#89

MODELLING BIKEABILITY;

Space syntax based measures applied in examining speeds and flows of bicycling in Gothenburg

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ABSTRACT

For numerous reasons related to energy demand, emissions, public health as well as liveable and attractive cities, a frequently stated aim in contemporary discussions on urban development is to increase amount and modal share of bicycling. In recent years, space syntax based methods have shown to be useful for providing informed premises for these discussions. Combining space syntax analyses with data on locations of residents, workplaces and destinations opens the door not only for predictive modelling of route choice preferences but also the potential amount of bicycling along routes. Building on previous research, the research presented in this paper develops space syntax based measures expected to capture bicycling and evaluates these measures by comparing the analyses with empirical data from studies carried out in cooperation with the City of Gothenburg. Among the variables considered essential for bicycling and included in our GIS model are: the slope and curvature of routes, the width and surface type of bicycle lanes and the kind and amount of traffic along the route. For modelling bicycling flow potentials, a measure termed Origin-Destination Betweenness (OD-betweenness) is used and tested, examining different combinations of variables and threshold distances.

The empirical data consists of gate counts of bicycle traffic and detailed GPS-tracks mapping actual bicycling speeds of ca. 900 trips along a selection of bicycle routes. Using multiple regression analysis to model speed data, eight variables were found significant. In addition to slope and curvature of routes, the significant variables relate to proximity to traffic signals, degree of separation from pedestrians, density of entrances along the routes and quality of paving of the cycle lane.

Concerning bicycling flow potentials, the most significant variables in the multiple regression model were: OD-betweenness within 5 km, segment angular integration within 10 km, density of residents and people at work (students included) within 1 km and network betweenness within 3km.

Based on the results of the current project, a proposal for further research is to elaborate on the OD-betweenness analyses by including speeds and preferably traffic safety in the betweenness measure. By using time along segments instead of metric length for defining the analysis threshold (radius), it should be possible to have a new and improved generation of space syntax based accessibility analyses for bicycling studies. A working name for such a measure is "least impedance origin destination betweenness".

KEYWORDS

Keywords: Bikeability, Bicycle Routes, Bicycle Speeds, Origin Destination Betweenness

1. INTRODUCTION

Among traffic engineers as well as urban planners and architects there is an increasing awareness of the positive effects of bicycling and the need to include it in planning and design of the built environment. From personal experiences, bicyclists know that route choice as well as speed are strongly influenced by the character of the terrain, by mode and amount of traffic on route, and by type and quality of the streets, lanes and paths that together constitute the route network for bicycling. Nevertheless, most contemporary urban and traffic planning practice handles bicycling only schematically. Typically, current tools for analysing bicycling rely on templates based on fixed speeds, paying little attention to variations in the type of bicyclist or explicit properties of bicycle routes and their context. Concerning amounts of bicycling, such as modal share of daily commuting on bicycle or numbers of bicyclists on specific routes, current policy and planning is often based on assumptions of a general percentage increase over the entire bicycle network, regardless of route location within this network and particular properties of those routes (Nilsson, 2013). As long as these simplified assumptions form the basis for analysis, it will be hard to make reliable comparisons of alternative proposals for bicycle infrastructure investments, for instance by means of cost and benefit analyses. Current transport modelling tools typically include numerous variables for transportation demand, distance measurements and route capacities, but scarcely take into account urban form variables related to the cognitive ease of route finding or the directness and smoothness of routes, variables that have proven to be essential for bikeability of the built environment (de Groot, 2007). In general, analyses that do not explicitly include urban form variables provide little support to urban planning and design in relation to bikeability. Therefore, from the perspective of traffic planning as well as from the perspective of urban planning and design, it would be useful to have more refined and user friendly methods for predicting speed and amount of bicycling.

In previous space syntax based modelling of bikeability at the neighbourhood scale, metric distance has been the standard measure for grasping peoples' preferences for convenient travel (Manum and Voisin, 2010; Manum and Nordstrom, 2013; 2015). However, due to the wide range of possible travel speeds, type and quantity of daily communing depends much more on travel-time than on metric travel-distance. By measuring only metric distances, previous models do not take the influence of different bicycling speeds into account; speeds that vary a lot depending on type of bicycle and bicyclist as well as on numerous features of the built environment. Hence, improved modelling of bikeability requires improved knowledge about the variation in bicycling speeds and how the built environment influences this. According to transportation research, speed along the bicycle network is also important regarding bicyclists' route choices (Broach, Dill and Gliebe, 2012). Therefore, understanding and measuring bicycle speed potential is a basis for understanding bicycle flow potentials. Besides being useful for design of bicycle routes and related issues of urban form, improved estimations of bicycling speeds and bicycling flows should also be applicable to traditional transport models, since transport quantities and travel times for different transport modes are basic issues in analysing transport mode choices.

