Northumbria Research Link

Momentum integration: the syntax of cycling

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Abstract

Cycling has long been known to have significant physical and mental health benefits for its participants. It has the potential to significantly reduce the carbon footprint of a city, increase personal mobility, improve transportation equality, improve air quality, and reduce congestion. While cycling has seen a major increase over the recent past, it is still a relatively small proportion of overall transportation. One significant factor in inhibiting the growth of cycling in many UK cities has been the lack of sufficient dedicated cycle routes. This deficiency is partly due to the lack of any recognized method of forecasting the practicability of future dedicated cycle lane provision.

Historically, the prediction of movement rates for cyclists, using space syntax methods, has been weaker than that achieved for pedestrian rates. This paper theorizes that cyclists' route choice is primarily dominated by the momentum of the cyclist rather than route complexity. In this paper we introduce momentum integration as an alternative mechanism to understand cyclist movement. Momentum integration unifies multiple aspects of movement (specifically angular complexity, elevation change, traffic lights position) into a singular system, which can be computed using traditional syntax methods.

This paper describes the methods of momentum integration and introduces new software known as 'Momentum Mercury', which uses open source, centre-line data to compute momentum integration maps. The paper then continues to produce a movement rate analysis comparison between traditional space syntax methods and momentum integration using a survey of

cycle usage in a major UK city. Analysis of this data shows that they are momentum method improves upon previous pedestrian correlation.

Keywords: Keywords: Transport planning, Cycling and pedestrian movement studies, momentum

Introduction

Over the last 10 years there has been a spectacular growth in utility cycling In Europe and other countries. Utility cycling is the use of a bicycle as a means of transport for non-exercise or leisure activities. This includes cycling as a means of commuting both to school and work, and also includes travel to use local facilities such as retail and entertainment, as well as social journeys to visit friends and relatives. Utility cycling differs from an aligned term used in the health community of 'active commuting' as it does not include walking and includes non work trips. In this paper we do not include the use of cycling to deliver goods and services (such as courier services, Velotaxis and cycle freight based delivery) as utility cycling.

Benefits of cycling

The benefits of utility cycling has been extensively researched (Fraser & Lock 2010). This type of non‐exercise activity thermogenesis (NEAT) (Levine et al. 1999) expenditure is known to have significant long-term health benefits (Oja et al. 2011). There have been a number of studies which have shown that utility cycling or active commuting reduces the risk of cardiovascular events (heart attacks) (Oja et al. 2011)(Garrard et al. 2012) Type II diabetes, hypertension, improved fitness and decreases in cancer risk including colon cancer. Gordon-Larsen et al. reported '*Active commuting was positively associated with fitness in men and women and inversely associated with BMI, obesity, triglyceride levels, blood pressure, and insulin level in me*n' (Gordon-Larsen et al. 2009). It is because of these benefits that health studies like those of Woodcock (Woodcock et al. 2009) suggest that active commuting has extensive health benefits for cities beyond that achievable by the introduction of low emission vehicles. Obesity is one of the leading preventable causes of death worldwide (Barness et al. 2007)(Mokdad et al.

2004)(Allison et al. 1999). This has been largely attributed to changes in diet and a move towards a more sedentary lifestyle (Kopelman et al. 2009)(Seidell 2005). Studies such as (Bassett Jr et al. 2008)(Wen et al. 2006), has shown that utility cycling or active transport has been associated with reduced levels of obesity, as well has having positive effects on body fat markers and body mass gain (Wagner et al. 2001). One major constraint on the participation in physical activity has generally been reported as lack of time or money to engage in organized sports or fitness programs or other structured exercise programs (Trost et al. 2002)(Kavanagh et al. 2012)(Bauman et al. 2008) [i]. Utility cycling overcomes this barrier by introducing small amounts of regular exercise and interleaving it with commuting tasks. This also has positive benefits with adherence to the maintenance of a regime of regular exercise. (Hillsdon & Thorogood 1996) Reported that activities that become part of everyday life are more likely to be sustained than those that require attendance at specific venues.

Beyond health there are other benefits gained by a switch to the use of cycling is transportation. In the UK, government figures assert that transportation is responsible for 27% of green house gas emissions[ii] with domestic cars and taxis representing 58% of domestic, transportation-related CO2 production. If a significant switch to cycling from road transport could be achieved then this could be a significant contribution to the reduction in energy and pollution. Undoubtably congestion to could also be relieved if a large switch to cycling could be achieved.

