The Effects of Street Connectivity upon the Distribution of Local Vehicular Traffic in Metropolitan Atlanta

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Abstract
Using Georgia Department of Transportation Average Annual Daily Traffic Counts for 13 counties in the Atlanta Metropolitan Region, we draw a distinction between streets where traffic is influenced by configurational and density variables and streets where traffic is influenced by street width and distance from center. Our findings suggest the need for a more explicit configurational theory of urban hierarchy than we currently have.

1. Introduction: how far does local street configuration affect the distribution of vehicular traffic?

This paper presents the results of analyses of traffic volumes in the Atlanta Metropolitan Area, as measured by the Georgia Department of Transportation (GDOT) in 3100 locations within 13 counties (4031 square miles) in the Atlanta Metropolitan Area, for the year 2001 (Figure 1). We choose this particular year so that traffic data can be related to population data from the 2000 US census. Our analysis looks at the effect of two network properties: street connectivity and street width. We also consider Euclidian distances from the City of Atlanta center, taken to be the City Hall. Finally, we consider population density, for which we have census block data, and the density of non residential development for which we have parcel based data. The density of non-residential development is taken as a proxy of employment density. We need a proxy because employment data is only available at the level of the traffic analysis zone, or the census tracts, which are not fine-grained enough for the purposes of our analysis. Population and non-residential development densities are computed within a 0.5 mile radius buffer surrounding each traffic count data point.

We decided to exclude all data points with more than 100,000 vehicles AADT, so as to not take into account freeways. After discarding freeways and data points for which some of the information is missing we are left with a sample of 2503 observations.

Our analysis uses a large data base to test whether the configuration of streets influences the distribution of vehicular traffic according to standard hypotheses in the field of “space syntax” (Penn, Hillier, Banister and Xu J, 1998; Barros Ana, Marques da Silva Paulo, Holanda Frederico, 2007). The literature of transportation studies has recognized the inadequacy of existing traffic models when it comes to understanding the effect of local street configuration (Cervero, 2006, 285). Thus, the development of measures of local street connectivity which are linked to the distribution of traffic flows has some larger potential value. While regional scale models have proven to be remarkably useful in transportation planning, and while the literature provides general conclusions regarding the effect of density on vehicle miles travelled at a metropolitan scale (Cameron, Kenworthy, Lyons, 2003, 267), there is a current preoccupation with the impact of local design and land use decisions on travel behavior (Crane, 2000, 3).

