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MEASURING THE CHANGES IN AGGREGATE CYCLING PATTERNS BETWEEN 2003 AND 2012 FROM A SPACE SYNTAX PERSPECTIVE

083

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Abstract

Space syntax is a set of techniques and theory that investigates relationships between spatial layout and a range of social, economic and environmental phenomena. Research in space syntax has shown how spatial layout influences on pedestrian movement (Hillier&Iida, 2005), vehicular movement (Penn et al, 1998), cyclist movement (Radford et al. 2005) and public transport volume. (Law et al., 2011) There has been a surge of interest on cycling in London this past 10 years that had resulted in the introduction of the Barclays Cycle Superhighway and Barclays Cycling Hiring Scheme. (Tfl, 2010) Despite the continous investment in cycling infrastructure, there has been little understanding of cycling activity patterns in general and in particular on the effect spatial configuration. The research objective is to measure the impact on how cycling behaviour have changed and to measure the impact these cycling infrastructure have on cycling route choice in comparison to previous research. We propose to first compare cyclist movement between 2003 and 2012 in describing the changes on travel behaviour in London. Initial findings suggests over 1000%+ increase on cycling movements on some routes. We will then propose a cyclist movement model by correlating cyclist movement value with spatial layout attributes, safety attributes, infrastructure attributes and urban character attributes. The correlation analysis will allow us to assess the uplift created by the Cycling Superhighway 07 (CS07) introduced in 2011 and to compare its results with other cycling routes in the system. Despite the introduction of CS7, initial findings suggest majority of cyclists still prefer to cycle along the most direct route of Elephant and Castle. This behaviour is line with previous research findings where commuting cyclists prefer to use major routes offering direct connections over secondary more quieter routes. These results will help us to better understand the trade off between cycling safety and cycling legibility which could help inform cycling route design in the future.

Keywords: *space syntax, cycling route choice, network science, London*

Theme: *Spatial Cognition and Behaviours*

1.0 Background

The year of 2007 marked the transition from a majority rural world population to one dominated by urban dwellers. Among other things, this shift to cities has increased the need to improve sustainable and active forms of transport, otherwise commonly known as walking and cycling. With the reassessment of the value of living in central areas a number of cities have managed a reduction in the use of private cars. Cycling has moved to the forefront of the design, planning and transport agenda. (Briggs 2012) Cycling in London is growing at a fast pace, with reported yearly increases of 9.2% in cycling numbers as recorded by Transport for London (TfL) on the Transport for London Road Network (TLRN). London also aims to have a target growth of a 400% increase in cycling by 2026 compared with 2001 levels (107.2% increases recorded in 2008 over 2001 base levels) Along the uptake of cycling, London's major has announced a 1 billion pound budget for cycling projects in London. The Barclays Cycling Hiring Scheme or 'Boris bikes' continues to grow as does the London Cycle Superhighway (TfL 2010).

Despite continuous investment in cycling infrastructure, there is a lack of an evidence-based understanding of cycling activity patterns and in particular on the role that of spatial configuration has on cycling activity. The surge of interest in cycling represents an opportunity to study the attributes influencing cycling route choice and more interestingly to look at the evolution of cycling movement patterns. (TfL 2012) The aim of this paper is therefore to measure the impact of how cycling behaviour have changed overtime and to measure the impact these cycling infrastructure have on cycling route choice in comparison to previous research. These results will help us to better understand the trade off between cycling safety and cycling legibility which can help inform cycling route design in the future.

2.0 Research question

In transportation, cycling research has focused on stated preference studies and discrete choice models in transport demand management. Previous transport studies have identified the following criteria influencing cyclist movement; distance, time, effort, number of junctions, number of traffic lights, pleasantness, attractions, quality of pavement, protection from weather, crowdedness, gradient, personal and traffic safety. (Hopkinson et al 1989) In a study to identify the extents of these criteria; distance, pleasantness and safety were identified as the most important attributes for cyclists. (Westerdijk 1990) What is missing in transportation research is a better understanding of how spatial configuration and accessibility influence cyclist movement patterns. Moreover there is a need to have a quantitative assessment of the relation between providing legible direct routes versus safe but less direct and segregated routes. Finally, the understanding of how cycling activity patterns have changed over time can provide useful insights on future cycling trends.

This paper builds on previous configuration and cognition studies using the techniques and methods of space syntax. Space syntax applies methods in graph theory to study the configuration of spatial networks in cities. (Hillier and Hanson 1984). An important aspect of space syntax is theorising the relationship between space and movement. Key to this idea is the theory of natural movement (Hillier et al. 1993) and spatial cognition. (Peponis et al. 1990) In transport studies, space syntax measures were shown empirically to relate strongly to pedestrian flows and vehicular flows, (Penn et al. 1998; Hillier and Iida 2005) public transport passenger volume. (Law, Chiaradia & Schwander 2012) In legibility and spatial cognition research, space syntax measures have shown empirically to relate to wayfinding and mental maps. (Kim and Penn 2004) In cycling research, the seminal paper from Radford, Gil and Chiaradia has found spatial configuration to correlate strongly with observed aggregate cycling movement through a multiple variable regression framework. (Radford et al. 2005) This research also found inconclusively that cyclist at an individual level follows neither metric shortest path nor angular shortest path. What appears missing in previous space syntax literature on cycling behaviour are two folds; one is the limited research in cycling route choice at an individual basis and second is limited research in looking at how cycling movement pattern changes overtime.

As a result, this research in particular will extend on previous cycling research and contribute to the latter where changes in cycling movement and cycling behaviour are examined overtime and specifically studying the trade-off between cycling safety and cycling accessibility.

The key questions of this paper are:

1. To what extent does spatial configuration influence aggregate cycling movement overtime?

2. To what extent does the introduction cycling infrastructure influences cyclist movement patterns overtime?

3.0 Research Approach

This research uses a pedestrian and cyclist movement patterns sample collected in London's Elephant & Castle area in 2003 and 2012. In this period the area has seen minor changes in spatial configuration but has experienced changes in both transport modal split and the provision of cycling infrastructure. This has allowed us to study the interactions between the changes in overall cycling volume and the changes in cycling infrastructure within a constant spatial configuration.