The aim of this research project has been to contribute to developing methods for modelling bikeability of the built environment. More explicitly, the aim has been twofold. First, for a better understanding of how street properties affect speeds, to develop an empirically based model for estimating bicycle speeds in inner city environment. Second, for understanding how urban structure, in terms of spatial configuration and density and a combination of the two, influences bicycle flows: to examine the relationship between aggregated bicycle flows and a set of space syntax based measures.

2. BACKGROUND

2.1 SPACE SYNTAX MODELS VERSUS TRAFFIC MODELS

Motorised travel is a highly technological and regulated activity, where the individual interacts with the environment mediated by the vehicle and the technical mobility infrastructure following strict sets of rules. Walking and bicycling, on the other hand, are shorter and slower travel modes, sensitive to environmental conditions and closely interacting with the urban context. This kind of interaction between built form and movements of people is a field where space syntax models have proven to be highly useful.

Differently from typical traffic models, the object of analysis in space syntax models is the built environment rather than mobility flows. This does not imply that space syntax models are representations of the physical environment. Rather that they are representations of what is called affordances (Gibson, 1986), that is, what a given environment affords (i.e, presents potentials for) a certain ability in an agent (Gibson, 1986: 127). Hence, they do not model either the physical environment or human activity, but what emerges in the meeting between properties of the physical environment and both physical and cognitive human abilities (Marcus, 2015). This is of principal interest to both urban and traffic modelling, since it presents a way forward in overcoming the subject-object dichotomy often found at the foundations of both urban and traffic modelling. We may, for instance, imagine models extending the space syntax approach to different traffic modes, where the built environment offers particular affordances for different vehicle types, creating what has been called modality affordances for the different locations within an urban landscape (Gil, 2016). Finally, there is reason to stress that current space syntax-models, in comparison to most models of cities as complex systems (e.g. Batty, 2013), are static in that they do not include a time variable. They are not predictive simulations, but rather descriptive models preparing for analysis. One may say that by modelling structure as affordances in the manner described above, they in a sense do capture process, that is, the potential for particular human activities created by a set of affordances, but they do not capture process where these affordances in themselves change over time.

2.2 SPACE SYNTAX BASED STUDIES ON BIKEABILITY

With the development of space syntax theory, measures and software, space syntax analyses have proven useful for modelling the bikeability of street networks (McCahill and Garrick, 2008). There have been two major space syntax developments in this respect. One is angular segment analysis, measuring network distance by taking into account the angles between intersecting street segments (also termed angular distance or angular depth). This is different from measuring network distance as topological steps of lines being either connected or not, as is the case in traditional space syntax axial analysis (Turner, 2001; 2005; 2007; Hillier and Iida, 2005; Hillier et al., 2012). The other is the development of software combing space syntax and GIS, such as the Place Syntax Tool (Ståhle et al., 2005). Raford et al. (2007) examined bicycling in London by means of shortest routes, space syntax integration using angular depth and other spatial configuration measures, and found "angular minimisation" to be essential for bicyclists' route choice, particularly for bicycle flow potentials at aggregated level.

The other development emerges from bicycling studies in the cities Trondheim and Oslo. These studies combined space syntax choice and integration measures within metric distance thresholds (radii) with the analysis of locations of residents, workplaces and other destinations at individual address-points applying the Place Syntax Tool . One result was that high values of street network integration around workplaces was significant for modal share of bicycling, while integration around home locations was not (Manum and Voisin, 2010). Furthermore, the studies of Trondheim showed convincing correspondence between bicyclists' route choice (as found in the empiric study) and segment angular choice with a metric radius. These analyses have proven useful for understanding bicycle potential of the existing bicycle route network and for illustrating the likely performance of alternative urban planning and design proposals (Manum and Nordstrom, 2013; 2015).

