discussed shortly, but a key finding is that approximately two-thirds of dead ends in the current PROW network represent places where the historic ROW has been lost or where it is not adequately documented. This two-thirds correlation, however, does vary widely (Figure 3A), with councils such as Barnsley, Doncaster, and Rotherham having a very high incidence of found paths associated with dead ends (94 %, 82 %, 80 % respectively), with the only correspondence below 50 % found in South Derbyshire (33 %). Again, this is likely due to its situation near several major rivers, with many paths actually ending at the river as historically this may have been used to gather water, wash clothes, fish, or embark on a boat. Other legitimate dead ends can be often be found on paths leading to 'attractions,' such as caves, viewpoints, or chapels. In general, however, dead ends tended to be historically rare. The causes for PROWs being lost are varied, but a few general trends from the detailed analysis were evident. Many are associated with major, disruptive land-use changes (quarries, collieries, reservoirs) or the construction of major pieces of more modern transit infrastructure (canals, motorways, railways, etc.). Many loses, however, as posited by the Ramblers, are simply due to clerical error. Between the eleven councils in the study area, 2.9 % of PROW approaching the council boundary end with no continuation of the footpath or intersection with a road. This figure ranged from a high of 12 % in Rotherham to a low of

2 % in North Derbyshire. There were also several incidents in the study area of dead ends occurring at old parish boundaries pointing to potential clerical errors before the era of modern mapping, but the analysis of the historic maps from 1840 onward could find no evidence of these few paths continuing, implying that the ROW was 'lost' even further back in historical time.