1. We proposed first to look at how cyclist movement patterns have changed overtime in the case study area which have witnessed a significant transport modal shift in the last 10 years through a cycling movement analysis and how this relate to changes in cycling infrastructure and spatial configuration.

2. We then proposed a cyclist movement model where aggregate cyclists movement would be associated to spatial configuration and cyclists infrastructure for the same gate locations in 2003 and 2012.

3.1 Cyclist movement model

The following section will describe in more detail the second stage of the research approach where aggregate cyclist movement is correlated with three criteria named accessibility and transport, safety and infrastructure, character and land use through a multiple variable regression model following previous research. (Radford Gil and Chiaradia 2005) The method of ordinary least square (OLS) is used for the estimation of the linear multiple variable regression model.

$$Log\ Cyclists\ movement = \sum \beta_1\ Accessibility + \sum \beta_2\ Safety + \sum \beta_3\ Character + \varepsilon$$

Equation 1

For each criterion a series of variables are explored in the case study. As a proof of concept, this assessment method offers the flexibility to incorporate different levels and kinds of evidence for each criterion. Future research should include variables specifying route pleasantness and level of infrastructure intervention. As this model assumes a simple linear relationship between the independent and dependent variable, further research is needed in model specification.

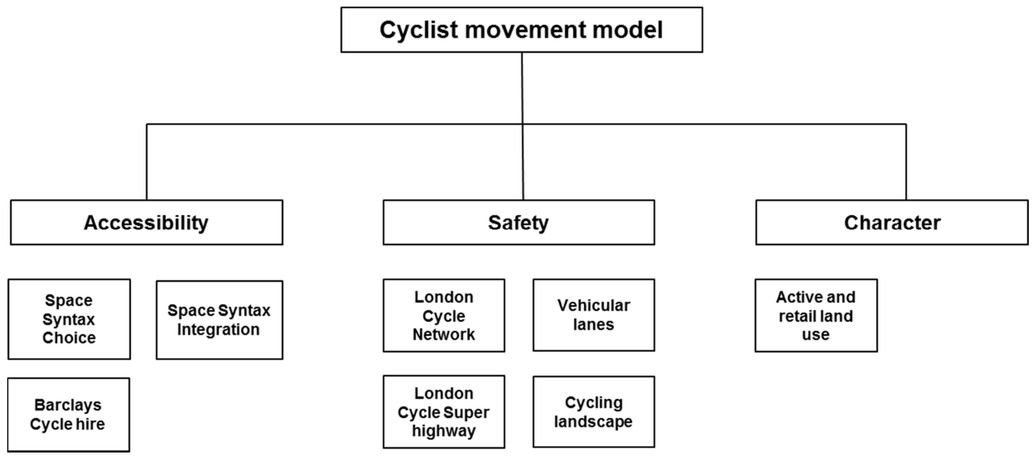


Figure 1 Cyclist movement model

Chart 2 Cyclist movement model variables

Type	Variables	Source
Accessibility and transport	Space Syntax NA Choice	Space Syntax Limited
	Space Syntax NA Integration	Space Syntax Limited
	Barclays Cycle Hire	TfL
Safety and infrastructure	London Cycle Network	TfL
	London Cycle Superhighway	TfL
	Cycling landscape provision (lanes and marked)	Google Streetview
	Number of vehicular lanes	Google Streetview
Character and Land use	Active and retail land use	Google Streetview

3.2 Accessibility and transport

Accessibility or distances to certain attractions had previously been identified as a key criterion in influencing cycling route choice. Three measures of accessibility have been proposed for the cyclist movement model; space syntax integration measure, space syntax choice measure, and access to number of Barclays Cycle hire within a set search radius. The chart below summarises the key variables for this criteria.

Chart 2 Accessibility and Transport variables

Variables	Definition	Source
Space Syntax NA Choice	400, 800, 1200, 1600, 2000, 2400, 3000, 5000, 10000, N metre	Space Syntax Limited
Space Syntax NA Integration	400, 800, 1200, 1600, 2000, 2400, 3000, 5000, 10000, N metre	Space Syntax Limited
Barclays Cycle Hire	Number of cycle hire locations within 100 , 200 metre	TfL

3.2.1 Space Syntax accessibility measures

In a space syntax network model, each segment of a street network is analysed using the computer software UCL Depthmap developed by Alasdair Turner, Eva Friedrich and Tasos Varoudis (Turner 2004). Two measures that relate to the urban environment most commonly computed in space syntax which will be used in this study are:

Space syntax segment angular Integration measures the reciprocal of the sum of the shortest path between every origins (i) to every destination (k), i.e. To movement potential of this street segment (Freeman 1977; Hillier and Iida 2005).

$$C_c(P_i) = (\sum_k d_{ik})^{-1}$$

Equation 2

Space syntax segment angular choice measures how many times paths overlap between all pairs of origins and destinations, i.e. Through movement potential of this street segment (Freeman1977; Hillier and Iida 2005).

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

Equation 3

This research will not use angular segment choice as specified in Hillier and Iida paper but rather follows the recent adoption of normalised angular choice (Hillier et al 2012). The normalisation of the choice measure is applied to each segment as specified below;

NA Ch_i = Log (angular $choice_i$ +1) / Log (angular Total $Depth_i$ + 3)

Equation 4

The following radiuses are included in the selection process of the cyclist movement model; 1200 metres, 2000 metres, 3000 metres, 5000 metres and N.

3.2.2 London Barclays Cycle Hire accessibility

London Barclays Cycle Hire is a public cycle sharing scheme in London launched in 2010 from Transport for London and operated by Serco Group. (TfL 2013c) There are currently approximately 8,000 Barclay cycles and 570 cycle hire stations in the city. This variable is defined as how many cycle hire docks are available within 100m and 200m from the gate location. Cycle hire usage has not been included.