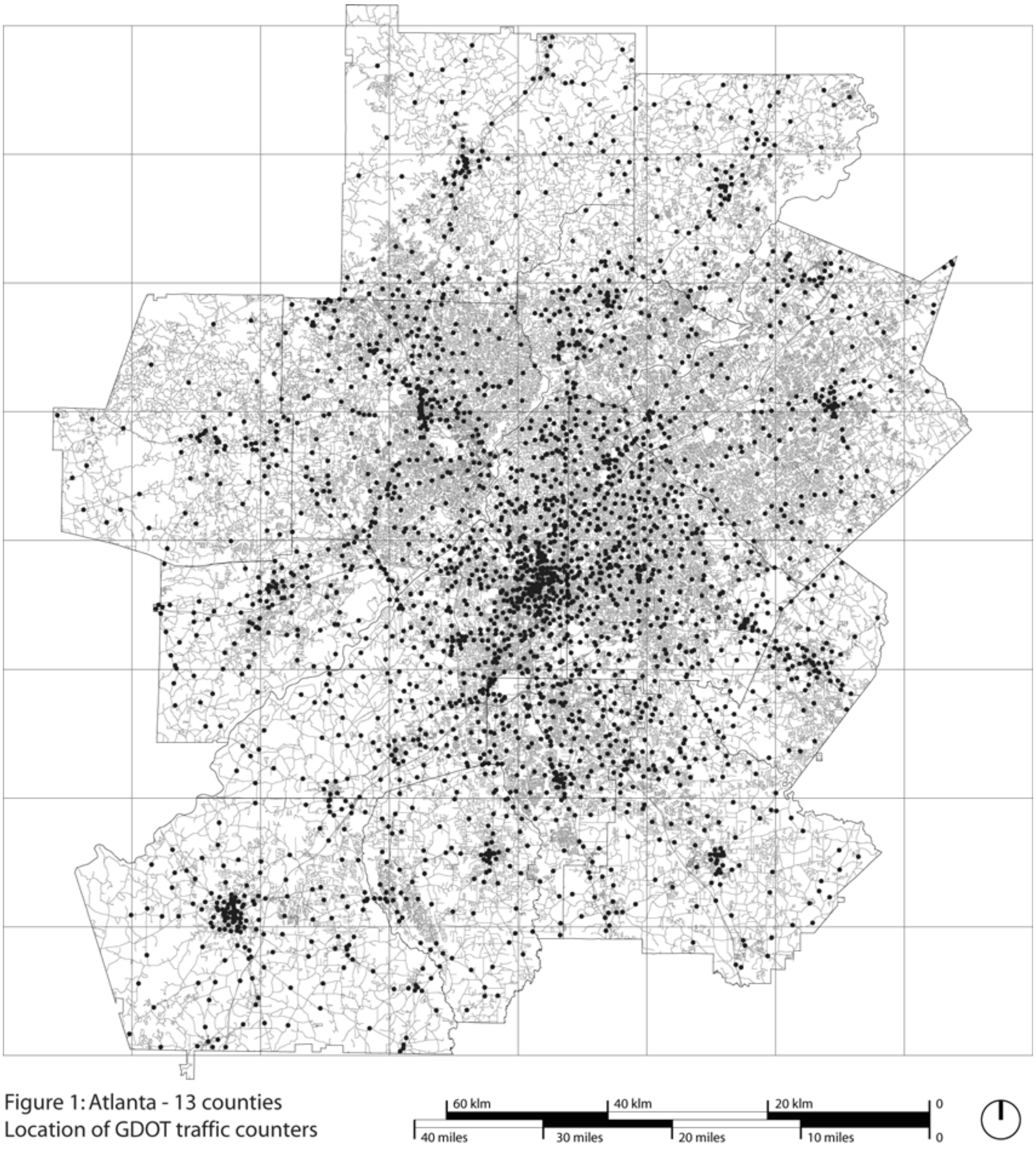


Figure 1: Atlanta - 13 counties
Location of GDOT traffic counters

Figure 1

The measures of street connectivity that we use here are metric reach, directional reach (Peponis, Bafna and Zhang, 2008) and global metric betweenness. Metric reach is a measure of street density: it is simply the total street length which is accessible from a street segment within a given network distance. Directional reach is a syntactic measure: it measures the total street length which is accessible from a street segment within a given number of direction changes, where a direction change is defined as a turn larger than a parametrically defined threshold. In this paper we use 5 miles 1 mile and 0.5 mile metric reach and 2 direction change directional reach at 30o threshold. We choose the 30o threshold because streets outside the old city-centers of the Atlanta Metropolitan Region tend to be quite curvilinear so that the 10o threshold we have often used in the past is likely to under-estimate the effective patterns of street continuity (Figueiredo, Amorim, 2005). The choice of

2 direction changes as a parameter is aimed at emulating the scale of traditional Integration radius 3 analyses. Reach values are computed for the mid-point of each road segment using Spatialist-lines, a GIS based software developed at Georgia Tech. Global metric betweenness is computed using NetworkX, a commonly available software. At this stage we have not been able to implement metric betweenness analysis within a parametrically specified range. Thus, the metric betweenness values express the extent to which a given road segment is a shortcut for all possible connections in the region. We should finally mention that betweenness values were calculated over a 10 county study area, thus consolidating a sample of 2160 observations.