TfL research shows that 61% of Central London journeys can easily be cycled". These benefits have led the UK government, amongst others, to promote cycling as '*the natural choice for shorter journeys, or as part of a longer journey, regardless of age, gender, fitness level or income' and* set the ambition '*To double cycling, where cycling activity is measured as the estimated total number of bicycle stages made each year, from 0.8 billion stages in 2013 to 1.6 billion stages*' [iii]

The importance of separated cycle paths to increase cycle mode switch
In the UK, driving led to the death of 1,850 people and 208,648 casualties in 2010. 45% of these deaths were of car occupants.[iv] [v]A substantial increase in

utility cycling on segregated tracks may lead to a reduction in car usage and hence to a long term reduction in these figures.

Walking and cycling carry a 5 to 10 times higher risk of injury per kilometer travelled than driving in a car (World Health Organization 2009)(Elvik 2009). The British Medical Association published a study identifying the health benefits of cycling as 20 times the injury risks (British Medical Association et al. 1992) . Despite this, the perception of safety remains an important consideration for an individual's journey mode split. In a report, TfL suggested that provision of a suitably located cycle route would be an important factor in the travel mode split by reporting '*Between two and three in ten of those cycling on these [Barclays Cycle Superhighway] routes had switched to cycling their trip as a result of the scheme*' [vi]. In a study to walking and cycling, (Pooley et al. 2011) Pooley suggested that '*poor safety was one of the key reasons for not cycling expressed by approximately 80% of respondents*'.

Studies such as (Buehler & Pucher 2012) suggest that cities in the USA with a greater supply of bike paths and lanes have significantly higher bike commute rates—even when controlling for land use, climate, socioeconomic factors, gasoline prices, public transport supply, and cycling safety. Studies of the lessons learned from cycling in Holland, Denmark and Germany show that cycle lane provision is one of the key factors involved in the promotion of cycling in these countries (Pucher & Buehler 2008). If we wish to promote cycling as an activity for younger people, who are also at risk of obesity, then it seems important that segregated facilities are designed into the urban fabric they use.

Current UK spending per head of population on cycle lane provision is relatively low. Given the exemplar of government spending on major structural transportation projects such as Crossrail and the high speed rail route, HS2, it is clear that transport can attract considerable capital. Given the very high benefit-to-cost ratio described above and the very low per-mile cost of cycle lane provision it seems necessary to look elsewhere to explain the low

funding provision of cycle lanes in the UK. We would like to take space in this paper to suggest that one of the barriers to the introduction of cycle lanes into major UK urban cities is the lack of planning tools. Vehicular traffic planning has the benefit of well-developed analytic tools, which allow accurate predictions of traffic flows for given network proposals. This permits the control of risk on high capital expenditure road building projects. By comparison there are no such tools at the level of cycle lane provision (Taylor & Davis 1999). While there are excellent resources on the design of the material qualities of cycle lanes, we would argue that there is no equivalent, empirically tested resource at the strategic level. The objective of our current research is to establish the underlying theoretic methods to allow accurate forecasting of cycle lane usage. We hope by doing this we will be able to shift the burden of design from intuition to scientific analysis.

Previous work

It seems natural that to create a cycle usage prediction model it is reasonable to begin by extending from another field. From a theoretical basis given that drivers are free to engage in discretionary travel behavior and free route choice, The two closest models are that of vehicular transport (Smith et al. 1995) and pedestrian movement (Hillier & Iida 2005).

Current transportation theories have been applied to cycle usage (Turner et al. 1997). While it seems natural to regard a cyclist as a very small slow car, the methodologies used for vehicular traffic have some practical problems when applied to utility cycling. On a practical basis there is the difficulty of collecting sufficient data of existing cyclists to make accurate urban models. Additionally it is well known that the current cycling population is a radically different demographic to that of the general public (and the target of utility cycling). Current urban cyclists, sometimes dismissively known as the 'lycra generation', are typically young male, risk-taking, licensed drivers (Daley & Rissel 2011). Data obtained from the use of rented bicycles in London clearly shows a different spatial usage primarily indicated by gender (Beecham & Wood 2014). As such, stopping and interviewing current cyclists is questionable in terms of its accuracy of predicting wider population behaviors. On a more theoretic ground, the four-step model algorithms fundamentally

assume that distance or rather time is one of the fundamental influences on driver behavior via the impedance function (Turner et al. 1997). We would argue that, in the case of London, given that many trips would already be quicker by bicycle, then journey time clearly isn't the dominating factor. We would also like to suggest that most traffic models assume that congestion is already a significant problem. For cyclists, at present, congestion from other cyclists or drivers isn't a principal deciding factor.