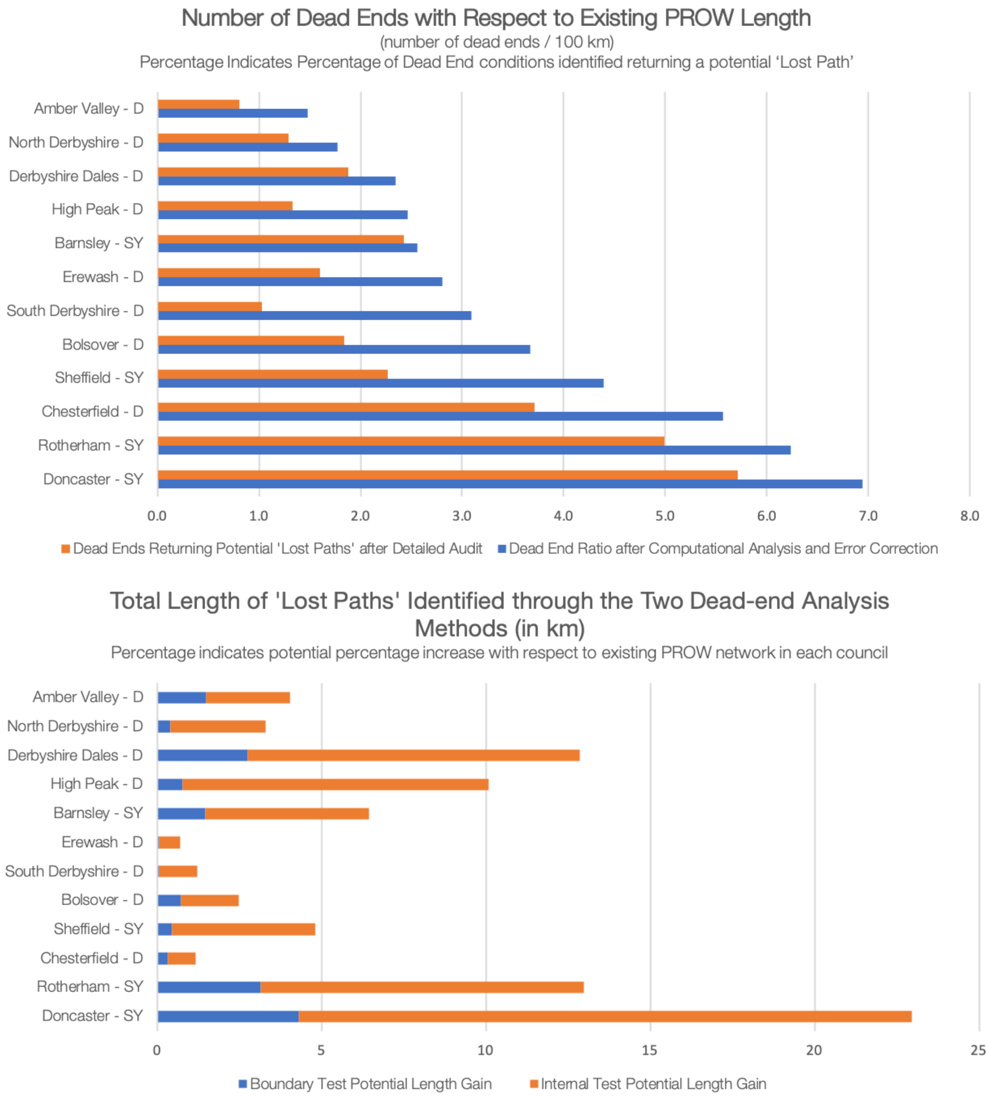

Fig. 3: Summary of some key findings from the path dead-end analysis

Should only those ROW with preliminary documentary evidence be recovered in the study area, however, approximately 87 km of PROW would be added to the network and overall network connectivity, coherence, and usability would be improved. (Figure 3B) How much effort does it take to confirm a potential lost PROW using this method? A general estimate of the time spent checking 236 dead end conditions in the study area yields a result of about 4km/hour, a leisurely walking pace.

It is hoped that the potential usefulness of this method has been sufficiently demonstrated, but should the study be scaled up, several improvements to the algorithms should be made. Many of the inconsistencies and errors between the raw computational analysis and the actual dead-ends were related to problems with the datasets themselves and how the initial user drew the lines. In South Derbyshire, for example, a very high introduction of error was related to improperly joined lines, which led to a problem with the method of testing proximity to points as intersections were assumed where none actually existed. In Rotherham, actual connections across the council boundary were often correlated to the end points of paths not falling within the range of tolerance as the user responsible for data entry often continued the path's polyline across the council boundary 50 – 100 m (or more). While these errors can be quickly detected, the time invested in programming methods to clean the data need to be balanced with other project goals, especially as such errors tend to be fairly idiosyncratic. Other errors could be fixed by properly accounting for potential dead-end conditions with the introduction of additional datasets. As an example, proximity to wide rivers could be used to exclude dead ends from the analysis where a path leads to but does not cross the river. In general, however, the author decided it was better to visually sort out 'false positives' if these could be done fairly easily rather than introducing a potential source of 'false negatives.' In the case of rivers, for example, incidents *were* found where a footpath did apparently dead end at a river, but where a ferry historically existed, the PROW being lost on the other side. Had the algorithm strived for too much cleverness in this case, the lost PROW would not have been identified.

4 Conclusion and Outlook

The findings of this first phase of research are intended to inform a broader research proposal into England and Wales' PROW network. While it is dangerous to extrapolate too much from the limited initial sample size with its topographic uniqueness, if a similar incidence of footpath loss and potential recovery were found across the two nations, exploring network continuity at dead ends would uncover an estimated 3200 km (2000 miles) of lost PROW. While this would represent a significant gain, this only accounts for around one-fifth of the estimated 10,000 miles lost. Other methods could be developed. In addition to network density and the presence of dead ends, other network properties may give additional insight into whether segments and nodes from the historic pattern of movement have been lost. These might include average distance between nodes in the network and the size and geometry of the 'cells' or rural blocks created by the network. In addition to broadening the geographical scope of the analysis and the methods employed, future phases could explore linking topographic data to the analysis of footpath topology in order to understand patterns of movement at a finer scale, and to link the analysis of PROWs with VGI data (e. g. Strava Data, Ramblers Pathwatch App Data) so to identify potential lost PROW based on how people currently move through space.

In the end, however, the intent of this research is to find ways to expand access to the network and to improve its overall usability. As previously mentioned, prior research has explored the economic benefits of the network especially with fostering tourism. Research into the benefits of footpaths should be expanded to touch upon issues of health and well-being, levels of deprivation and affluence, and other types of racial, ethnic, and demographic disparity. While the network represents a significant cultural legacy which could enrich the lives of millions, the network is continually under threats from encroachment and ill-considered development on the one hand to neglect and disuse on the other. Of particular concern to the Ramblers and other outdoor enthusiasts is the accessibility of this important cultural legacy to immigrants and the children of immigrants who often are unaware of their rights to roam in the countryside and who may feel intimidated using the network, elderly and disabled people who have trouble navigating much of the network especially where it has fallen into neglect, and young people who rely less on paper forms of navigation and increasingly on digital tools to navigate through space. If the network is to survive and thrive throughout the 21st century, the level of foresight and the ambition of planners needs to match or surpass that of those who fought the fights in the mid-20th century to enshrine the network protections into law. At the same time, it cannot exist only as a legal construct, but needs to be improved and cultivated as a physical object interwoven with the daily lives of all the residents of England in Wales as it has been for millennia.

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Data

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