3.3 Safety and infrastructure

Safety and infrastructure had previously been identified as a key criterion in influencing cycling route choice. Four measures of perceived safety based on cycling infrastructure have been incorporated for the cyclist movement model. This includes; the location of London Cycle Network, London Cycle Superhighway, London cycling landscape provision and the number of vehicular lanes. More research is needed in disaggregating this variable into differing cycling landscape quality and defining a landscape quality index with differing levels of interventions.

Chart 3 Safety and infrastructure variables

Variables	**Definition**	**Source**
London Cycle Network	0 or 1	TfL
London Cycle Superhighway	0 or 1	TfL
Cycling Landscape provision	0 or 1	Google Streetview
Number of vehicular lanes	0 to 8 lanes	Google streetview

3.3.1 London Cycle Network

Currently there are over 600km of London Cycle Network routes in London.[1] The implementation of a London Cycle network can range from segregated cycle tracks which are off-carriage way to Cycle lanes, to shared paths with pedestrians, to motor traffic speed reduction, to road markings and to rectification of potholes. (LCN 2013) This variable is specified as a dummy variable where 0 indicate not on London Cycle Network and 1 indicate the gate is located on London Cycle Network.

3.3.2 London Cycle Superhighway

London Cycle Superhighway was announced by Ken Livingstone in 2008 with the aim of creating continuous cycling routes into central London. There are a total of 12 routes planned and as of 2012, only three routes are in used; this includes CS3, CS7 and CS2. [2] Safety, priority and junction design are important consideration in the design of the Superhighways. The image below illustrates all the London Cycle Superhighway in the city and a photo describing the dedicated blue lanes for cyclist. This variable is specified as a dummy variable where 0 indicate the gate is not on London Cycle Superhighway and 1 indicates the gate is located on London Cycle Network.

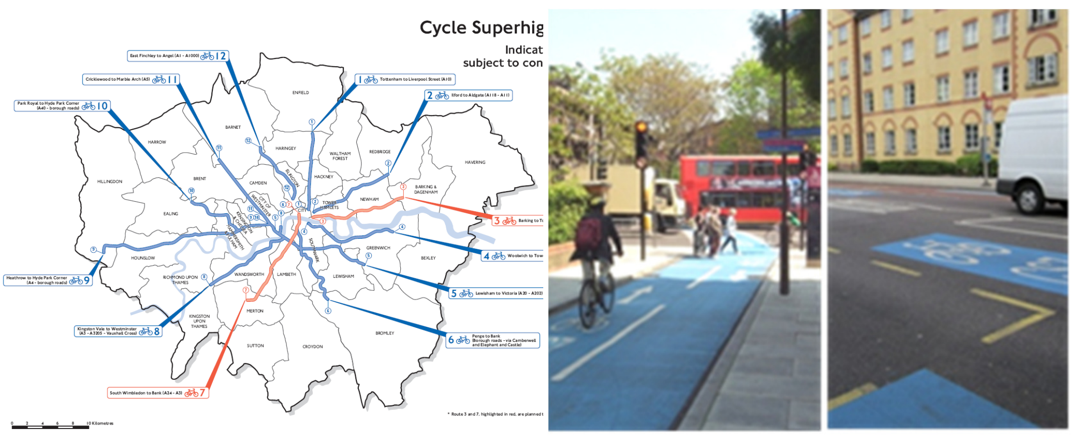


Figure 3 London Cycle Superhighways (TfL 2013B)

3.3.3 Cycling landscape (segregated lanes, lanes and marked included)

A third derived measure of safety is the cycling landscape infrastructure provision. This dataset has been gathered and observed directly from Google Streetview. Routes with provision of cycling landscape includes all routes that are marked with a cycling sign on the surface, a dedicated cycle lane that is part of the street network or a dedicated cycle lane that is segregated cycle lane from the street network have all been included. (TfL 2005) This variable is defined as a dummy variable where 0 indicate the gate does not have any cycling landscape infrastructure and 1 indicate the gate has some form of cycling landscape infrastructure. At the moment, routes with cycling landscape will include most of the routes identified in London Cycling Network and London Cycle Superhighways.

3.3.4 Number of vehicular lanes

A fourth derived measure of safety is the number of vehicular lanes per segment. This dataset has been gathered from Google Streetview. Number of lanes is counted for each segment in both directions. This variable is defined as a discrete variable between 0 to 8 lanes on the specified gate location.

3.4 Character and Landuse

The character and land use of the route has previously been identified to influence cycling route choice. Instead of a stated value of character, a measure of perceived character based on land use has been incorporated for the cyclist movement model. Therefore this takes into consideration the location of retail and active land use, where 0 indicates no active land use and 1 indicates existence of active land use. More research is needed in further quantifying this criterion of to include vistas, green coverage and quality of public spaces as a perceived quality of character.

Chart 4 Character and Pleasantness variable

Variables	Definition	Source
Retail active land use	0 or 1	Google Streetview

3.4.1 Active land use

The presence of active land uses along a cycling route improves convenience, the sense of security and the urban vitality of a route. It also increases the opportunities for economic transactions, as it is more likely that cyclist would to stop by on their way instead of diverting their route to consume. Again, this variable is defined as a dummy variable where 0 indicate no retail and/or active land use and 1 indicate retail and/or active land use. More research is needed in the specification of this variable to include the frequency and diversity of land use.

4.0 Elephant and Castle Case study

This section analyses the Elephant and Castle data set. The first stage is the cyclist movement analysis that describes the spatial configuration of the study area, its land use distribution and its cyclist movement pattern for both 2003 and 2012. The diagram below illustrates the differences between the two time periods for the Elephant and Castle case study. The second stage is a cyclist movement model where we regress cyclist movement with the variables identified in section three.