2. The effect of street width and the distinction between wider and narrower streets

Table 1a, shows the linear correlations between logged traffic volumes and spatial variables – measures of reach, metric betweenness and width are also logged to better approximate normal distributions. While all correlations are significant, it is clear that street width has the stronger association with traffic volumes. This suggests that street capacity is associated with traffic volumes much more powerfully than street connectivity. Of the connectivity measures, directional reach is more powerfully associated with traffic volumes followed by 5 mile reach.

We run several linear regression models including width, distance from the City center, global metric betweenness and one of the reach measures at a time. As shown in Table 1b, multiple r2 values are between 0.506 and 0.550. Width always has the strongest standardized beta coefficient. However, adding the various connectivity variables noticeably increases the predictive power of the model.

Table 1a

	Log 0.5 mile metric reach	Log 1 mile metric reach	Log 5 mile metric reach	Log 2dc directional reach (30^o)	Distance from center	Log width	Log global metric betweenness
Bivariate r^2 values for AADT (2001) and spatial variables	0.073 (p=0.0001) (n=2503)	0.117 (p=0.0001) (n=2503)	0.177 (p=0.0001) (n=2503)	0.199 (p=0.0001) (n=2503)	0.040 (p=0.0001) (n=2503)	0.415 (p=0.0001) (n=2503)	0.127 (p=0.0001) (n=2160)

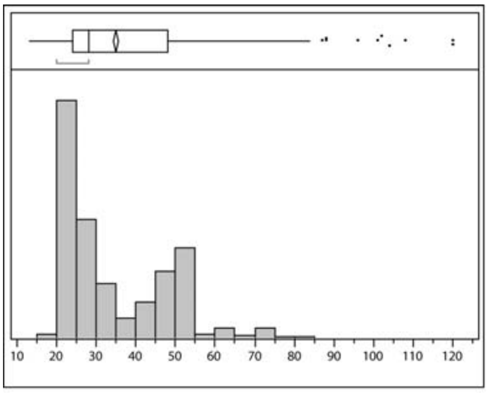
Table 1b

	Multiple r^2 values for AADT(2001) and spatial variables	Standardized beta coefficients			
		Width	Reach (see 1st column for specification)	Distance	Log global metric betweenness
Model includes width, 0.5 mile reach and distance	0.506 (p=0.0001) (n=2157)	0.605	0.150	0.193	0.273
Model includes width, 1 mile reach and distance	0.520 (p=0.0001) (n=2157)	0.585	0.217	0.238	0.270
Model includes width, 5 miles reach and distance	0.550 (p=0.0001) (n=2157)	0.547	0.423	0.415	0.238
Model includes width, 2 dir. changes reach and distance	0.536 (p=0.0001) (n=2157)	0.557	0.230	0.123	0.242

Table 1

Traffic volumes, street width, reach, metric betweenness and distances from City Hall; Table 1a *Linear correlation coefficients between logged AADT (2001) values and spatial variables – all data points;* Table 1b *Multiple regression models with logged AADT (2001) as dependent variable, and width, distance and a measure of reach as independent variables – all data points*

Given the strong association between width and traffic volumes we took a more careful look at the distribution of street width values. As shown in Figure 2, this distribution is bi-modal, with one peak around 25 feet (7.6 m) and the other around 55 feet (16.8 m). We decided to split the sample taking the mean as a break off point (34.8 feet – 10.6 m), because the mean also corresponds to the "valley" between the two "peaks" of the scatter-plot. As expected, the narrower streets have less traffic volumes than the wider streets. The mean AADT is 8895 and the median 7300 for the former; the corresponding values are 28460 and 25039 for the later. However, splitting the sample by street width is not equivalent to splitting it by traffic volume. The maximum AADT for narrow streets is 68000 while the minimum for wider streets is 800. Thus, wider and narrower streets overlap for a considerable range of traffic volumes.