The alternative process is to begin to consider a cyclist as a 'fast' pedestrian. This has been the basis of previous consideration by the field of space syntax (McCahil & Garrick 2008). There has already been work done by Radford (Raford et al. 2007)(Raford et al. 2005) suggesting a strong correlation with aggregate movement methods using a multiple variable regression framework Further, Radford's work suggested route choices for an individual cyclist are not consistent with taking the metric shortest path or the topologically shortest path.

Law et. al. (Law et al. n.d.) investigated a multiple regression model including a number of factors of which the most significant was that of Normalized Choice Radius N and Presence of the London Cycle Superhighway. While they reported a correlation of .62 adjusted R-square between observed cyclist movement and their predictive values it seems natural to object to the underlying theoretical position. Any model based on a linear regression model suggests an independence between elements of a route choice. Traditionally space syntax has promoted the use of a 'global' and holistic approach to a route choice, which a multiple regression model cannot represent. Take, for example, a cyclist traveling from North London over the river to South London. The multiple regression model suggests that the presence of a perfect cycling super highway, meticulously maintained and pleasantly aligned with a number of attractive features on a dead end leading to the rivers edge would attract cyclists to it which clearly is not so. If we consider changes of elevation the direction of travel is an important factor in this. Multiple regression can only look at a segment in isolation and can have no knowledge of whether the cyclist is going up or down hill, regression can take no account of the direction

of movement and the resultant asymmetries (Dalton 2003). We would argue that the presence of cycle lane provision, no matter the quality, would not influence many cyclists, if it were not part of a viable route choice. So while the presence of facilities may cause cyclists to switch from other routes (and implicitly defect from other forms of transport) it cannot be considered in isolation of the wider configurational properties as is assumed in regression. We would argue it is this lack of consideration of deep structural issues, which suggests that a more structural approach to the understanding of cycle route choice is required.

Previous work by (Asami et al. 2003) introduced the notion of 'extended axial curves' to permit the integration of changes of elevation in the space syntax graph representations. While promising, this work was principally centred on the notion of neighbourhood and differs from the momentum method by having a different purpose and using the axial line as the core representation. The extended axial curve method primarily uses breaks in co-visibility as the principle method of function rather than changes in elevation as this paper argues is important when considering cycling. In a similar vein (Jiang & Claramunt 2002) proposed a new method of node-based integration which could include elevation information but failed to present any empirical data on either pedestrian movement or cycling which might justify the approach.

The momentum method

In this paper we would like to suggest that a cyclist is neither a slow car nor a fast pedestrian. We would suggest that the mental models used by cyclists are unique to that particular form of transport and are not adequately understood in all their subtleties by extensions from other models or other models augmented by multiple regression. In Fajans et al.'s paper (Fajans & Curry 2001) they suggest that a cyclist's frame of mind is dominated by the energy expenditure they must make to reach somewhere. From experience, for a cyclist travelling along a long flat well-maintained surface, distance is suddenly a much less significant factor. What then does limit behavior while cycling? Steep inclines were identified in a meta study by (Fraser & Lock 2011) as an environmental factor negatively associated with cycling. There

have also been several ad hoc reports of cyclists not stopping at traffic lights. Our working hypothesis is that cyclists resemble early steam engines: that it is the power-to-weight ratio which is limited whereas rolling resistance is not. From this point of view, it is gradient change which is a influence on route choice, as is the necessity to stop and start. By integrating several route factors into the graph-theoretic structure of space syntax what we are attempting to do is to merge the factors that are normally applied retrospectively via multiple regression and knit them into the global structural framework. Using the above example, the presence of an incredibly flat and traffic light free dead end would have little contribution to the wider scale structure.