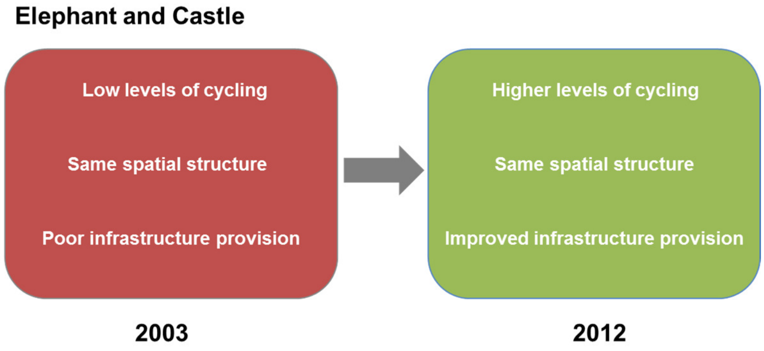


Figure 4 Elephant and castle case study in 2003 and 2012

4.1 Background

Elephant and Castle is located in London Borough of Southwark. The study area is bordered by Kennington Road, Lambeth Road, Great Dover Street and New Kent Road. The map below illustrates the study area for the case study and the existing cycling routes in the study area. The dark blue line represents the **London Cycle Superhighway 07 (CS7)** which covers the route from Colliers Wood to Southwark Bridge. The light blue line is the **London Cycle Network Route 02** that runs from Brook Drive (Imperial War Museum) to Deptford. The red one is the **London Cycle Network Route 23**, from Southwark Bridge to Crystal Palace. The London Green Links (green lines on the map) are a walking & cycling network known as the **Elephant & Castle Green Links** as proposed in the April 2012 Framework from Southwark.

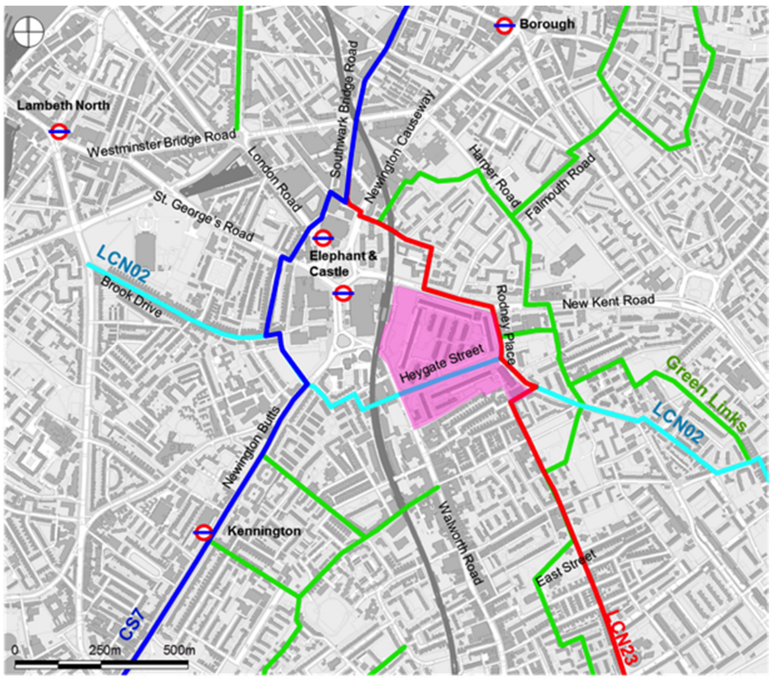


Figure 5 The figure describes the Elephant and castle study area with the London Cycle Network; LCN23 in red, LCN02 in aqua and London Cycle Superhighway CS7 in blue and green lanes in green

4.2 Space syntax measures and land use distribution of study area

A spatial network model for the case study was provided by Space Syntax Limited and has been constructed based on the road centre line segment model. (Turner 2007) The space syntax choice map (Fig.6) are visualised using the colour spectrum: red for high accessibility through to orange, yellow, green and blue for areas with low accessibility. Looking to the spatial accessibility of the area, it was found that high volume of pedestrians, vehicles and cyclists align with highly accessible street segments, the radials converging at the Elephant & Castle - Walworth Road, New Kent Road, Elephant & Castle, St George's Road, London Road and Newington Causeway. The figure also indicates a stronger association between active land use with highly accessible routes than with less accessible routes.

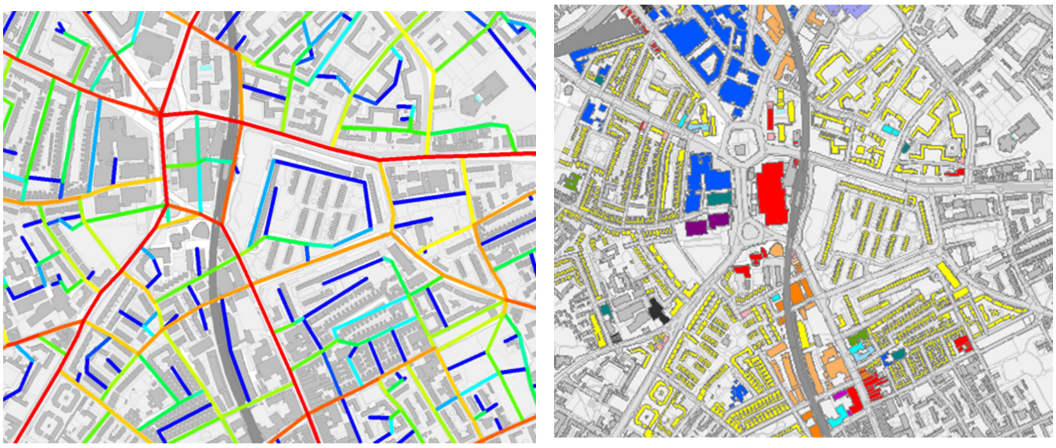


Figure 6 Left Space syntax normalised choice **Right** Land use distribution of the case study area

4.3 Cycling movement pattern

In order to understand the existing cycling movement pattern of the area, two sets of observational studies have been conducted in 2003 and 2012. In 2003, the observation was taken in over 50 locations in the area. Human observers recorded cyclist's movement for five minutes each hour from 10:00 hours to 20:00 hours. Differently, in 2012 camera-based cyclist movement survey were carried out in 22 different locations throughout the day, from 07:00 to 19:00 on Tuesday 21st August 2012. On that day, the weather was dry and overcast. For the survey 5 minute directional counts were extracted at each location every half hour. Later on, the results were transformed into hourly movement rates. There are 21 locations where there are overlaps between the 2003 and 2012 observations. The diagram below shows these gate locations. Cyclists flows are visualised using the colour spectrum: red for high movement levels through to orange, yellow, green and blue for areas with low movement level. The figure below shows the recorded average daily pedestrian flow per hour on a weekday for both 2003 on the left and 2012 on the right using the same ranges for visualisation. Both of these data have been gathered by Space Syntax Limited.