In the studies of Oslo, based on the methods developed in the analyses of Trondheim, the mapping included several variables in addition the space syntax street network configuration measures. Among these were perceived danger from heavy traffic, perceived social danger/ safety from a lack of people and activities (particularly at night), and attractiveness of routes from the presence of parks, sea/water and other kinds of natural features. Based on the thorough mapping of these aspects of bikeability, the municipality of Oslo has developed ambitious plans for improving the bicycle route network. The analyses of Oslo showed that the choice or betweenness centrality measure is far from sufficient for estimating bicycle flows (Manum and Nordstrom, 2015). Or to put it somewhat different: the measure grasps the potential bicycle flows of the street segments in a bicycle route network, but due factors not captured by the measure, this potential is often hard to achieve. The main reason is perceived safety in terms of fear of being injured at streets cramped by cars, trucks, buses and trams. Instead, many bicyclists use less direct and longer routes that they consider safer.

A conclusion from the Oslo studies is that traffic safety together with bicycling speeds are the main issues regarding bicyclist' route choice. In addition, and even more important if aiming to increase modal share of bicycling in daily commuting, traffic safety is the main reason for people interested in bicycling not to commute by bicycle. This is in particular the case for women (Nordström, 2013). In conclusion, the studies of Oslo indicate that there is great need for examining bicycling speeds and for including both safety and speed in bikeability modelling. This, together with the research of Dalton (2015) and Broach et al. (2012) arguing for the inclusion of "impedance" along routes in space syntax measures that use spatial and cognitive distance, is the background for the bikeability modelling explored in the case of Gothenburg presented in this paper.

3. METHODS AND MEASURES

3.1 EXAMINING SPATIAL POTENTIAL FOR BICYCLE SPEED ALONG ROUTES

For examining speed potentials, we mapped the speeds of real bicycling along a selection of bicycle routes in Gothenburg. The routes were chosen for being representative of the bicycle route network of Gothenburg and for being relevant references for the planning and design of future bicycle routes. The number of routes examined was 7 and their total distance measured in both directions was 13 km. Figure 1 shows the selected routes.

Then, 15 bicyclists were selected and recruited, representing a variety of daily commuter bicyclists, being between 20 and 66 years old, using different kinds of bicycles and some dressed for exercise while others for relaxed bicycling. In order to check the representativeness of the sample, we carried out a survey on 2000 bicyclists in the same areas of Gothenburg, checking for clothing, bicycle types, gender and likely age. The selected sample showed to be fairly representative, with some bias towards too many participants in the 21 to 35 age range. In order to capture bicycling as daily commuting, the survey was carried out between 07:30 and 09:30 and between 16:00 and 18:00. The speed measurement was done by GPS-tracking with "Cykelstaden", a software application developed by the traffic office in Gothenburg, together with Clickview, their software for handling the data, mapping the routes and speeds of a total of 875 bicycle trips.

The next part of the study consisted in mapping variables likely to influence bicycle speeds. Since the variables reduce or increase the speed of bicycling, they can be considered speed

Figure 1 - Bicycling routes of the study and the median speeds along the route segments.

impedances of the routes. Impedance is a term used in transport analysis meaning resistance to movement, analogous to physics, where impedance measures resistance to electrical current. The street segments, based on a road centre line data set, were processed to create a street network model adapted to capture the different impedances used in this study.

The street segments representing the routes were modelled as a bi-directional system, i.e. with one element in each direction. The street sections between junctions were subdivided into a number of segments that based on their length would give approximately constant bicycling speeds. Breaking and acceleration around junctions was handled by creating a separate segment within 20 meters from each junction. Streets were also subdivided by the kind of bicycle route (see Table 1); in the cases where the kind of route was not constant between junctions, the street was subdivided into segments consisting of only one kind of route. Based on the bicycle speeds' correlates with street curvature described by de Groot (2007), streets with sharper curves than a radius of 10 meters were subdivided into five segments: the curve, adjacent segments of 20 meters (2 pc.) and the remaining ends of the street (2 pc.). Segments where slope varied much were subdivided into lengths with little variation of slope, using the categories 0-2% slope, 2-4% slope and so forth. Finally, the speed impedance variables for the individual segments were assigned, using in the categories listed in table 1.