We have produced a model that we call the momentum model, That is, route choices are dominated by the avoidance of shifts in acceleration or the desire to preserve momentum. This model holds at its core three primary elements: changes in direction, which maps back to the space syntax notion of least angular change; changes in elevation or gradient, a factor mentioned by (Fraser & Lock 2011) in relation to route choice; presence of traffic lights and other junctions. This suggests that if two paths exist, from the same origin to the same destination, that the cyclist would prefer the one with a lower *potential probability* for the necessity to stop (either for traffic lights or other traffic). This, in theory, partly explains the phenomena of cyclist preference for the use of London's canal cycle paths and the success of 'rails to trails' in the USA (since, by their origins, they are flat and contain no traffic lights).

In this paper we have taken the initial concept of momentum to be a linear combination of elements. So the 'distance' from node A to node B is

$$D_{ab} = k_a \alpha_{ab} + k_g G_{ab} + k_t T_{ab}$$

Equation 1

Where $k_a \alpha_{ab}$ is the angular distance from node A to node B as commonly used in space syntax. $k_g G_{ab}$ is the change in elevational distance between A and B, and $k_t T_{ab}$ is the number of traffic lights and junctions encountered

between A and B. k_a k_g k_t are effectively combinations of weights and conversion factors.

From this perspective it is possible to compute the equivalent of momentum integration and momentum choice. Given d_{ik} which is the distance of shortest route by considering the path with the minimum distance D_{ik} Momentum Integration (M$_c$) can be considered as:

$$M_c(P_i) = \left(\sum_k d_{ik}\right)^{-1}$$

Equivalently Momentum Choice (M$_b$) can be considered as:

$$M_b(P_i) = \sum_j \sum_k g_{ik}(p_i)/g_{jk}(j < k)$$

In this paper, we have not used the normalized angular choice of (Hillier et al 2012), but given that the measures break the fundamental assumptions for the normalization of choice we have instead elected to use the more general formulation of local relativisation by using both vicinity (Dalton 2006) and depth decay (Conroy Dalton & Dalton 2007). Technically given the current lack of relativisation this then should not be regarded as Momentum momentum integration & Momentum choice, but momentum centrality and momentum betweenness. However future work will introduce relativisation of the total momentum day and at that point the mentum integration label will be accurate. Momentum integration also seems to siting near the dividing line between the theoretic measures and simulation. The system certainly includes a description of cyclist mentality (minimizing change in momentum) yet at the same time it does not use the Montecarlo sampling method typical of much simulation research. From this point of view we would regard the system as still being largely theoretic in nature.

We wrote specifically designed software called Momentum Mercury to implement these calculations. This software uses open source, Open Street Map data using road centerlines (Haklay & Weber 2008). While road

centerline data has only a colloquial definition and while the road centerline data is not reproducible (no two people will digitize road centerlines of the same area in the same way), road centerline data is commonly available for almost all urban locations and is commonly used in many traffic route guidance programs/Apps/devices. As such, while road centerline data is a poor substitute for the more theoretically sound axial maps, it does permit us to geolocate the road segments which permits cross referencing the position of traffic lights and the presence of cycle lanes. While open street map data does not contain elevation information this can be derived from Shuttle Radar Topography Mission (SRTM) (Farr et al. 2007) data. It is reasonable to use digital elevation model data (DEM), since it has a fairly high resolution (1 arc-second, or around 25 meters, for the United States, and 3 arc-second, or around 90 meters at the equator, for the rest of the world), has near-global coverage (from 56°S to 60°N), and is in the public domain. While both the road centerline and digital elevation data is coarse it does permit a comparative analysis of traditional space syntax measures against momentum integration using movement observations.

Momentum Mercury software.

The Momentum Mercury software allows regions of open street map data to be imported along with the appropriate SRTM elevation data. The software is written in the Java language permitting cross platform usage of the tool, see figure 1 for an image of the software in use. The software is capable of reading sections of exported Open Street Map data (Haklay & Weber 2008) and future work is planned to extend the importing mechanism to import higher quality road centerline and elevation data. Momentum Mercury imports both road centerline, rail, underground rail (light grey in figure 1) and building outline data (black figure 1). The system uses advanced Binary Partition tree data structures (Thibault & Naylor 1987) to permit real time interaction with multi-gigabyte data using a fluid and uncluttered zoomable user interface (ZUI)(Bederson et al. 2000). Interaction is via intention base menus on the top left corner augmented by command key combinations. For the images presented in this paper all the information has been transformed using the