Figure 7 Top Gate locations **Bottom** Cycling movement pattern in 2003 (left) and in 2012 (right)

4.3.1 Active land use

The 2003 cyclist movement pattern shows high levels of cyclist movement on the primary routes in the network – Newington Butts, Walworth Road and New Kent Road – where the radials converge in Elephant & Castle. In contrast, movement rates are significantly lower in the secondary network, between the radials and especially in residential streets. Therefore, this distribution confirms cyclist' preference for direct and highly accessible routes in the street network. The highest footfall of 60+ is along Elephant and Castle, Newington Butts and New Kent Road, 40-60 cyclist per hours along St.George's Road, London Road and Walworth Road and the rest of the routes below 40 cyclist per hour.

4.3.2 Cycling movement pattern 2012

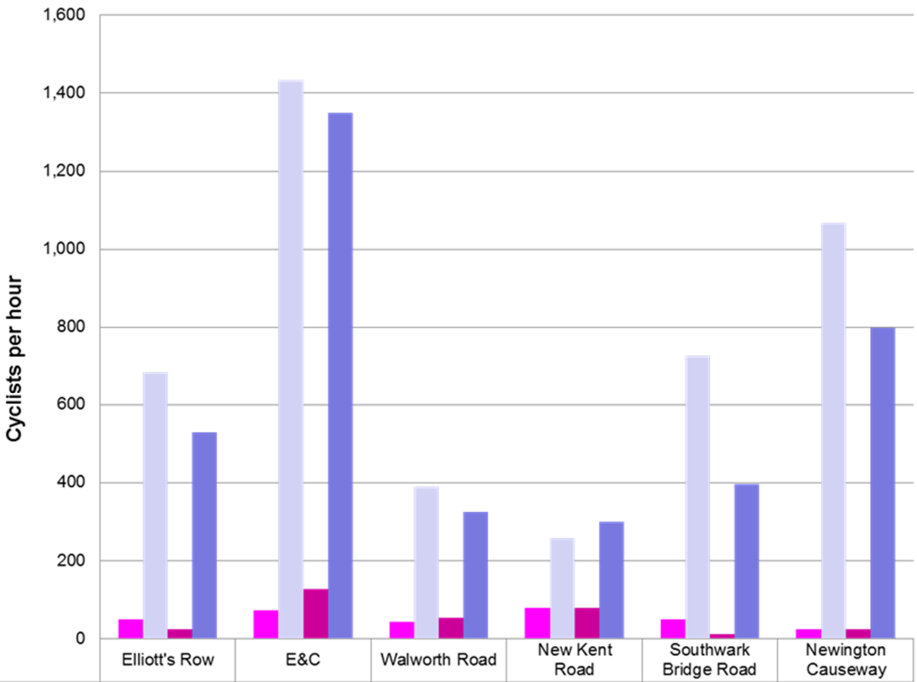
The 2012 cyclist movement pattern shows an overall increase in volume as compared to 2003 cyclist movement pattern. In contrast, cyclist movement distribution increased significantly on Elliot's Row, which is part of London Cycle Superhighway CS7. During the morning period the dominant movement follows Newington Butts, Elephant and Castle and Newington Causeway heading north towards Southwark Bridge and London Bridge. An important secondary movement line was recorded along Elliott's Row, Princess Street, Ontario Street and Southwark Bridge, which overlaps with CS7. Medium levels of cyclist movement were recorded on the Northern Roundabout radials: London Road, St. George's Road and New Kent Road as well as

Walworth Road leading onto the Southern Roundabout.

4.3.3 Comparing cycling movement pattern between 2003 and 2012

Taking all into consideration, a comparison between 2003 and 2012's cycling numbers shows a 600% average cycling activity increase in the area. Elliot's Road, along a quiet but segregated section of CS7, recorded the largest increment. However, when taken as a whole, 68% of cyclist prefers to use the Elephant & Castle route over Elliot's Row along London Superhighway CS7 between the Northern and Southern roundabout. This behaviour is in line with previous research findings where commuter cyclist prefers to use major routes offering direct connections to secondary quiet roads despite the introduction of dedicated cycling lanes along the cycling superhighway. The figure below shows in pink 2003 AM peak and PM peak movement and in blue 2012 AM peak and PM peak movement for five street segments in the study area.

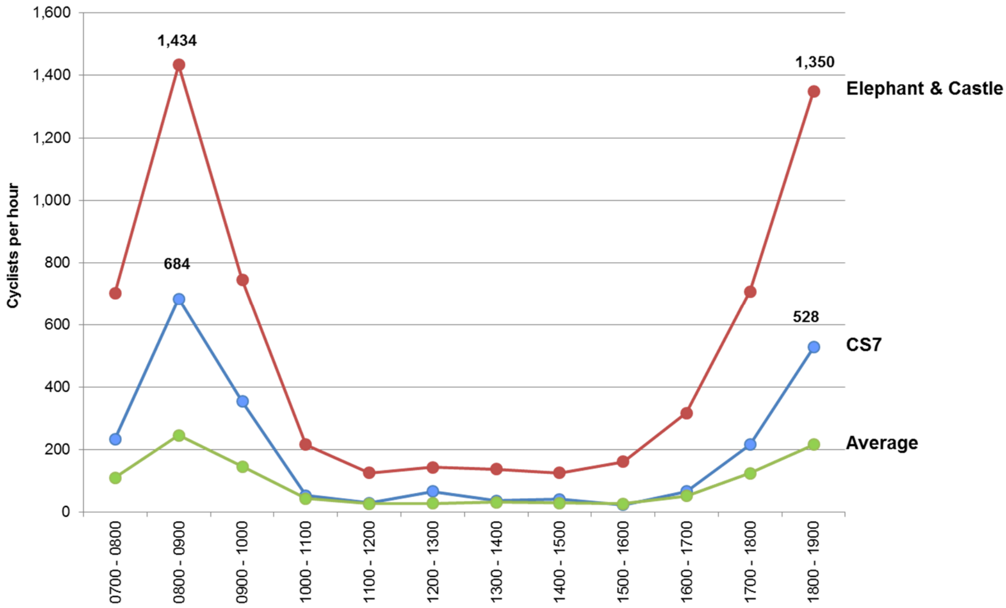
Chart 5 Cyclist movement comparison for 6 streets between 2003 and 2012