	Impedance variable	Categories / Units
1	Kind of route	• "pedestrian street, walking-speed street" (walking and bicycling merged) • "slow bicycling-speed street" • lane for bicycling at same level and not physically separated from car traffic • one-way separate lane for bicycling • two-directional separate lane for bicycling • bicycling and walking lane (merged, but separate from car traffic)
2	Width of bicycle lane	• Metres
3	Kind of bicycle lane surface material	• Asphalt • Concrete • Natural stones • Gravel
4	Kind of separation from pedestrians	• Furniture, vegetation etc • Height difference (different level) • Different surfaces
5	Slope	• Percentage (%)
6	Horizontal curvature (radius)	• Degrees
7	Length of segment	• Metres
8	Distance between junctions	• Metres
9	Segment connected to junction	• Yes \ No
10	Entrances along segment, within 15m from segment	• Count / 100 metres (All kinds of entrances to buildings, within straight line distance)
11	Entrances along segment, within 30m from segment	• Count / 100 metres (as previous)
12	Car parking	• Yes \ No
13	Bus stop	• Yes \ No

Table 1 - Impedance measures assigned to street segments

Unfortunately, the GPS application failed to deliver reliable data concerning waiting times at each intersection, making it impossible to examine the total impedance along routes at the current stage. Therefore, the next step of the research should include a supplemental study on speeds and waiting times at intersections. To estimate speed-models including many dimensions such as impedances along routes and categories of bicycles and bicyclists requires extensive GPS data (El-Geneidy et al.,2007; Romanillos et al. 2016 ;Arnesen et al. ,2017). A way to gather detailed route specific covariates in proceeding research without laborious manual work, is to collect sensor data such as data from an Inertial Measurement Unit (IMU), see Mohanty, Lee et al. (2014) and the references therein, applying for instance accelerometers measuring smoothness of road surface as well as very detailed information of the bicycling speed.

The final step in modelling consisted in assigning the value of each impedance variable to every separate street segment. Some variables, such as slope, curvature and length of segments, were generated automatically from GIS. Others, such as kind of route, surface, width and separation type, required a combination of examining ortho-photos and site surveys. All the variables of speed impedance modelled in GIS are the data to be compared with the empirical data of bicycling speeds extracted from the GPS-tracking.

All the impedances considered were added to the statistical model for calculating their impact on bicycle speed. To find the most important independent variables and test their significance, a multiple regression analysis (OLS) was performed. The level of significance used was 0.05. Finally, the R2 value was calculated to see how much of the measured variation could be explained by the variables in this this study.

3.2 EXAMINING STRUCTURAL SPATIAL POTENTIAL FOR BICYCLE FLOW ALONG ROUTE

The second part of the method, modelling flow potential, is based on space syntax theories and measures. Flow potential is here about predicting the amount of bicyclists along street segments. It is not based on the impedance of the segments like the speed model, but rather on their location in the street network relative to all other segments. Segments with higher network centrality according to various measures are expected to have more bicyclists due to their higher potential, which can be interpreted as being more important for the network as a whole.

The empirical data used were gate counts of bicycle flows at 174 points, conducted by the municipality of Gothenburg in 2014 (Björklind, 2015). The counting was done during rush hours 07:00-09:00 and 15:30 – 17:30 and during lunchtime 11:30-13:30. In this project, the unit applied is the daily average of these counts, measured as number of bicyclist per hour.

The next step consisted in identifying the urban form variables to examine. The street-network model examined was a bicycle route segment map based on an axial line map provided by the consultancy firm Spacescape. The selection of variables was based on experience from previous research. Altogether, 21 street-network analyses were conducted, examining 6 spatial measures and 3 different distance thresholds for each measure (Table 2).

Measure	Analysis parameters
Axial integration	Topological distance, topological radius along the network (7, 12, N)
Segment angular integration	Angular distance (least angular change), metric radius along the network (3000, 5000, 10000 m)
Segment angular choice	Angular distance, metric radius along the network (3000, 5000, 10000 m)
Accessible population	Total number of residents and workplaces, metric radius along the network (3000, 5000, 10000 m)
Attraction betweenness	Angular distance, metric radius along the network (3000, 5000, 10000 m), with accessible population as attraction weight.
OD-betweenness	From residents origins to workplaces and enrolled students and vice-versa, angular distance, metric radius (3000, 5000, 10000 m)