Quantiles

100.0%	maximum	120.00
99.5%		84.00
97.5%		72.00
90.0%		52.00
75.0%	quartile	48.00
50.0%	median	28.00
25.0%	quartile	24.00
10.0%		21.00
2.5%		20.00
0.5%		18.52
0.0%	minimum	13.00

Moments

Mean	34.844586
Std Dev	14.527772
Std Err Mean	0.2903813
upper 95% Mean	35.413999
lower 95% Mean	34.275174
N	2503

Figure 2
Street Width Distribution (feet)

Table 2a

	Log 0.5 mile metric reach	Log 1 mile metric reach	Log 5 mile metric reach	Log 2dc directional reach (30°)	Distance from center	Log width	Log global metric betweenness
Bivariate r^2 values for AADT(2001) and spatial variables	0.116 (p=0.0001) (n=1548)	0.148 (p=0.0001) (n=1548)	0.146 (p=0.0001) (n=1548)	0.152 (p=0.0001) (n=1548)	0.018 (p=0.0001) (n=1548)	0.066 (p=0.0001) (n=1548)	0.160 (p=0.0001) (n=1248)

Table 2b

	Multiple r^2 values for AADT(2001) and spatial variables	Standardized beta coefficients			
		Width	Reach (see 1st column for specification)	Distance	Log global metric betweenness
Model includes width, 0.5 mile reach and distance	0.287 (p=0.0001) (n=1248)	0.170	0.312	0.217	0.376
Model includes width, 1 mile reach and distance	0.312 (p=0.0001) (n=1248)	0.153	0.397	0.278	0.359
Model includes width, 5 miles reach and distance	0.301 (p=0.0001) (n=1248)	0.178	0.469	0.401	0.311
Model includes width, 2 dir. changes reach and distance	0.293 (p=0.0001) (n=1248)	0.210	0.300	0.109	0.33

Table 2
Traffic volumes, street width, reach, metric betweenness and distances from City Hall – Only streets narrower than 34.8 feet are include; Table 2a: Linear correlation coefficients between logged AADT(2001) values and spatial variables – narrower streets; Table 2b: Multiple regression models with logged AADT(2001) as dependent variable, and width, distance and a measure of reach as independent variables – narrower streets

The results are shown in tables 2 and 3. The multiple regression coefficient for wider streets is marginally stronger than for narrower ones. In addition, the rank order of variables differs. For wider streets, width has the strongest impact, followed by distance from center. For narrow streets, either reach or betweenness have the stronger impact. Thus, our analysis suggests a clear distinction between the logic of traffic in narrower and wider streets. In narrower streets, traffic seems tuned to connectivity, independently of distance from center. In wider streets traffic seems conditioned by street capacity as well as distance from center. In the case of narrow streets, our analysis confirms the intuition that configurational variables play the major role in the distribution of traffic. In the case of wider streets, however, configurational variables seem to play a secondary role.

Table 3a

	Log 0.5 mile metric reach	Log 1 mile metric reach	Log 5 mile metric reach	Log 2dc directional reach (30^o)	Distance from center	Log width	Log global metric betweenness
Bivariate r^2 values for AADT(2001) and spatial variables	0.054 (p=0.0001) (n=955)	0.057 (p=0.0001) (n=955)	0.015 (p=0.0002) (n=955)	0.056 (p=0.0001) (n=955)	0.065 (p=0.0001) (n=955)	0.211 (p=0.0001) (n=955)	0.024 (p=0.0001) (n=912)

Table 3b

	Multiple r^2 values for AADT(2001) and spatial variables	Standardized beta coefficients			
		Width	Reach (see 1st column for specification)	Distance	Log global metric betweenness
Model includes width, 0.5 mile reach and distance	0.313 (p=0.0001) (n=912)	0.424	-0.044	0.259	0.203
Model includes width, 1 mile reach and distance	0.312 (p=0.0001) (n=912)	0.425	-0.025	0.266	0.202
Model includes width, 5 miles reach and distance	0.327 (p=0.0001) (n=912)	0.430	0.187	0.416	0.187
Model includes width, 2 dir. changes reach and distance	0.334 (p=0.0001) (n=912)	0.407	0.154	0.268	0.190

