Development of a GIS based toolbox for mapping Cycling Potential across Scotland

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1 Introduction

1.1 Objective

The Cycling Potential Tool (CPT) aims to provide an evidence base, and to start conversation, about areas throughout Scotland which may receive a high benefit from investment in cycling at a local level. The CP tool looks at a number of criteria spanning four modular areas; environment, schools, development and tourism. The aim is for the tool to be able to locate areas where investment can be targeted most effectively and to also be able to sense check existing or planned projects. Cycling Scotland (CS) is currently engaged with more than 10 local authorities and other partners, with the aim of rolling out the tool throughout the entire country.

CP was originally developed by CS in 2014. In early 2016, CS began work with AECOM to convert CP into a bespoke GIS toolset which is being continuously developed going forward.

1.2 Concept

There are several key drivers of how CPT was derived. Transport for London's Analysis of Cycling Potential Report (December 2010) examined the potential for growth in cycle travel amongst Londoners, the cycling market and potentially cyclable trips. In 2012, CS commissioned MVA Consultancy to help identify sources of data and forms of data collection which could be used to monitor levels of cycling in Scotland. This report developed a series of recommendations, some of which fed into and influenced the development of the project;

- *"Transport Scotland/Cycling Scotland should consider the possibility of further research to quantify the relationship between relevant urban realm indicators (including the amount and quality of cycling and pedestrian infrastructure, current traffic volumes and speed, etc.) and the public's perception of their neighbourhood;"*
- *"To inform future decision-making, any significant investment in cycling infrastructure should be evaluated using robust Before and After monitoring which can be used to quantify the benefits of the resulting changes in walking and cycling…"*

Ipsos MORI performed some preliminary work on attempting to understand CPT in Scotland. Their initial work looked at the socio-demographics of those who already do cycle, and mapped out where in Scotland (at a local output level) people matched this socio-demographic profile, regardless of whether they cycled or not. This showed a rough estimate of where people are likely to take up cycling, at least from a socio-demographic standpoint.

Finally, Cycling Scotland also worked with Steer Davies Gleeve to begin to develop Cycling Potential further. This work produced a hexcell based mapping approach which looked at some of the datasets from the original pilots. The methodology that came from this was a good starting point but focused on larger settlements. Due to the makeup of Scotland, we required something that was more attuned to local factors which has led to continued development.

2 Cycling potential method

CS originally developed a manual approach to determine CPT before this process was automated in GIS. The following section presents this approach and how it was developed for the environment module before being applied to the pilot area of Alloa, Clackmannanshire.

2.1 Manual process – Alloa pilot area

The environment module looked at a number of datasets which analyse the environmental features and constraints of an area. When originally applying this module to Alloa the first step was to separate the town into polygon areas following sense checking discussions with the CS contact at the local authority. Data for nine criteria were then extracted from within the boundary of the polygon and scored in order to establish the CPT score for that section. The criteria are detailed in Table 1.

All of the criteria used in identifying CPT within a polygon were given a score between 1 and 5, depending on the results. This score was determined using absolute methodology or relative methodology when the former was unsuitable.

Absolute methodology used fixed bandings to determine a rank in datasets which could be treated the same nationally. This methodology was used in Average Speed, Topography, Travel to School and Travel to Work with examples of each banding shown in Table 2.

Table 2: Absolute scoring

Rank	*Speed (mph)*	*Standard Deviation of Hilliness*	*Avg. Distance (to work and school) (km)*
1	*0-24*	*0-10*	*1 to 3*
2	*25-29*	*10 to 25*	*3 to 4*
3	*30-34*	*25-40*	*4 to 5*
4	*35-40*	*40-55*	*0 to 1*
5	*40+*	*55+*	*5 +*

Relative methodology was used when a figure could not be used nationally. A score was determined by comparing the data of that section with that of the average of the rest of the polygons within that settlement. The data was converted to a number with a score of 100 representing the average. All relative methodology used the same banding scores, which are shown in Table 3.

Table 3: Relative scoring

Rank	*Score*
1	>137.5
2	112.5-137.5
3	87.5-112.5
4	52.5-87.5
5	<52.5

The scores for each polygon were calculated manually using a mixture of spreadsheets and manual measurement tools within GIS.

The final CPT score for each polygon was the average rank of all of the analysed datasets. This process was completed on each of the polygonal areas within the settlement. At the end of the process a map displaying the colour coded scores of each polygon and a table containing the results of each dataset was produced.

2.2 Automated process – Alloa pilot area

Although the manual approach detailed in the previous section provided the desired output, the process required multiple manual steps making the application of the method time consuming to repeat in other geographies across Scotland. In addition the resulting score generated by the manual approach was applied to the each output area as a whole rather than providing a varying level of suitability across the study area. As a result, the manual approach did not assist in identifying more localised areas of CPT or constraint within the study area. To overcome these limitations a series of GIS tools were developed to both automate and scale the process so that it could be applied to any geography in Scotland.

The underlying method applied to automate the approach is based on the Multi Criteria Analysis (MCA) concept. MCA is a widely used technique when assessing site suitability and is designed to combine, weight and rank several different types of information in a raster format and visualise it so multiple factors can be evaluated at once. The MCA approach also retains the local information contained in each input dataset to allow continuous variation in suitability to be mapped across the AoI.

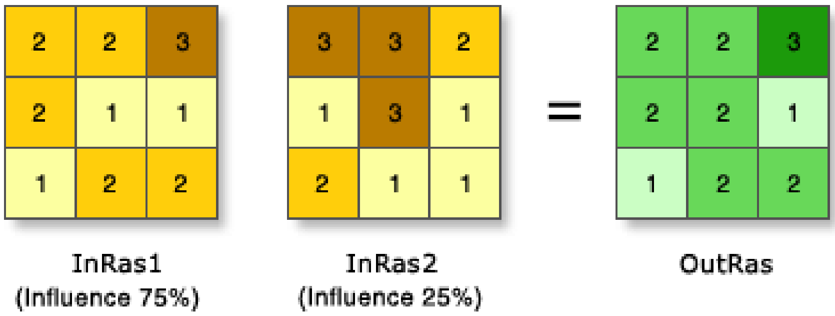
For example, when considering access to the cycle network and topography the two layers would be rasterised based on specific criteria before being combined to produce a single scored output. In this example there may be a location which is very accessible to the cycling network and therefore the raster layer would receive a score of 3, however at the same location a steep slope exists with a relative score of 1. When these two layers are then overlaid with equal weighting an overall score of 2 would be achieved for that location.