Web-Mercator (Favretto 2014) transformation from their original latitude and longitude data. All data for this paper was processed on a 2.3 GHz Intel Core i7 Macbook Pro.
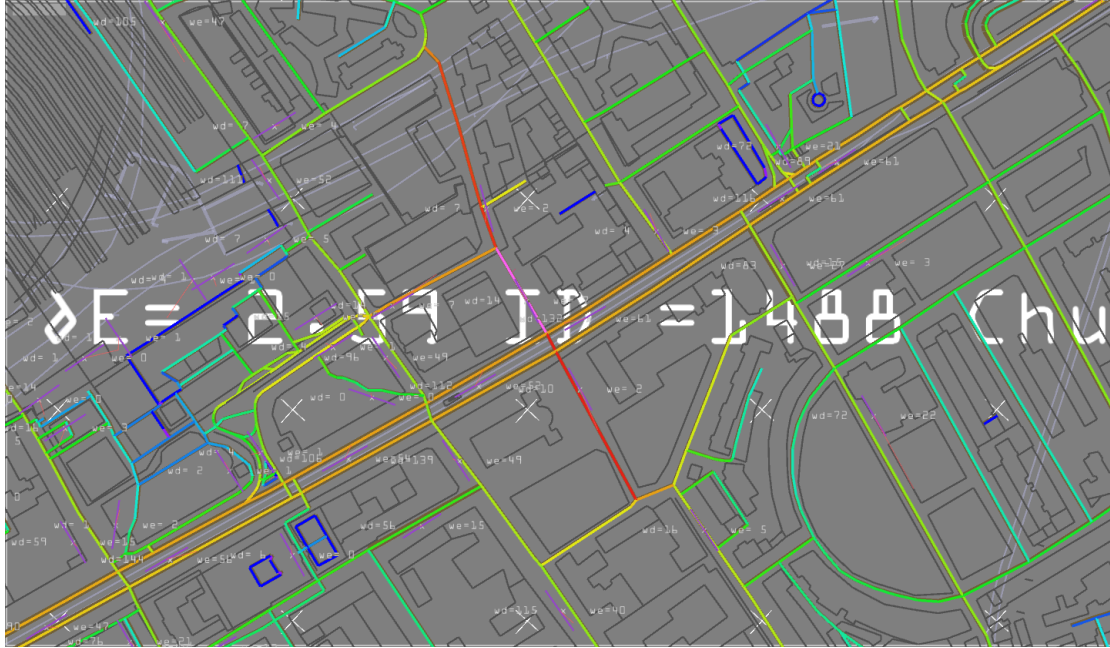

Figure. 1 section of open street data coloured by angular step depth from origin

Fig. 1 shows an angular segmental map taken from open street map data. These segments have been interconnected at junctions with any turning restrictions ignored. In the figure, a segment in Charlton Street has been selected (pink). The segments are coloured by angular depth from the selected segment (pink). With red representing zero depth through the spectrum to blue as maximum depth (Magenta is used for segments beyond current radius or are unconnected from the system). Grey lines represent building walls or rail tracks. Purple unconnected segments, with numbers, represent cycle observations.

Figure 2. Traffic lights

Fig. 2 shows yellow, open circles representing the locations of traffic lights in the test area. The map has been coloured by depth from the pink starting segment. As can be seen from the image, the (red) segment above the starting segment (pink) is at depth zero (red) while the depth below the segment (green) is at an increased depth due to the necessity to stop at traffic lights to reach it.