Table 2 - Spatial network measures calculated

Besides the commonly used measure of axial integration, segment angular integration and choice, calculated in Depthmap 10, we also examined two variations of the space syntax choice measure recently implemented in the Place syntax tool (Ståhle et al, 2005), called Attraction betweenness and Origin-destination betweenness or OD-betweenness. Attraction betweenness, as used by Berghauser-Pont and Marcus (2015), is similar to segment angular betweenness in terms of scoring each segment along the shortest angular route, but differs by multiplying the score with an "attraction". In this study, examining potential flows of bicycling, the "attractions" are the population accessible within a metric threshold distance. In OD-betweenness, each segment is scored for being on the shortest routes between a set of origins and a set of destinations, instead of routes between all nodes of the network. The score, assigned to the segments, is a combination of the weight of the origin (number of residents) multiplied by the normalised weight of the destination (i.e. dividing the destination weight by the sum of all destination weights). The network analysis in this study operates on three data sets: a set of address points of residents (the origins), a network graph of segment lines representing all possible routes and a set of address points of workers and enrolled students (the destinations). Every address point is linked to the nearest axial segment in the network. First the calculation uses metric distance for the radius threshold, then, it uses angular distance (least angular change) for the shortest route calculation, as specified in the parameters of the spatial measures in Table 2.

Whereas the first regression model deals with speed potential, the second regression model deals with flow potential, mainly testing structural properties of the street segments related to all the other segments in the network. Similar to the first, multiple regression analysis (OLS) is used to test various predictor variables and find their significance and importance in explaining the variation in the observed bicycling flows.

4. RESULTS

4.1 THE SURVEY DATA

Table 3 shows a summary of the GPS speed data, whereas Table 4 shows the results for each of the 7 routes. Figure 1 maps the speeds along the routes by colour range, showing speeds in both directions. The results include all segments except the 20 m segments closest to junctions. These segments are excluded due to an automatic functionality of the GPS-unit causing unreliable speed data close to or in combination with full stops. As expected, due to the slope, bicycling speeds at the hill north of the river are among the fastest as well as the slowest, depending on direction of travel. Not surprisingly, we also see that speeds are very low on routes including numerous traffic-light junctions, such as parts of Östra and Västra Hamngatan, see Figure 1. The average speeds differ significantly across different routes, being 40% slower at Västra Hamngaten than at Göta Älvbron, 13 and 21 km/h, respectively. This illustrates the need for developing models handling bicycling speeds as a measure dependent on route properties at a detailed scale. The range of speeds is similar to former studies dealing with bicycle speeds. Most studies show free flow speed varying between 14 km/h and 20 km/h in urban contexts (El Geneidy et al., 2007; Cheng Xu et al., 2015).

	Median speed	85 percentile
Göta älvbron	21	30
Lindholmsallén	21	27
Vasagatan	18	24
Nya allén	16	26
Kyrkogatan	16	20
Östra Hamngatan	14	24
Västra hamngatan	13	23

Table 3 - Summary of speed tracking on the bicycle routes, averaged for both directions

4.2 THE BICYCLING SPEED MODEL

The first analysis, examining impedances expected to affect the median speed on the street segments, shows that nine predictors are significant and contribute to the explanation (see table 5). Their explanatory usefulness varies, but not to a large extent. The variance inflation factors (VIF) show that the variables do not covariate to any considerable amount. The F-value for the whole model is significant, which shows that at least some of the prediction variables contribute to the explanatory power of the model.

	Unstand.		Stand. Coef			Correlations			Collinearity Statistics	
Model	Coef.	Std. Error	Beta	t	Sig.	Zero order	Partial	Part	Toler-ance	VIF
(Constant)	14,491	,905		16,007	,000					
Connected signal intersection	-5,430	,454	-,486	-11,972	,000	-,452	-,573	-,470	,934	1,070
Number of entranes_ 30 meter	-,025	,008	-,147	-3,014	,003	-,317	-,173	-,118	,652	1,535
Slope downhill	,999	,159	,256	6,297	,000	,353	,345	,247	,932	1,073
Pedestrian street	-2,399	,796	-,148	-3,013	,003	-,272	-,173	-,118	,640	1,562
Double sided bicycle track	1,350	,354	,171	3,813	,000	,249	,217	,150	,764	1,308
Horizontal curvature	,029	,009	,134	3,331	,001	,062	,191	,131	,960	1,042
Length of segment	,012	,003	,210	4,294	,000	,309	,243	,169	,644	1,554
Slope uphill*segment lenght	-,005	,001	-,171	-3,684	,000	-,040	-,210	-,145	,716	1,396
Natural stone	-1,193	,470	-,120	-2,537	,012	-,236	-,147	-,100	,687	1,455

Table 4- The results of the multiple regression analysis (OLS) for median speed potential.