Alternatively the cycling network may be more distant and received a score of 1 whereas the topography this time is generally flat receiving a score of 3. Once combined, an overall score of 2 would be achieved giving that location the same cycling potential as the previous example.

In terms of weighting each layer in this example, we may want to increase the weight of accessibility to 75% and topography to 25%. Based on a score of 1 and 3 respectively this would produce a score of 1.5 therefore achieving an reducing the overall score when compared to equally weighted layers.

Note that for this study a standard MCA scale of 1 -10 was applied where 10 offers the greatest potential. This approach was the inverse to the manual scoring where a lower score was considered the highest potential.

Figure 1 - MCA concept (ESRI 2017)

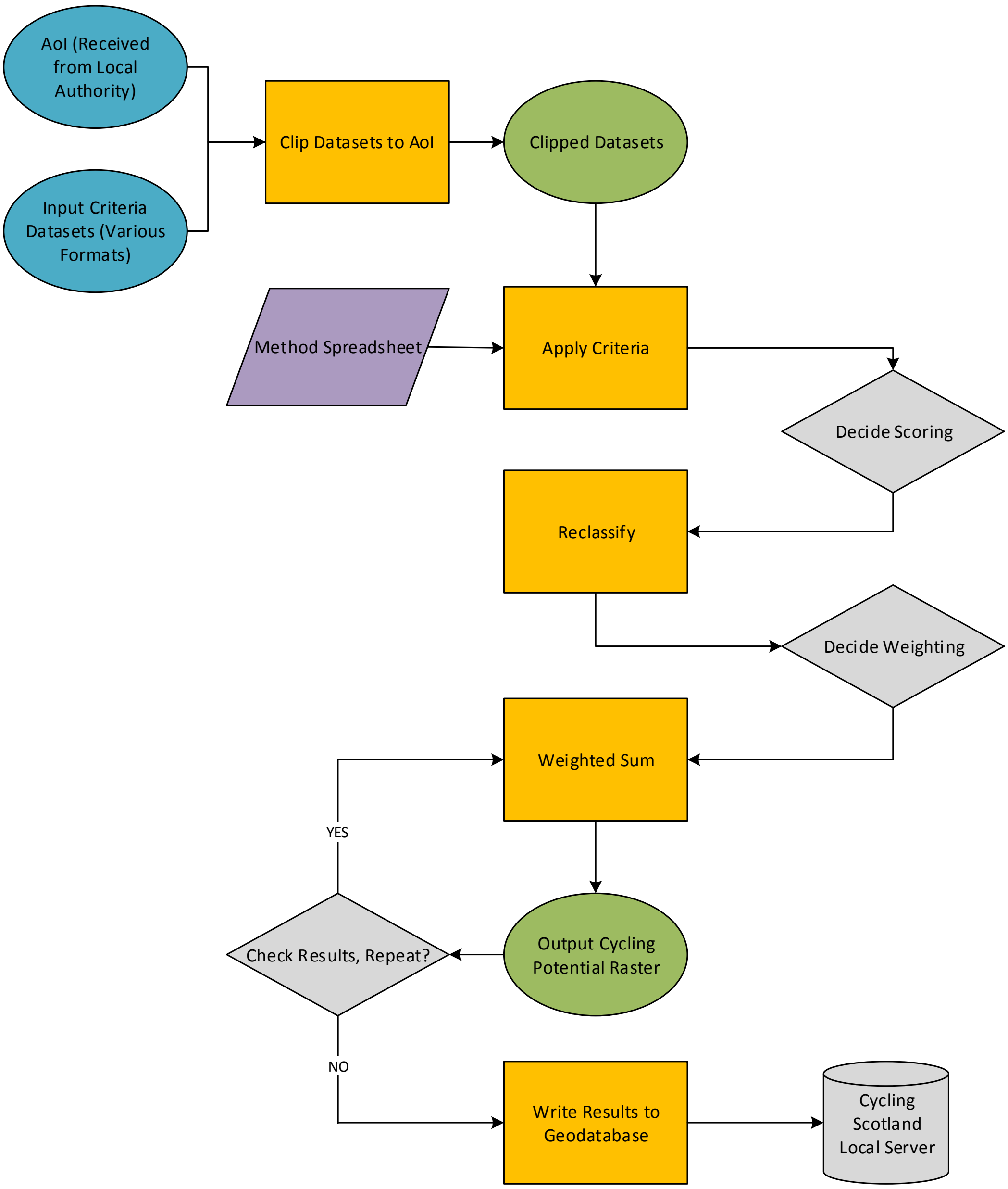


Essentially MCA offered a way to rapidly assess each AoI while maintaining the ability to remove or include additional rasterised datasets if required (e.g. the provision of Local Authority specific datasets), therefore allowing flexibility between different geographies across Scotland.

In terms of applying the MCA concept a series of GIS based tools were developed with ArcGIS Desktop using the ModelBuilder development tool. ModelBuilder essentially allows for a number of GIS process to be combined together into a continuous workflow therefore significantly reducing the need for the manual measurements previously applied.

The following diagram provides a conceptual diagram of the ModelBuilder workflow that was developed for the Cycling Potential mapping process. Each step illustrated in the workflow is discussed in the following paragraphs:

Figure 2 - ModelBuilder workflow



2.2.1 Data selection

Prior to developing the ModelBuilder workflow it was required to take each criteria of the manual approach and identify an appropriate GIS dataset which offered sufficient national coverage. The details of each of these datasets and the GIS processing that was applied is summarised in the Table 1.