Figure 3. Elevation

Fig. 3 shows elevation information plotted at junctions as filled circles. Here we can see depth gain is limited below the selected segment as this requires the cyclist to gain elevation after crossing the Euston Road (large, two-lane left-to-right diagonal). Above the selecting segment, red represents the loss of elevation. Elevation points are plotted form lowest (red) to highest (blue). In Mercury Momentum, elevation loss (going down hill) is regarded as a zero change in elevation. This is partly to avoid negative weights on segments and partly to represent the fact that energy cannot be 'absorbed' by a cyclist.
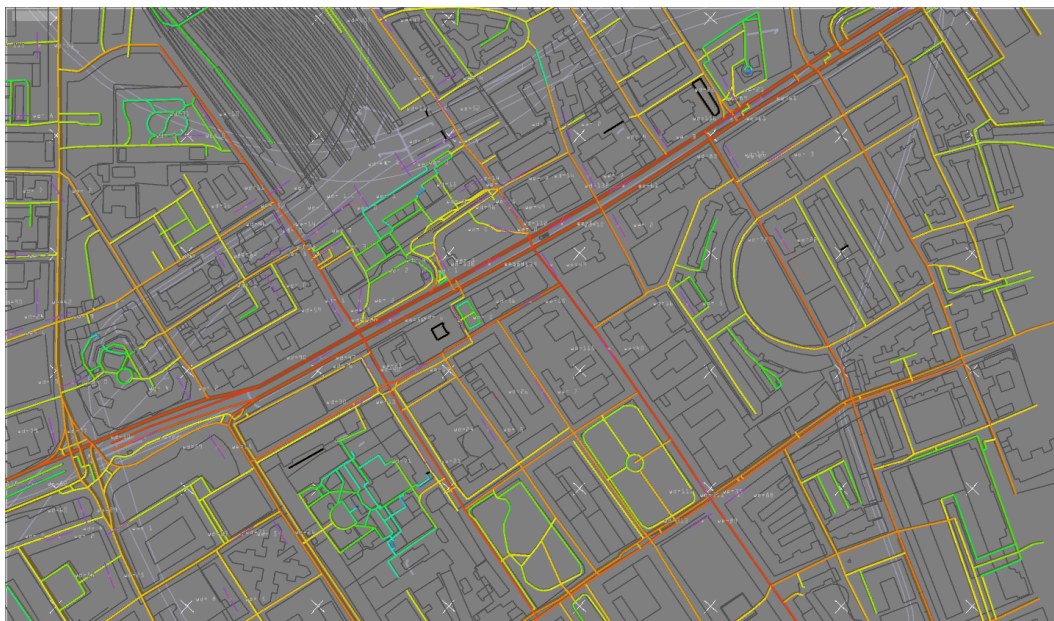

Figure.4 Segmental Angular Integration of the central London area used.

Fig. 4 shows an angular segment integration map of central London based around the Euston Train station (the centre of the software-training observations). Using the standard colour scheme introduced in Axman (Dalton 1997), and Depthmap (Turner 2004), the global integration core can be seen to be focused on Euston road (the long red diagonal). Open Street Map errors, where building outlines have been miss-labeled as road centerlines, can be see adjacent to Euston Road on figure 4. as thick black lines. As with any analysis using road centerline data, errors in base line data can be reduced but not fully eliminated by automatic means. One of the dangers of using road centerline data over axial maps data is the lack of data provenance and quality control found in normal axial models.

EVALUATION

The hypothesis of this evaluation is that a system of momentum integration, which incorporates both elevation and the presence of traffic lights should predict better, in a manner which reflects reality to a greater degree, than a simple regression model.

In this evaluation we used cycle observation data kindly supplied by Space Syntax Ltd. This geo-located data represented a number of high quality studies taken at number of locations within London. The observations were supplied as geo-located data attached to segments. While the data was collected for many periods over a day with separate observations for weekdays and weekends, in this analysis the weekday averages were used. The observations were made using the gate counting method. Gate count observations are parsed from GML data and allocated to the nearest segment within a limiting radius of 10m.

In this pilot study, we used a method of segmental integration as the primary means of syntactical computation. It was known in advance that the parameter estimation procedure would require multiple runs of the model to get accurate results. Segmental Integration was chosen as a computationally rapid method, which was also a simple enough method to verify as correct. While a method similar to angular choice (Turner & Dalton 2005) but including traffic lights and elevation would undoubtedly produce more accurate results it would be computationally more intensive and time consuming in this early evaluative period. Angular integration is known to strongly correlate with Angular Choice and the use of Angular integration, as the basis of this paper, should be seen as an initial probe into a more complex methodology.