Model Summary[j]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
Table 5	,740i	,548	,534	2,68861	,010	6,434	1	293	,012

i. Predictors: (Constant)
, Connected signal intersection
, Number of entrances_30 meter
, Slope downhill, Pedestrian street
, Double sided bicycle track
, Horizontal curvature
, Length of segment
, Slope uphill*segment length
, Natural stone

j. Dependent Variable: Median speed

Table 5 - Summary of the multiple regression analysis for median speed potential.

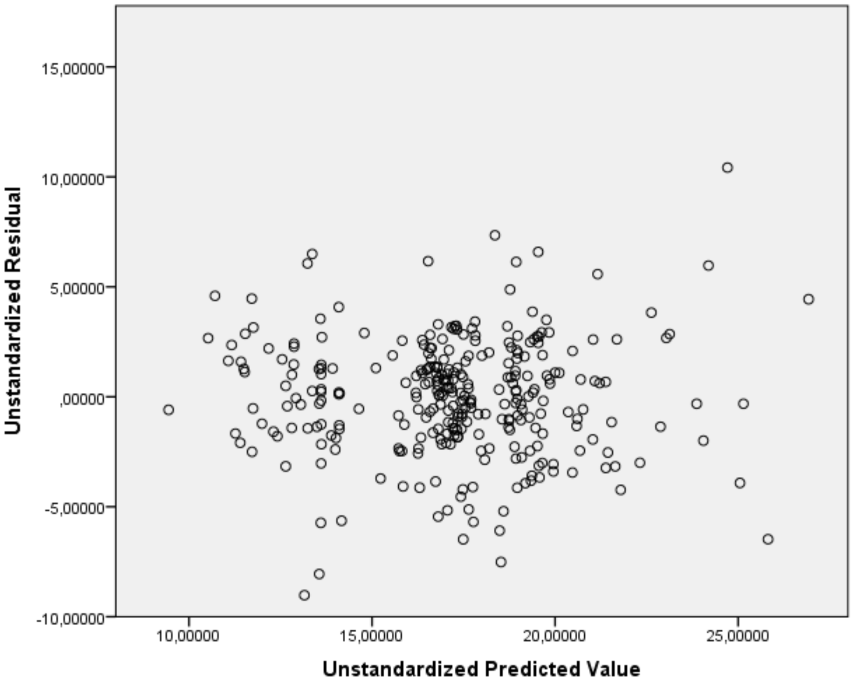

Figure 2 - Residual plot for speed model.

Figure 2 shows the residual plot for the speed model. Even though the plot seems fairly random, it is not completely ruled out that the residual plot can hide some variable not taken into account, for example prevailing wind directions and delays caused by congestion. The R2 of the model is 0.54, which mean that the selected variables explain 54% of the speed variations (table 6). Having the complexity of bicycling flows in mind, this is an acceptable result, particularly when also having in mind the potential improvements that can be made to the model in the future. One example is to the effect of slope, which currently is modelled in intervals, but with continuous modelling the effect might improve the model. Figure 3 shows the median speed from the GPS data (left) compared to the median speeds estimated by the regression model.