Table 1 - Cycling Potential Criteria and Rationale

Criteria	*Reasoning*	*Data Source*	*GIS Processing Method*
Area of Interest (AoI)	*Area of Interest provide by Local Authority to be assessed for Cycling Potential*	*Not Applicable*	*Not Applicable*
Physical Barriers	*Layer required to mask out physical barriers such as mountainous areas, large rivers, motorways and railway lines. This will prevent such locations being considered for cycling potential.*	*OS Open Data*	*Raster layers representing physical barriers were used to mask areas not suitable for cycling.*
Population Density	*Density has been chosen rather than population volume as the sites being measured are differing sizes and are located in areas of differing population. Denser areas are likely to have higher potential.*	*Population figures from Super Output Areas*	*The population density value for each Output Area polygon was rasterised. The resulting raster was then reclassified based on statistical breaks*
Topography	*Areas which are less hilly are likely to have a greater potential for cycling.*	*OS Terrain 25m*	*Applying the OS 25m DTM, the hilliness of the area was based on the proportion of slope across the AoI. This also helped identify locally inaccessible locations within the AoI.*
National Cycle Network (NCN)	*Areas which have access to existing cycle infrastructure are likely to have a higher potential.*	*NCN shapefile provided by Sustrans.*	*Euclidean distance was applied to the cycle network to generate a distance raster. The resulting raster was then reclassified based on suitable distance criteria*
Additional Cycle Routes	*Areas which have access to existing local cycle routes (non NCN) and / or specific road infrastructure are likely to have a higher potential.*	*Local Authority Cycle Routes.* *OS Vector Map / OS Open Map Local i.e.:* *- Local Street* *- Minor Street*	*For roads classified as Lesser roads (e.g. 'local roads, minor roads, and B-Roads) these were* ***optionally*** *incorporated into the Cycling Network dataset and the same Euclidean distance process discussed above was applied.*
Average Road Speed	*Areas with a lower road speed are likely to have greater potential.*	*OS Vector Map / OS Open Map Local i.e.:* *- A Roads* *- B Roads etc.*	*For each discrete speed limited road identified Euclidean distance was be applied. Each discrete road speed distance raster was then weighted (depending on the speed value) and combined using the Weighted Sum process to produce a single output*
Distance to Work	*Areas which are within a reasonable distance to cycle are likely to have greater potential.*	*2012 Scottish Census - Table LC7102SC*	*The percentage of those within cycling distance to work was calculated for each Output Area polygon before being rasterised. The resulting raster was then reclassified based on statistical breaks.*
Travel Mode to Work	*Travel Mode to work is a useful indicator of cycling potential for the Output Area of interest. It is assumed that an area with a greater number of existing cyclists generally encourages others to also cycle.*	*2011 Census travel to work, General Register Office for Scotland*	*The percentage of those using bicycles as a travel mode to work was calculated for each Output Area polygon before being rasterised. The resulting raster was then reclassified based on statistical breaks.*

Distance to School	*Areas which are within a reasonable distance to cycle are likely to have greater potential.*	*2012 Scottish Census - Table LC7103SC*	*The percentage of those within cycling distance to school was calculated for each Output Area polygon before being rasterised. The resulting raster was then reclassified based on statistical breaks.*
Access to Services	*Areas which are within a reasonable distance to cycle are likely to have greater potential.*	*OS Vector Map / OS Open Map Local i.e.: - Bus Station - Coach Station - Primary Education - Secondary Education - Higher Education - Further Education - Hospital - Medical Care - Leisure or sports centre*	*Network Analyst was implemented, with the resulting service area isochrones being used to identify whether specific services are within an acceptable distance via cycle routes The resulting service areas were then be converted into a raster and reclassified if required.*
		Points X i.e.: - Doctors Surgeries - A&E Hospitals - Hospitals - Walk in centre - Clinics and health centres - Gymnasiums, sports halls and leisure centres - Convenience stores - Supermarket chains - Shopping centres and retail parks	*For additional services identified the same process discussed above will be applied.*

Following the collation of the national datasets for each criteria, the steps displayed in the workflow shown in Figure 2 were developed within ModelBuilder to allow for the MCA process to be applied. The following provides more detail of each of these steps:

2.2.2 Clip datasets to AoI

The first step was to clip all input national datasets to a 1km buffer zone around the AoI. This allowed for any neighbouring features to also be considered as part of the assessment e.g. a cycling network may border the AoI boundary which would otherwise be missed if a buffer zone was not applied.

2.2.3 Apply criteria

With the clipped data prepared, the next step was to rasterise each dataset by applying the GIS processes detailed in Table 1. Further detail on the types of processes applied is detailed as follows:

- **Polygon to raster**
  Polygon to Raster was required to convert vector based datasets such as Output Areas into the raster format required for the MCA process. To ensure consistency, all rasters were generated to a cell resolution of 1m, therefore allowing the finest level of detail to be retained during the MCA overlay process.

- **Slope raster**

  Identifies the slope (gradient, or rate of maximum change in z-value) from each cell of a raster surface. This process was applied to the OS Terrain 25m data to identify difficult gradients for cycling.

- **Euclidean distance raster**
  The Euclidean distance raster contains the measured distance from every cell to the nearest source i.e. the cycling network. The distances are measured as the crow flies (Euclidean distance) in metres, and are computed from cell centre to cell centre. In the context of this study the further you are from the source object of interest i.e. the cycling network, the lower the potential for cycling will be.

- **Network analyst**

  In order to assess the accessibility to a service once on a cycle route, Network Analysis was applied to produce isochrones surrounding each service feature. The isochrones produced essentially consolidate the distances required to get to the service of interest into a series of bands each representing how distant you are from the service at any location on the cycle network.

- **Reclassify raster**

  As a final step in the GIS processing and prior to applying the MCA concept each raster produced must be reclassified to a common scale. Each raster was reclassified to a range of values between 1 and 10, where 1 is considered as having low cycling potential and 10 representing the greatest potential.