Clearly, to perform an evaluation, it is necessary to fix the values of both k_a, k_g and k_t. To do this we split observation data into two components, the set Q which would be used to fix the values of both k_a, k_g and k_t and W which would be used to evaluate the final outcome. It should be noted that $Q \cap W =$

$\emptyset$ and $Q \cup W = P$ were P is the entire data set. To create the parameter set Q observations of daytime movements were selected from the observation datasets P. To ensure observational consistency we began with a set around Euston station as the training set. In this case we used 93 observations. We used a method of linear gradient descent to optimize the parameters R, k_g and k_t (R is the angular radius k_g and k_t weights on gradient and traffic lights) against observed cycle movement leaving $k_a = 1$. To optimize, we looked at both the Person's r-squared and Spearman's Rank Correlation Coefficient rho between observed movement and the weighted contributions of angular integration, elevation and traffic factor. Spearman's Rank Correlation coefficient is less sensitive to outliers and power factors (linear, square or log) and is a good indicator of underlying methods. Once the reasonable value was established, a high discrepancy between the Pearson and Spearman factors (0.4 and 0.696) led us to look at the model produced. By plotting, we adjusted the model to work with the log of observation and the reciprocal of normalized total depth (i.e. angular integration).

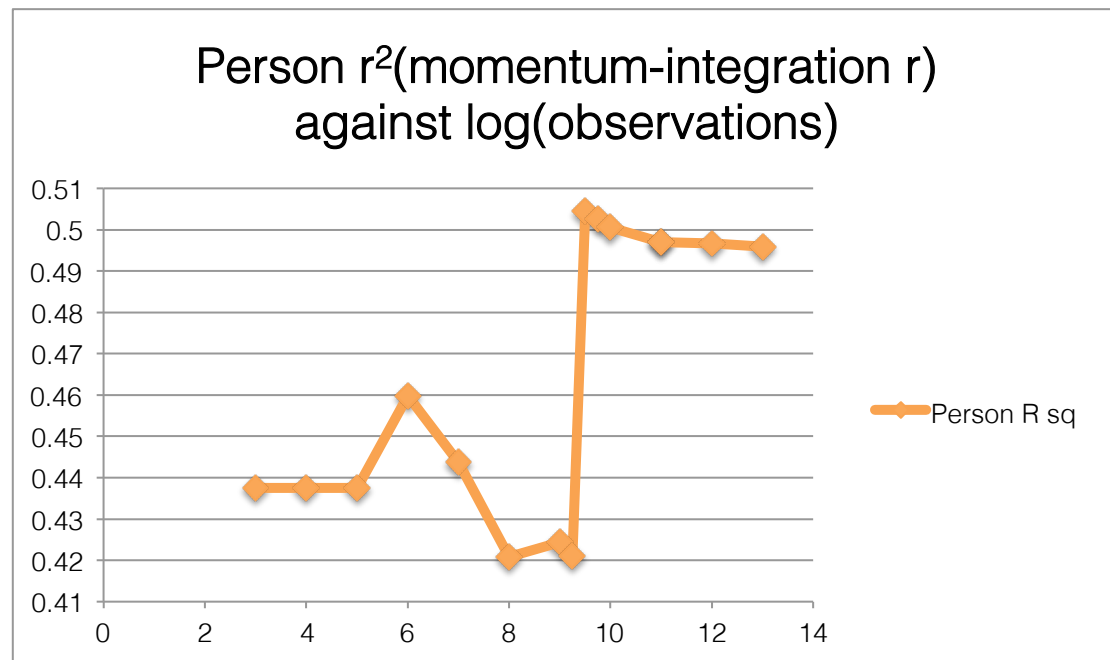
Figure 5 – Plot of change of Pearson **correlation** r^2 **against angular radius**

Figure 5 shows the plot of the Pearson correlation coefficient, r^2, between momentum integration, with angular radius r, and the log of observations for