	Elliott's Row	E&C	Walworth Road	New Kent Road	Southwark Bridge Road	Newington Causeway
2003 AM Peak	48	72	42	78	48	24
2012 AM Peak	684	1,434	390	258	726	1,068
2003 PM Peak	24	126	54	78	12	24
2012 PM Peak	528	1,350	324	300	396	798

The difference between the most accessible route over the most comfortable route persist throughout the day as indicated in the figure below. It shows cycling movement distribution across time where the X axis shows the time period and Y axis shows the average cyclist per hour. The red line show the Elephant and Castle route, the blue line show Elliott's Row on CS7, the green line shows average cyclist movement for all gates. Qualitatively, faster commuter cyclists were observed more on Elephant and Castle whilst slower non commuter cyclists were observed on CS7.

Chart 6 Cyclist movement distribution across the time comparison



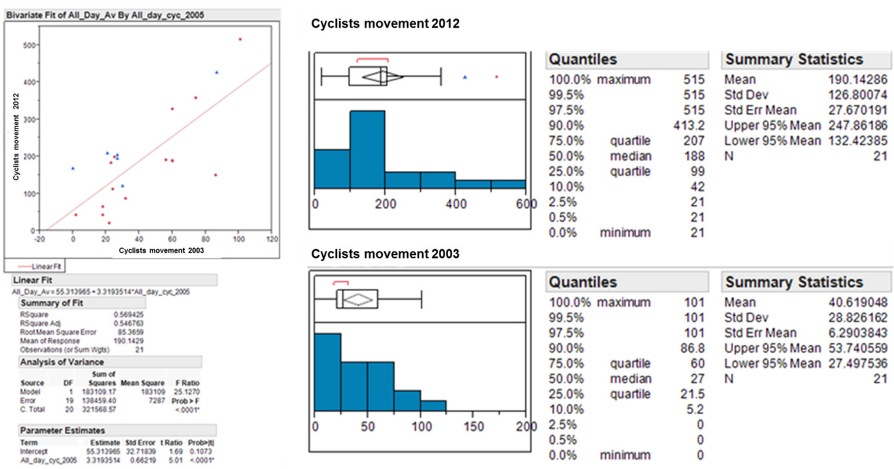


Figure 8 Correlation and distribution between 2003 and 2012 observed cyclists movement

Lastly, correlation between observed cyclist movement in 2003 and 2012 reveals strong preferences for new cyclists in 2012 to use the most accessible routes as in 2003 with a coefficient of determination R-square of 58% and adjusted R-square of 54%. Other than one instances, the gates with cycle superhighway are all above the regression line indicating the differences in distribution between the two periods are possibly caused by cyclist's infrastructure. Statistically, this preference for the same route between observed cyclists in the two time periods correspond to the long tail scaling distribution of movement patterns where the majority of cyclists are on the minority of the segments. (Jiang 2007) Routes that are preferred overtime are also routes that are faster for cyclists to traverse requiring less cognitive information or in space syntax terms the least angular costs. (Turner 2000; Dalton 2001; Hillier and Iida 2005) Further research is needed into clarifying this relationship overtime.

5.0 Cyclist movement model regression results

In accordance to previous research, cyclist movement is first correlated against space syntax accessibility measures. Second, a multiple variable regression model is applied through a stepwise regression process in selecting the most suitable cyclist movement model. Linear multiple variable regression model is applied where regression results are reported and normality assumptions checked. Only the gates that have overlapped between 2003 and 2012 are chosen for the cyclist movement model.

5.1 Spatial measure regression results

The graph below illustrates the correlation coefficient between cyclist movement for both 2003 and 2012 with different spatial accessibility measures. The results suggest first, higher radius accessibility measures correlates to cyclist movement better than lower radius accessibility measures. Secondly, higher correlations were achieved in 2012 as compared to the same gates for 2003. This might be attributed to generally low cyclist movement generally in 2003 which have gates with zero cyclist. Thirdly, integration measure explains cyclist movement positively and in some case slightly better than choice measure. Both Integration Radius N and Normalised Choice Radius N are applied in the next step in selecting the most suitable cyclist movement model through the stepwise regression process.

Chart 7 Cyclist movement correlation spatial measure comparison

	Cycling movement 2003	Cycling movement 2012
NAChR1200	32%	29%
NAChR2000	35%	34%
NAChR3000	37%	37%
NAChR5000	38%	39%
NAChRN	40%	46%
IntR1200	28%	41%
IntR2000	36%	45%
IntR3000	29%	42%
IntR5000	39%	42%
IntRN	40%	47%

5.2 Stepwise regression results

The chart below illustrates a stepwise regression selection process between Log cyclists movement and Normalised Choice Radius N with all the variables in the cyclist movement model for 2012 as illustrated in section 3. The stepwise regression optimises for a model that best correlate with cyclist movement. The results suggest that the most suitable cyclist movement model is a combination of normalised choice N and the dummy variable of London Cycle Superhighway and the number of lanes. Due to high correlation between number of lanes (supply) and accessibility (demand) only Normalised Choice and London Cycle superhighway are selected for the cyclist movement model. The integration RN measures achieve a lower fit and correlation in combination with the London Cycle Superhighway variable.