2.2.4 Weighted overlay

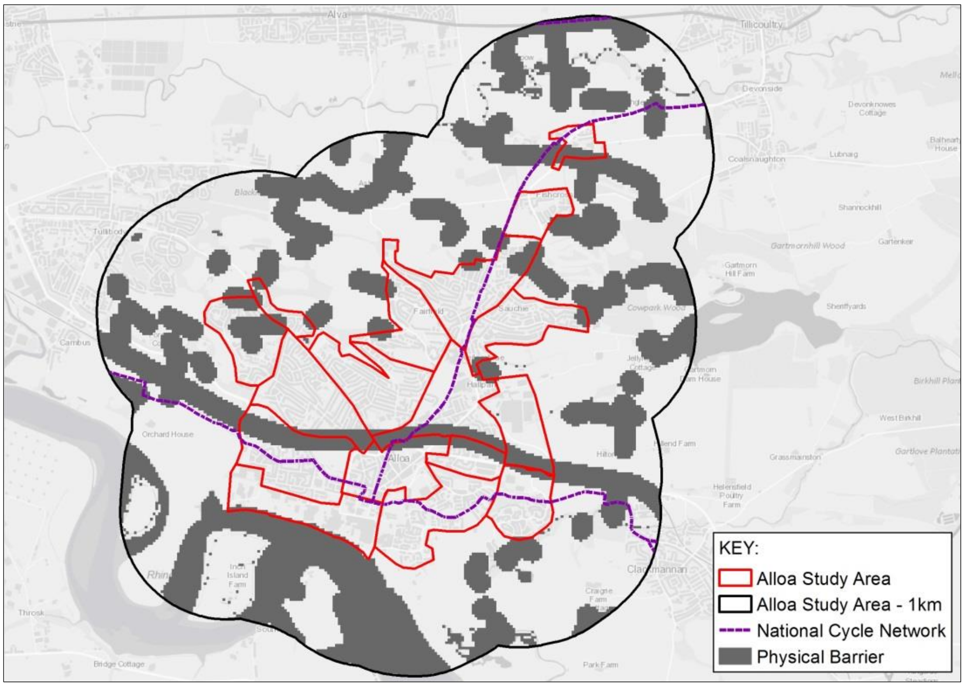
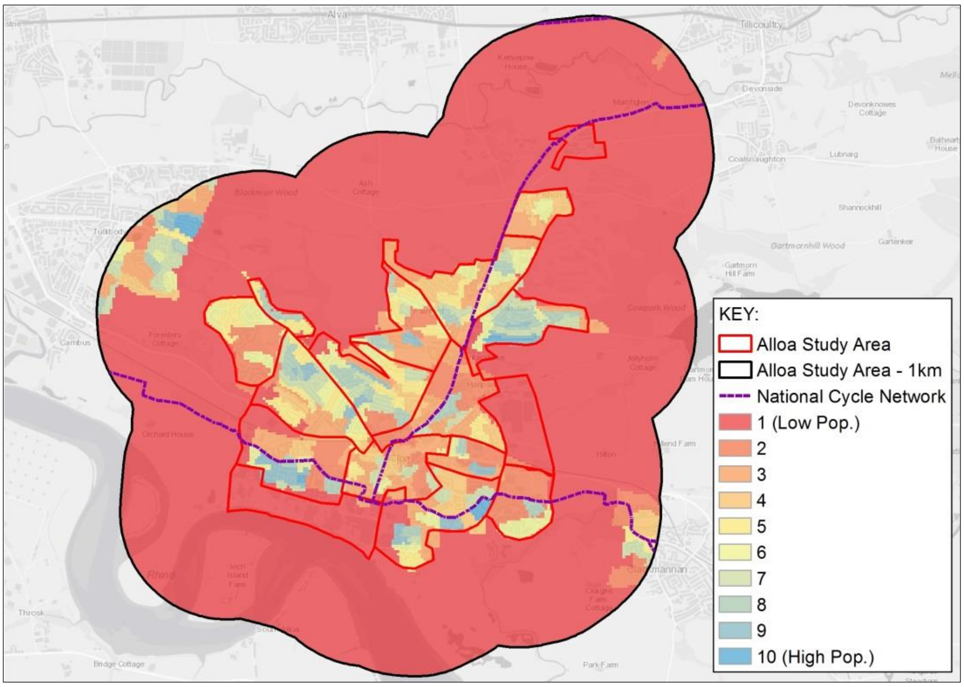
Once each raster was reclassified to a common scale they were then combined to produce a composite raster layer representing the overall CPT for the AoI. As part of this step it was also possible to weight each layer based on their relative importance.

On completion of the weighted overlay process the results were assessed against the manual results produced for the pilot area which is discussed in more detail in the next section.

3 Results

The following table presents the results of each step of the MCA process introduced in the previous section. The results are provided as individual maps produced for each of the criteria introduced in Table 1. Note that the results were based on the output areas that make up the Alloa settlement which was buffered by 1km to capture any features located on the borders. In addition, for simplicity, only existing National Cycle Networks were considered and no other OS roads or paths were incorporated into the network.

Table 4 – Automated cycling potential outputs

Criteria	*Manual Assessment*
Physical Barriers	
Population Density	

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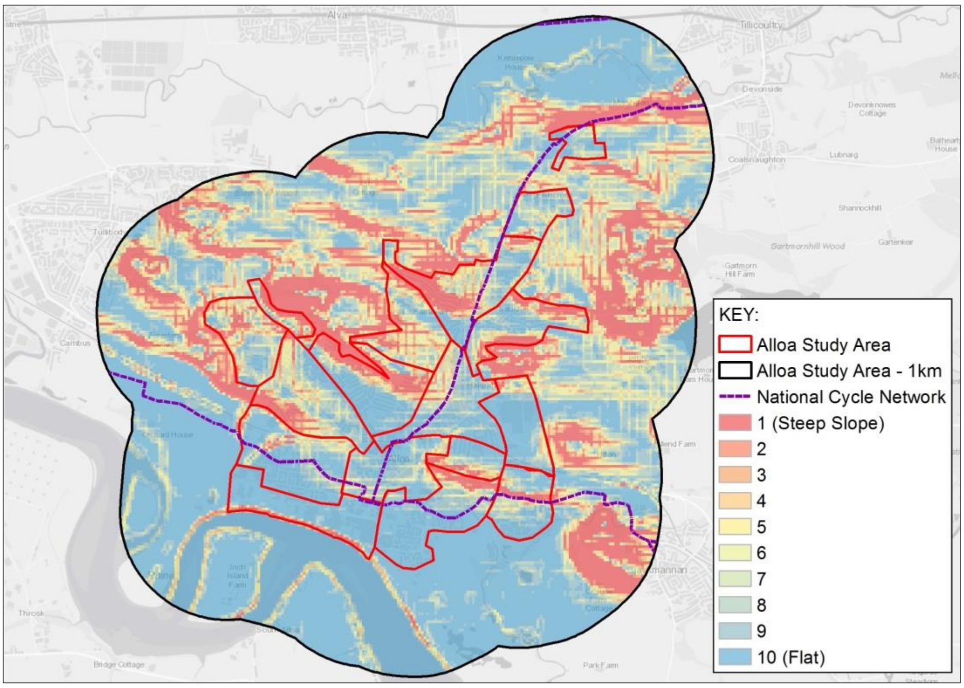