the test area (significance, p value, was always <0.001). Spearman's Rank correlation showed a smoother change confirming the more accurate Pearson correlation improvement shown. Using the log of observation of movement is a common process in space syntax to allow for a feedback effect from urban multipliers. From this model, a new correlation r^2-value was computed and it is this model which will be reported. For the base case, pure angular integration, the gradient descent method found an optimal radius of 9.5 radians with a Person r-squared of 0.51 (see figure 5). A plot of the values for the Person r squared correlation against radius is shown in figure 5. This shows that there is a curve with a peak correlations at R= 9.5 radians. When examining the map, this radius appears to match the limit that one might intuitively correlate with the radius of a cyclist in that area of London.
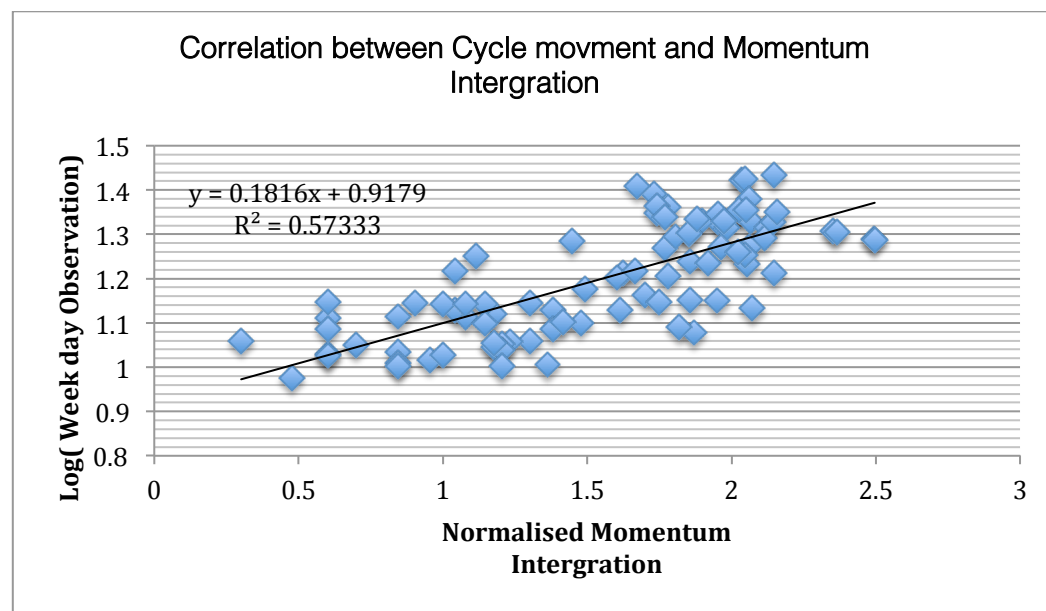

Figure 6 Correlation between observed cycle movement and optimized parameters.

Introducing both elevation and the presence of traffic lights leads the method to create an optimal correlation of r2= 0.573 with angular radius R= 9.5 and gradient factor k_g= 0.01868 and traffic factor = 0.000185.

Testing these against the observations for a second area (Saint Luke's containing 100 observations), not used to optimize the model parameters, gave a correlation against predicted movement of r2= 0.503 (roe= 0.676) for

the pure angular case and r2= 0.534 with df = 98, p-value < 2.2e-16 for the case combined with traffic lights and elevation. It should be noted that the presence of both elevation and traffic lights cause a 6% increase in correlation with observed movement. For the multiple regression case, we calculated the model in the R language giving an Adjusted R-squared of 0.504 when including all factors (depth, elevation and presence of traffic lights). This suggests that, for this dataset, the correlation is improved via the use of the momentum-based model.

Conclusion

The objective of this paper was to examine the route momentum model over classic route angular complexity. The results of test data of r2=0.504 for the pure angular case and r2= 0.534 with p <<0.001 supports the hypothesis that incorporating elevation and traffic lights into the syntactical model is an improvement over not including them and over including them in a multiple regression model. This should be seen as a conservative pilot approach to the inclusion of factors that effect cyclists into an urban cycling model. It should be remembered that this pilot approach uses angular integration, as a 'proof of concept' measure, rather than the more accurate but resource-consuming angular segmental choice. This approach also uses raw open source data and satellite observed digital elevation data. Given the limitations of the source data it seems reasonable to assume that more accurately collected street & elevation models and a change to the use of angular segmental choice should result in a concomitant improvement in the final observed correlation. As important as these findings, this paper has seen the introduction of the Momentum Mercury software as a tool to provide an analytic approach to the design of cycle lane provision. Such tools may close the gap between cycle lane provision, as it stands, and future cycle lane provision as it deserves to be.

Future work

While considerable strides have been made in this pilot work, it does leave a large amount of work uncompleted. Clearly, any use of segmental-like methods within a space syntax framework suggests the use of choice measures as being those which most likely correlate highly with observed

cycle movement. Other improvements could include the use of high fidelity road centerline data, which would be expected to improve the correlation with observed movement. The elevation data used was from the public domain, and was quite coarse, and future work should seek to use far more accurate urban elevation data. Further experiments need to be conducted in locations of low and high elevation change. Finally, this model does not include the presence or absence of cycle lane data. From a cycle facility planning view, future models should include cycle lane presence (or proposed presence) and other elements such as the presence of cycle friendly road markings at traffic lights.

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