Current Estimates

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
☑	☑	Intercept	2.11522498	1	0	0.000	1
☐	☐	LCN	0	1	0.023228	0.127	0.72573
☐	☑	LCS	1.3128467	1	4.681296	27.081	7.17e-5
☐	☐	LCN_LCS	0	1	0.000148	0.001	0.97768
☐	☐	Landscape	0	1	0.108258	0.612	0.44547
☐	☐	marked	0	1	0.053547	0.297	0.59331
☐	☐	Marked_landscape	0	1	0.00188	0.010	0.92064
☐	☐	Active	0	1	0.000677	0.004	0.95235
☐	☐	Retail	0	1	0.106843	0.604	0.44851
☐	☐	Residential	0	1	0.000677	0.004	0.95235
☐	☑	Numb_lanes	0.2193966	1	1.258195	7.279	0.01524
☐	☑	NAChRN	1.5346804	1	0.837567	4.845	0.04182

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p	AICc	BIC	
1	Numb_lanes	Entered	0.0032	4.567626	0.3740	19.358	2	45.7863	47.5081	○
2	LCS	Entered	0.0004	3.868446	0.6908	2.9595	3	34.0635	35.7416	○
3	NAChRN	Entered	0.0418	0.837567	0.7594	0.976	4	32.2973	33.5199	○
4	Landscape	Entered	0.4455	0.108258	0.7682	2.4612	5	35.509	35.7762	○
5	Retail	Entered	0.2636	0.2335	0.7874	3.3506	6	38.3163	37.0126	○
6	LCN_LCS	Entered	0.2928	0.20421	0.8041	4.3794	7	41.981	38.3372	○
7	LCN	Entered	0.5561	0.06537	0.8094	6.0685	8	47.7629	40.8	○
8	Marked_landscape	Entered	0.8401	0.00822	0.8101	8.0294	9	55.325	43.7702	○
9	Residential	Entered	0.8669	0.006188	0.8106	10	10	64.6022	46.7586	○
10	Best	Specific	.	.	0.7594	0.976	4	32.2973	33.5199	⦿

Figure 9 Cyclist movement model stepwise regression results

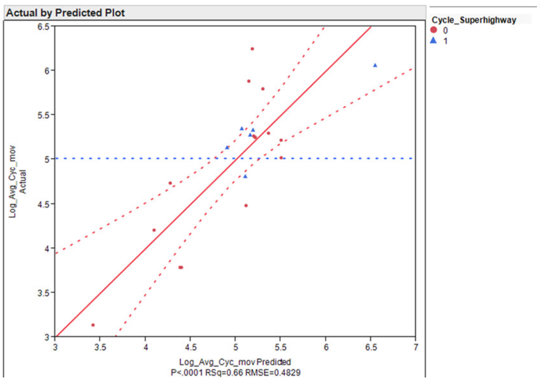
5.3 Cyclist movement model regression results

The most suitable cyclist movement model in correlating with cyclist movement consists of Normalised Choice RN and the London Cycle Superhighway dummy variable. The model assumes a linear multiple regression model where Log cyclists movement is regressed against accessibility and cycle superhighway.

$$Log(Cyclists\ movement_i) = \beta_i Accessibility_i + \alpha_i Cycle\ Superhighway_i + \varepsilon_i$$

Equation 5

The method of ordinary least square (OLS) is used for the estimation of the linear multiple variable regression model where the assumption of the normality of residuals and collinearity is checked. The regression results using OLS are presented below.



Summary of Fit

RSquare	0.656342
RSquare Adj	0.618157
Root Mean Square Error	0.482865
Mean of Response	5.016017
Observations (or Sum Wgts)	21

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	8.015421	4.00771	17.1888
Error	18	4.196847	0.23316	Prob > F
C. Total	20	12.212268		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.0425006	0.704274	1.48	0.1561
NAChN	2.9528164	0.531938	5.55	<.0001*
Cycle_Superhighway[1-0]	1.4015116	0.290496	4.82	0.0001*

Figure 10 Cyclist movement model regression results

The result suggests a high correlation of 65% R-square or 62% adjusted R-square between cyclist movement with the combination of Normalised Choice Radius N and London Cycle Superhighway. The higher t-ratio and lower P-value for Normalised choice also suggests accessibility has stronger influences than the London Cycle Superhighway variables. These results correspond to our earlier finding from the cyclist movement analysis where despite the improvements in cycling landscape, accessibility of the route is a more important factor in explaining aggregate cyclist movement. For robustness purposes, interactions between independent variables have been tested. This includes interactions between the choice and the cycle highway variable and an exponential form for the choice variable. (Choice*Cycle superhighway; Choice*Choice)The R-square improves to 69%. Due to the small sample size these results are not conclusive and therefore not reported formally.

6.0 Key findings

Taking all into consideration, some results can be pointed out. First, cyclists prefer to use the most continuous routes when there is a change in cycling volume and modal shift. This suggests a process where new cyclists whom have switch transport modes prefer to use the most accessible and least angular routes. This behaviour is in line with previous research where commuting cyclists prefer to use major routes offering direct connections over less direct routes. Statistically, this preference for the same route corresponds to the scaling distribution of movement in spatial networks where the majority of cyclist movement is on the minority of the segments. Second, cycling landscape provision can also increases the usage of a route significantly as illustrated by the introduction of London Cycle Superhighway 07 along Elliot's Row. This behaviour is also in line with previous research where cyclist prefers to use safer routes with more cycling landscape infrastructure provision. Thirdly, proportionally cyclist still prefers to use more direct routes over a less direct route with improvement in cycling landscape. This preference on the most accessible route over the most comfortable route persists throughout the day in this case study. To end, the evidence in the research suggests to optimise the efficiency of cycling infrastructure, improving cycling infrastructure in more spatially accessible location is therefore recommended. An important limitation to this research is the small sample size. Thus future research is recommended to collect a larger sample size and identifying the extent on cyclist's preference between comfort and accessibility. More research is needed in the statistics particularly the specification of the regression model and its functional form. Lastly, future research is needed on better understanding cycling route choice at a disaggregated scale in continuation from previous research. (Radford et al 2005)

Notes

1 London Cycle Network programme started in 1995 to designate and improve cycling routes in the city. LCN+ was established in 2000 to extend and improve the network. More information can be found in www.londoncyclenetwork.org.uk concerning the definition and the landscape provision for the London Cycle network.