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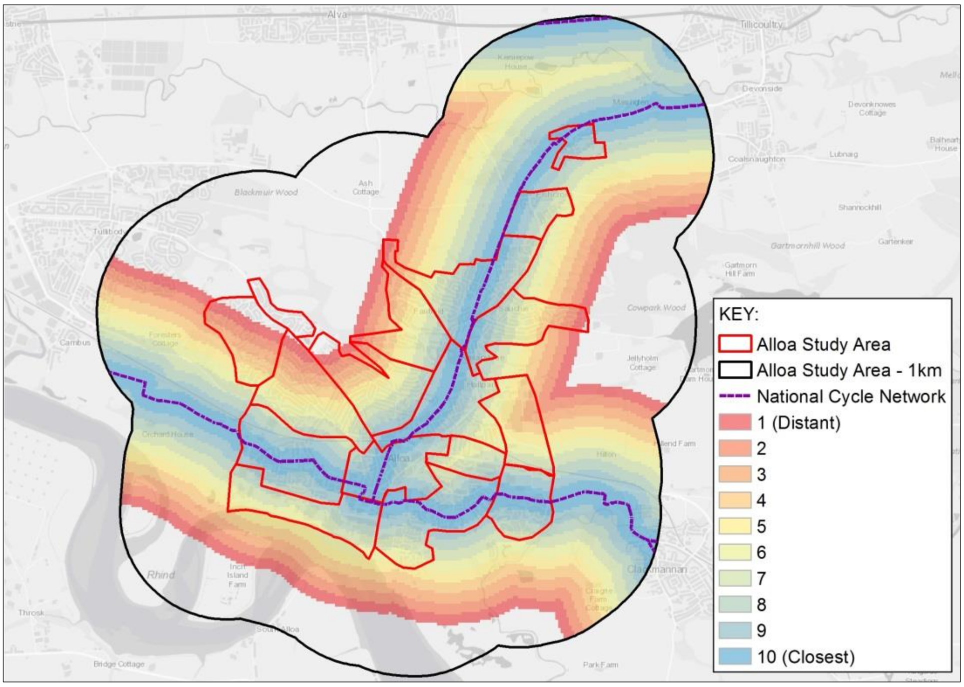

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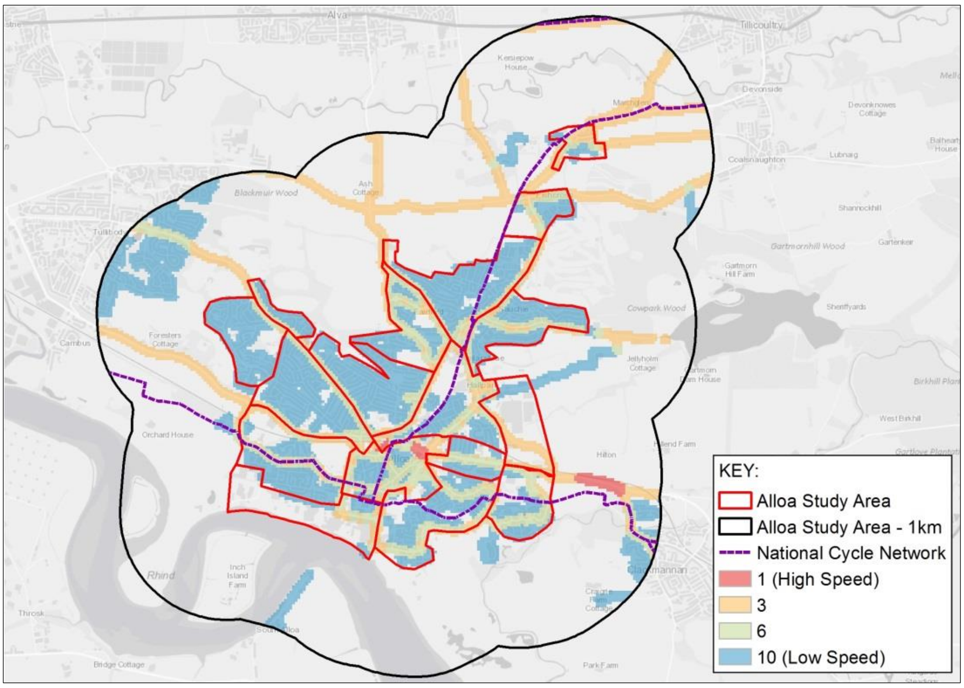
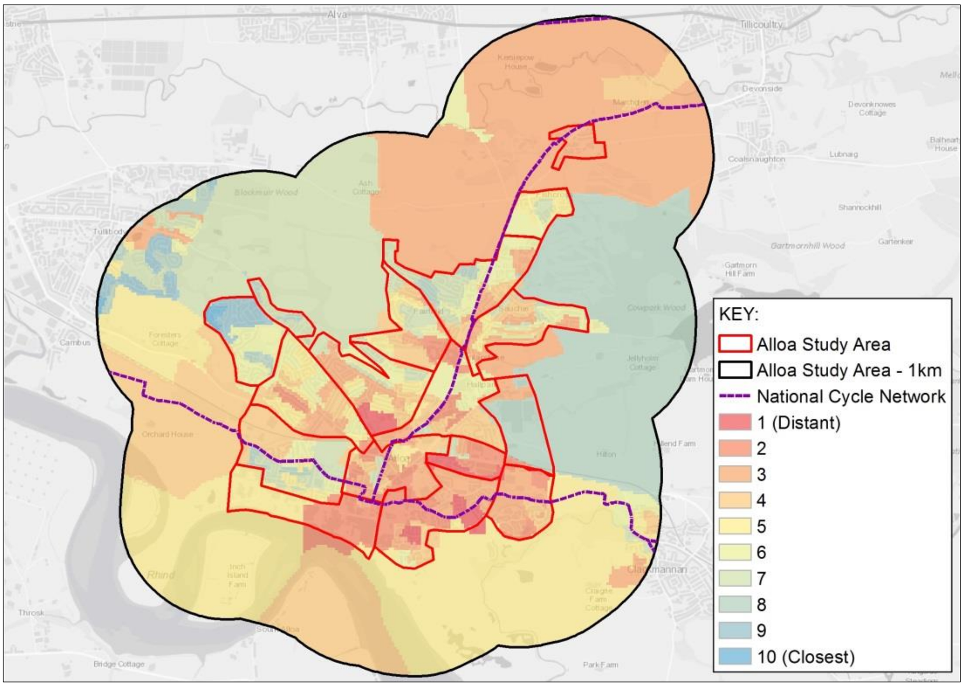
Average Road Speed	
Distance to Work	