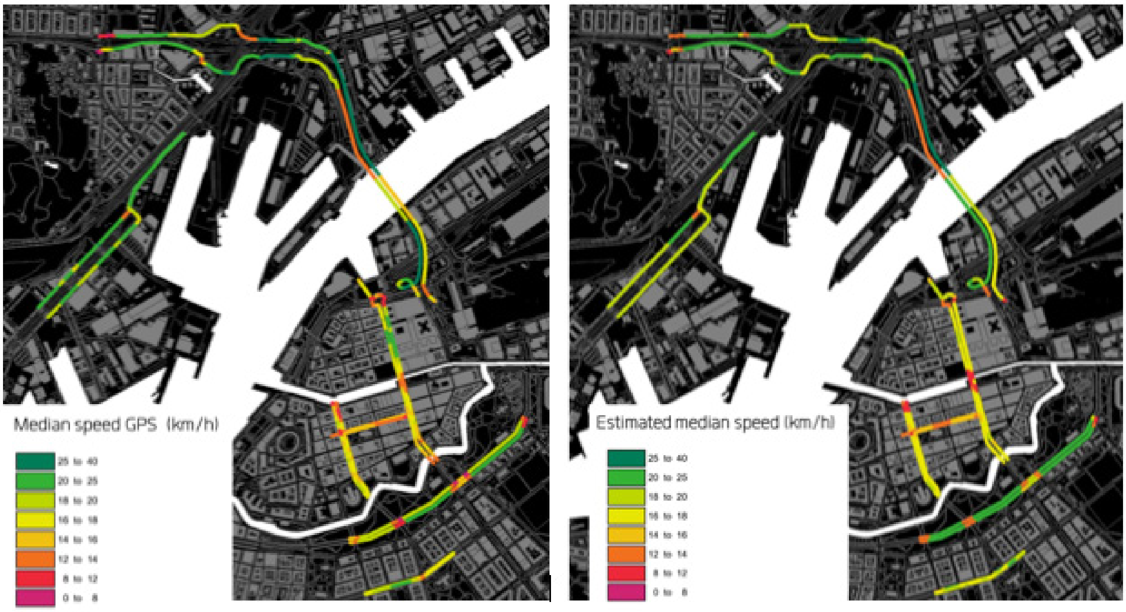

Figure 3 - Speed from GPS-tracking (left) and estimated by the model (right)

4.3 THE BICYCLING ROUTE MODEL

The second model, dealing with network measures expected to predict the potential for bicycle flows, also explains the measured variations to a fair extent. All variables are significant and contribute to the explanatory capability of the model. Their explanatory power varies, according to the coefficients seen in table 7, but not to a large extent, and OD-betweenness is the most significant. This can be explained by the fact that OD-betweenness can be considered to measure the potential amount of bicycle trips to work, which according to travel survey data is the most frequent bicycle trip in Sweden (Saxton, 2015).

At first glance surprisingly, accessible population within 1 km correlates negatively with bicycle flows. Looking closer, the variable has a positive correlation up to a certain accessible population, and is negative in the densest parts of Gothenburg. This explains that accessible population is a proxy for low speed potential, which implies that bicyclists choose alternative routes in less dense parts of the city. This corresponds to the results related to route choices in Oslo (Manum and Nordstrom, 2015).

	Unstand.		Stand. Coef			Correlations			Collinearity Statistics	
Model	Coef.	Std. Error	Beta	t	Sig.	Zero order	Partial	Part	Toler-ance	VIF
(Constant)	,648	,585		1,108	,270					
OD betweenness least angular within 5000 m	2,882E-05	,000	,258	3,709	,000	,507	,286	,220	,725	1,380
Segment angular integration within 10 000 m	,002	,000	,635	5,763	,000	,550	,421	,341	,289	3,461
Attraction density (population within 1 000 m)	-1,525E-05	,000	-,326	-3,209	,002	,239	-,250	-,190	,339	2,953
Network betweenness (shortest route within 3000 m)	4,080E-07	,000	,141	2,030	,044	,416	,161	,120	,728	1,373

a. Dependent Variable: log_y

Table 6 - Multiple regression analyse (OLS). Bicycle flow potential

A closer look at variance inflation (VIF) shows larger values than the first analysis, up to 3,4 seen in table 7, although they are judged to be acceptable in this analysis. The F-value for the whole model is large and significant, which indicates that at least some of the predictors contribute to the explanatory power of the model. The residual plot from the analysis is random.

Model Summary[j]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
Table 7	,679[i]	,460	,446	,61644	,460	32,853	4	154	,000

i. Predictors: (Constant)
, Nbe_Walk_3000
, Axial_Aac_Boende_Arbetande_Walk
, Odb_5000_stud_deg
, T1024_Integration_R10000_metric