2 London Cycle Superhighway was announced by Ken Livingstone in 2008 with the aim of creating continuous cycling routes into central London. Cycle Superhighways are designed to be direct, continuous, comfortable, easy to find and safe. More information can be found in http://www.tfl.gov.uk/roadusers/cycling/11901.aspx

References

Barabási, Aalbert-Laszlo and Albert R`.0eka. 1999. *Emergence of scaling in random networks, Science*, 286, 509-512.

Brigg, David. 2012. *World Class? London's Transport Progress and Future Challenges.* sponsored by Seimens.

Freeman, Linton C. 1977. **"**A set of measures of centrality based on betweenness." *Sociometry* 40: 35-41. pp. 37. Lehigh University.

Hillier, Bill, and Julienne Hanson. 1984**.** *The social logic of space*. Cambridge, MA: Cambridge University Press.

Hillier, Bill, Alan Penn, Julienne Hanson, Tadeusz Grajewski, and Ju Xu. 1993**.** "Natural movement: or, Configuration and attraction in urban pedestrian movement." *Environment and Planning B: Planning and Design* 20(1): 29–66.

Hillier, Bill 1996. "Cities as movement economies." in: *Urban Design International* 1 (1): 41-60.

Hillier, Bill 2006. *Space is the machine*. Cambridge, MA: Cambridge University Press.

Hillier, Bill, and Shinichi Iida. 2005. "Network and psychological effects in urban movement." In *Proceedings of Spatial Information Theory: International Conference*, COSIT, edited by A.G. Cohn and D.M. Mark. Ellicottsville, N.Y., U.S.A.,September 14-18, Lecture Notes in Computer Science (Vol. 3693). Springer-Verlag, Berlin, Germany, pp. 475-490

Hillier, Bill, Tao Yang, and Alasdair Turner. 2012. "Normalising least angle choice in Depthmap - and how it opens up new perspectives on the global and local analysis of city space." *JOSS* 2012 : 155-193.

Kim, Young Ook, and Alan Penn. 2004. "Linking the spatial syntax of cognitive maps to the spatial syntax of the environment." *Environment and Behavior* 36 (4): 483-504. ISSN 00139165. 01/2004;

Law, Stephen, Chiaradia, J. Alain, and Christian Schwander. 2012. "Towards a multimodal space syntax analysis: A case study of the London street and underground network." Presented at: 8th International Space Syntax Symposium, Santiago de Chile, Chile, 3-6 January 2012. Published. *Proceedings: 8th International Space Syntax Symposium*, edited by M. Greene, J. Reyes and A. Castro. Santiago de Chile: PUC, 8021:1-8021:20.

Hopkinson, Carsten and Tight, 1989. *Review of literature on pedestrian and cyclist route choice criteria.* Final report for workpacakage 3 of DRIVE project V1031: An intelligent traffic system for vulnerable road users. WP 290, Institute for Transport Studies, Unviersity of Leeds.

Jiang, Bin. 2007**.** *A topological pattern of urban street networks: universality and peculiarity,* Physica A: Statistical Mechanics and its Applications, 384, 647 – 655.

London Cycle Network team. **"**London Cycle Network Plus project." http://www.londoncyclenetwork.org.uk/.Acessed May, 2013.

Peponis John, Zimring Craig, Choi Yoon K. 1990. "Finding the Building in Wayfinding". *Environment and Behavior* 22(5): 555-590.

Penn, Alan. 2001. "Space syntax and spatial cognition: Or, why the axial line?" Paper presented at the Third International Space Syntax Symposium, Georgia Institute of Technology, Atlanta, GA.

Penn, Alan, Bill Hillier, David Banister, and Ju Xu. 1998**. "**Configurational modelling of urban movement networks." *Environment and Planning B: Planning and Design* 24:59-84.

Raford, Noah, Chiaradia, Alan Gil, Jorge. 2005. "Critical Mass: Emergent cyclist route choice in central London", in *Proceedings of the 5th International Space Syntax Symposium*, edited by A. V. NES. Delft, TU Delft, Faculty of Architecture, Section of Urban Renewal and Management.

Space Syntax Limited. 2013. http://www.spacesyntax.com/

Transport for London. 2013. "London Cycling Design Standards" (2005). Transport for London http://www.tfl.gov.uk/businessandpartners/publications/2766.aspx. Accessed April 2013.

Transport for London. 2013. "Cycling Revolution London End of Year Review Transport for London". (2010) http://www.tfl.gov.uk/assets/downloads/roadusers/Cycling/cycling-revolution-london.pdf). Accessed April 2013.

Transport for London. 2013. “Operational and Financial Performance Report” (2012). Fourth Quarter, 2011/12 Transport For London. http://www.tfl.gov.uk/assets/downloads/Part-1-Item06-Ops-Fin-Invest-Prog-Q4-2011-12.pdf. Accessed April 2013.

Transport for London. 2013. “Barclays Cycle Superhighways official website” (2013a). Transport for London. http://www.tfl.gov.uk/roadusers/cycling/11901.aspx. Accessed April 2013.

Transport for London. 2013. “Barclays Cycle Superhighways map” (2013b).Transport for London http://www.tfl.gov.uk/assets/downloads/roadusers/Cycling/barclays-cycle-superhighways-map.pdf. Accessed April 2013.

Transport for London. 2013. “Barclays Cycle Hire official website” (2013c). Transport for London. http://www.tfl.gov.uk/roadusers/cycling/14808.aspx. Accessed April 2013.

Turner, Alastair. 2004. Depthmap 4, A Researcher's Handbook, http://www.vr.ucl.ac.uk/depthmap/handbook/depthmap4.pdf

Turner, Alastair. 2007**.** "From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis" *Environment and Planning B: Planning and Design* 34(3) 539 – 555

Varoudis, Tasos. 2013. “depthmapX – Multi-platform Spatial Network Analyses Software” (2012), https://github.com/varoudis/depthmapX. Accessed March 2013.

Westerdijk, P.K. 1990. *Pedestrian and Pedal Cyclist Route Choice Criteria*. Institute of Transport studies, University of Leeds. Working Paper 302.