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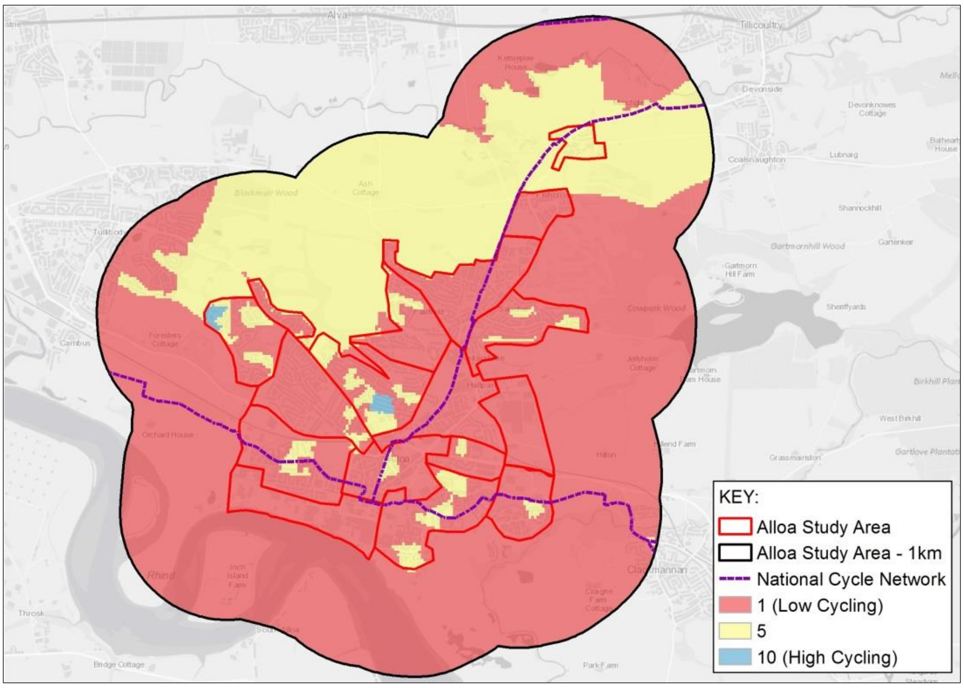
<td>
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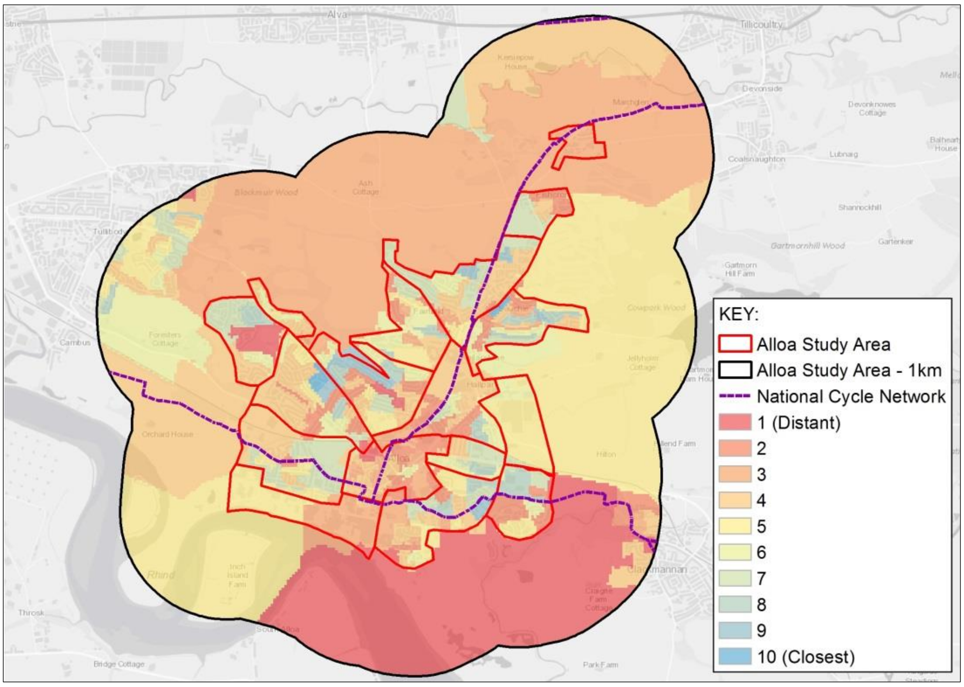
<td>
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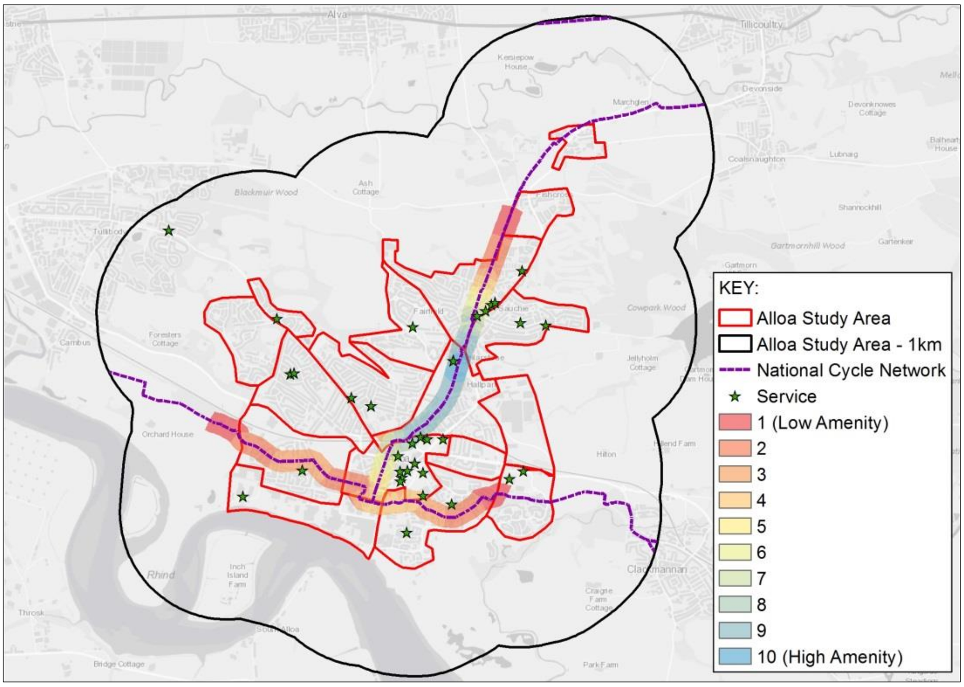
<tr><td>Access to Services</td><td>
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4 Discussion & conclusion