j. Dependent Variable: log_y

Table 7 - Model summary for bicycle flow potential

Finally, the R2 of the model is 0.45, which mean that 45% of the variations in the measured flow can be explained by the selected predictors. This is lower than the speed model result (0.45 compared to 0.54), and can be explained by the large number of relevant issues not included in the model. Some variables that according to research are essential for route choice not yet included in the model are the differences in speed and the feeling of safety and comfort (Spacescape, 2015). For example, some fast commuter routes along the water have low betweenness values while they have many bicyclists. On the other hand, many of the busiest streets have high betweenness values but few bicyclists. This confirms patterns found in previous research (Manum and Nordstrom, 2015). The discrepancy of the betweenness measures and flows of bicycling at particular kinds of routes can be explained by bicycling speeds and traffic safety. The separate commuter routes allow for convenient and fast bicycling, implying that bicyclist choose these routes for being the quickest and easiest despite unfavourable metric distance. Regarding the busy central streets, these are often crammed with traffic, in some cases large amounts of cars as well as trams and buses, and in other cases pedestrians. The first cases are dangerous for the bicyclist; the second cases force the bicyclist to slow down and give priority to pedestrians. In both cases, it is often more convenient, safer or quicker for the bicyclist to choose alternative routes, even though they might be longer in metric distance or cognitively less direct. To conclude the discussion of the results, a possible issue with the bicycle network representation should be mentioned. An important measure in the analysis is angular change at junctions. This research project used an axial map produced for other purposes, without comparing the angles at junctions in this axial map with the geometries of real bicycling routes through junctions. Such comparisons should be part of future research, likely resulting in more detailed modelling of lines at junctions and an improved model.

5. CONCLUSIONS

This project illustrates the variety of bicycling speeds along urban routes and sheds light on the relative influence of some particular bicycle route variables significant for bicycle speeds. In addition to the obvious result that downhill slopes correlate with higher speeds whereas signal crossings correlate with lower speed at adjacent segments, the most significant of the variables examined were: many entrances along the segment (-), mixed use with walking (-), two-way bicycle lanes (+), radius of curvature (+) and length of segment (-). As mentioned earlier in the paper, there is a need to handle bicycle speed and route properties at a detailed scale. In the work of Arnesen et al. (2017), a Markov model for predicting bicycle speed along a route with high resolution considering vertical and horizontal curvatures is being developed for this purpose. In this Markov model, the speed in the current road segment is dependent of the speed in previous and future segments, providing more realistic speed profiles. A suggestion for further work is therefore to include the larger variety of covariates presented in this paper into this more advanced methodology of speed modelling.

Regarding bicycle flows, the project has examined a selection of space syntax based spatial measures, measures that can be mapped directly from GIS. The latter is important to apply the analysis tools on large urban systems. The most significant variables regarding bicycle flows are OD-betweenness least angular change within 5km (+), segment angular integration within 10 km (+), accessible population within 1 km (-) and network betweenness (as shortest distance) within 3 km (+). Even though bicycle flows are influenced by many personal, social and economic issues to ever be fully grasped by space syntax models and GIS-analyses, this project shows that several of the measures examined, particularly the OD-betweenness, convincingly capture the main patterns of bicycle flows. Due to the importance of bicycle speeds and traffic safety on route choice and these issues not being included in the current model, adding variables influencing those factors should significantly improve the correlation with flows of real bicycling.

Based on this conclusion, the main issues for future research are to examine how speed differences, perceived safety and convenience can be analysed in GIS based tools that include space syntax measures. One way of achieving this is to convert traffic safety and convenience into added travel time. This method has been discussed in transport research (Ellis, 2015) and is currently work in progress within the research project Stratmod (Norheim and Tørset, 2015) where impedance values from the aforementioned report is used to calculate generalised time for each road segment. Another option, suggested by Dalton (2015) is to add impedances into a spatial configuration model by converting impedances, for instance the effect of traffic signals, into weights added to topological distance. Based on the results of the current project, our approach to further research will be to elaborate on the OD-betweenness analyses by including speeds and ideally traffic safety into the betweenness measure. The first step, in addition to improving the speed model to include the range of speeds caused by different kinds of bicycles and bicyclists and by impedances along routes, will be to convert speeds on the segments into time and then apply trip time rather than metric distance as the radius/threshold unit in the spatial analyses. By measuring time along segments (intersection impedances included), it should be possible to develop a new and improved generation of space syntax based accessibility analyses - analyses where the bicycling potential of a bicycle route network is based on spatial configurations but also on "time and convenience" of real bicycling at the routes. A working title for the new measure is "least impedance origin destination betweenness".

ACKNOWLEDGEMENTS

This research project on measuring bikeability has been supported by the Traffic Office in Gothenburg together with Chalmers Architecture and Chalmers Transport.

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