To assess the benefits and limitations of the automated toolset two levels of validation were completed:

1. Based on the results displayed in the previous section, the outputs from the Alloa pilot study were compared to the manual approach to ensure that the automated assessment performed as expected.
2. To test the CPT in other locations, CS applied the process on a number of areas put forward by their partners. Feedback was then received by each partner which identified any further benefits and weaknesses.

The following sections discuss the outcomes of these two validation exercises.

4.1 Comparison of the manual and automated processes on Alloa

With reference to table 5, the manual version of the CPT process highlighted the South and South-West of Alloa as having the highest levels of CPT. (Areas 9, 10, 15 and 16 on the plan)

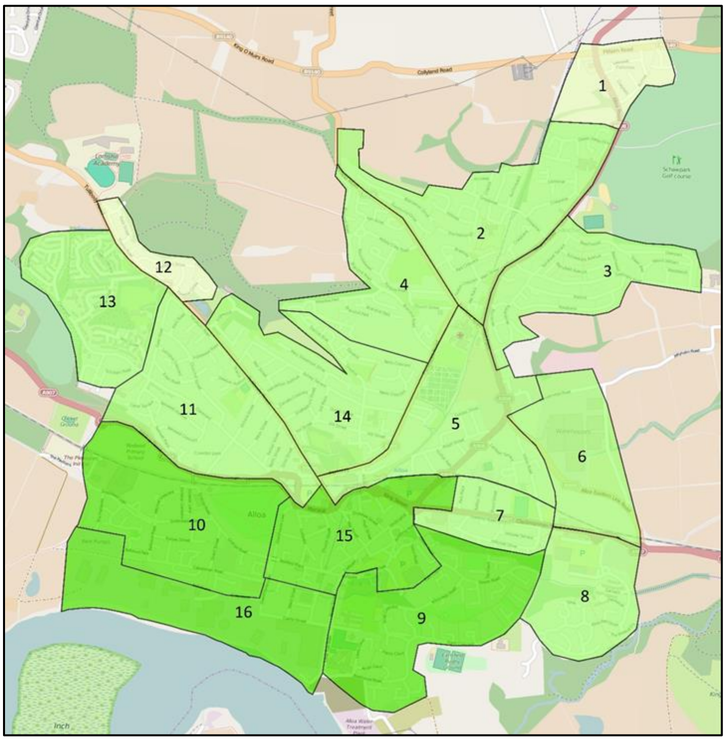
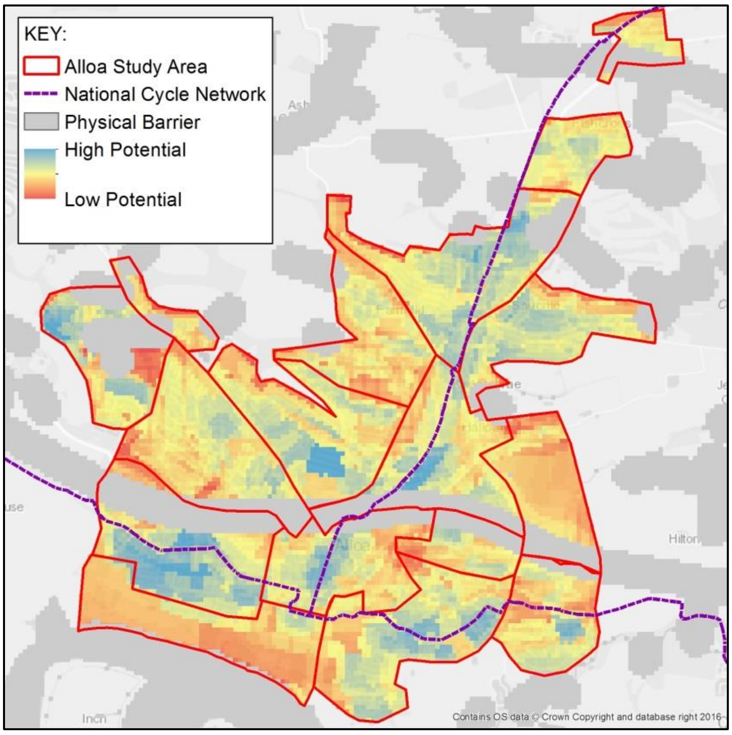
When the automated version of the tool was tested on Alloa it produced similar results. The majority of the high potential areas are located in what would have been areas 9, 10 and 15 in the old model. It also highlights some local variations which the manual version could not have picked up, such as the impact that the NCN route has on the potential of an area as it travels north through areas 5 and 2.

4.2 Partner feedback

Following the application of the CPT tool on a number of partner specified locations, CS received feedback on the tool and on the outputs that were automatically produced.

On the whole the key benefit identified by the partners was CPT's ability view multiple aspects of cycling potential in a single map therefore providing a wider evidence base on the subject. In terms of limitations the main comment related to assessing impacts of changing the network. Specifically, a small section of cycle network was judged to be unsuitable and it was recommended by the partner that it was removed from the process. It was found upon doing this that the removal of the section did not particularly impact the cycling potential of that area. This was useful feedback as the tool had not been tested to this length previously with regard to impacts relating to changes in the network. As a result, this feedback, particularly on network impact, was used to influence the next phase of development. This led to the production of the 'Quality of Service' process (discussed further in this section) which re-focussed the tool on the existing network and examined a range of criteria around the network's quality ensuring that it has a greater influence on the cycling potential of an area.

Table 5 - Manual vs. automated approach

Cycling Potential (Manual) – • *Dark Green = Greatest Potential* • *Light Green = Least Potential*	
Cycling Potential (Automated)	

4.3 Overall benefits of the model

There are a wide range of benefits that have been gained from automating the Cycling Potential process in GIS. The most impactful benefit of these is the speed at which the process can be completed. This allows greater access to, and more widespread use of, the tool as it requires fewer resources to analyse each area. This was clearly shown when looking at the original pilot area of Alloa, before the automation was in place running the environmental module throughout the local authority took over a month. Once the automation was in place and tested again on the same pilot area, the work was completed within a working day. The improved completion time has increased the use of CPT, which has led to the tool informing understanding in Clackmannanshire and elsewhere.

Another considerable benefit of automating the process in GIS was the ability to add additional resolution to the tool and calculate more accurate and refined results. Prior to automation, analysis was completed in user defined polygonal areas which were each assigned a single score. However with the application of more advanced techniques analysis was complete down to a 1m cell resolution which allowed results to be far more detailed and show local variation which may have otherwise been missed.

In terms of enhancing CPT further, other GIS based datasets can be overlaid to identify correlations between cycling potential and other such policy areas such as, socio-demographics, deprivation indices, air quality and other environmental aspects not currently considered in the model.

4.4 Overall limitations of the model

There are limitations to CPT, as with any tool to aid decision making, in achieving a balance between capturing real-world complexities and providing an easy-to-understand conclusion. The application of the models requires an in-depth knowledge of GIS systems and is an essential pre-requisite for the end-user running the tool. Furthermore, it was found that the methodology and workings of the tool was difficult to explain to partners reducing transparency and therefore a genuine understanding of what the tool is doing.

To contend with this lack in transparency an extensive user guide for the tool was produced which guides the end user through the process and lowers the barrier to entry. This ensures that someone who has no technical knowledge can still see the benefits that can be gained from using the CPT tool.

4.5 Subsequent developments

Since the initial development of CPT as presented in this paper, a wide range of improvements have been developed. This improvement focuses on making Quality of Service (QoS) for the existing cycle network the primary base criteria for the model, therefore ensuring any change in this network are indicated more effectively in the final output. Further details on the QoS concept and a number of other improvements are detailed as follows:

- ***Quality of Service:*** The QoS approach allows for the existing cycle network to be modelled using GIS techniques. QoS is made up of the following criteria, each having an influence on the potential cycling experience:

    - Surface Quality – details the quality of the cycling surface i.e. its ease to cycle upon and lack of objects such as manhole covers or other ironworks.
    - Number of adjacent cyclists – details the number of cyclists that can cycle adjacent to each other i.e. the width of the route allowing a greater volume of cyclists;
    - Number of conflicts – details the quantity of conflicting objects the cyclist may come into contact with along the route e.g. entrances to petrol stations and retail centres, bus stops located within cycle facilities, side roads, signalised junctions, parking areas taxi ranks, and loading bays.

- ➢ Junction time delay – the noticeable delay in which cyclists experience at junctions and crossings.
- ➢ Traffic Comfort – details the cycle route typology e.g. off road routes are considered the most preferable compared to on road or shared bus lane alternatives.

Once the above criteria were adapted into GIS layers, it was possible to calculate and overall QoS for each cycle route which was subsequently integrated into the environmental module accordingly.

- ***Origin and Destination*** - Based on the Data Zone census information dataset, an additional model was developed to determine whether once on the existing network (i.e. within the users origin data zone) is it possible to complete a journey along the network to a place of work (i.e. the destination data zone). This process was useful in identifying locations that had good cycle network access but also allowed those to use the network to facilitate their journey to work.

- ***Potential Cycle Numbers*** - Applying the results of the 2011 census, a method was developed that relies on a number of assumptions and estimations and takes population, mode and travel distance and determines how many people could potentially cycle. This potential number of people can then be compared to the baseline situation to estimate the net increase in cyclists. Subsequently, this potential increase in cycle numbers can then be used to calculate the beneficial impact on other metrics such as carbon reduction health etc.

The application of the above additional tools has allowed for further analysis which we would not otherwise have been able to feasibly complete using manual methods. This has added additional benefit to the tool and shows partners the quality of infrastructure, where people are currently travelling within their settlements and the number of people that could actually make use of the network which, in line with the cycling potential of an area, could potentially help target locations for new infrastructure and other intervention in further development plans.

Furthermore, using more complex GIS methods and automation also allows there to be many more directions in which the tool can develop due to the wide range of data, spatial and network analysis tools that are present in GIS software, many of which could not easily be done manually.

5 References

Analysis of Cycling Potential, Transport for London (2010) - http://content.tfl.gov.uk/analysis-of-cycling-potential.pdf

Measuring Outcomes – Robust Methods for Monitoring Cycling in Scotland, MVA Consultancy (2013) - http://www.cyclingscotland.org/wp-content/uploads/2015/03/20130110-Monitoring-Cycle-Use-Report-FINAL-January-2013.pdf

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