Table 3

Traffic volumes, street width, reach and distances from City Hall – Only streets wider than 34.8 feet are included; Table 3a*: Linear correlation coefficients between logged AADT (2001) values and spatial variables – wider streets;* Table 3b*: Multiple regression models with logged AADT (2001) as dependent variable, and width, distance and a measure of reach as independent variables – wider streets*

3. Taking density into account

In this section we extend the analysis by introducing population and non-residential development densities computed for 0.5 mile radius buffers surrounding the data points. Density is the primary spatial variable used in the transportation studies literature and so it is important to get a sense of whether the effects of street connectivity survive after density measures are introduced in our models. The reason we introduce 0.5 radius buffers at this stage, rather than larger ones, is to avoid excessive overlap between the buffer zones and thus to better differentiate local conditions. The analysis is presented in tables 4 and 5.

For narrow streets the addition of density values improves the linear regression model. However, the impact of density is less than the impact of configurational variables or distance from the center. For wide streets the addition of density values does not improve the linear regression model. Street width and distance from center remain the most powerful explanatory variables.

Table 4a

	Logged population density	Logged non residential development density	0.5 mile reach	2dc reach	Distance from center	Log width	Log global metric betweenness
Bivariate r^2 values for AADT(2001) and spatial variables	0.075 (p=0.0001) (n=1493)	0.132 (p=0.0001) (n=1548)	0.115 (p=0.0002) (n=1548)	0.152 (p=0.0001) (n=1548)	0.018 (p=0.0001) (n=1548)	0.066 (p=0.0001) (n=1548)	0.160 (p=0.0001) (n=1248)

Table 4b

	Multiple r^2 values for AADT(2001) and spatial variables	Standardized beta coefficients					
		Population density	Non residential density	Width	Reach (see 1st column for specification)	Distance	Log global metric betweenness
Model includes population and non residential densities, width, 0.5 mile reach and distance	0.323 (p=0.0001) (n=1207)	0.175	0.200	0.140	0.131	0.282	0.382
Model includes population and non residential densities, width, 2 dir. changes reach and distance	0.368 (p=0.0001) (n=1207)	0.234	0.174	0.150	0.248	0.263	0.327

Table 4

Traffic volumes, population density, non-residential development density, street width, reach and distances from City Hall – Only streets narrower than 34.8 feet are included; Table 4a*: Linear correlation coefficients between logged AADT (2001) values and spatial variables – narrower streets;* Table 4b*: Multiple regression models with logged AADT(2001) as dependent variable, and population and non-residential development densities, width, distance and a measure of reach as independent variables – narrower streets*

Table 5a

	Logged population density	Logged non residential development density	0.5 mile reach	2dc reach	Distance from center	Log width	Log global metric betweenness
Bivariate r^2 values for AADT(2001) and spatial variables	0.017 (p=0.0001) (n=945)	0.001 (p=0.437) (n=955)	0.054 (p=0.0001) (n=955)	0.055 (p=0.0001) (n=955)	0.065 (p=0.0001) (n=955)	0.211 (p=0.0001) (n=955)	0.024 (p=0.0001) (n=912)

Table 5b

	Multiple r^2 values for AADT(2001) and spatial variables	standardized beta coefficients					
		Population density	Non residential density	Width	Reach (see 1st column for specification)	Distance	Log global metric betweenness
Model includes population and non residential densities, width, 0.5 mile reach and distance	0.319 (p=0.0001) (n=905)	0.029	0.073	0.426	-0.087	0.261	0.202
model includes population and non residential densities, width, 2 dc reach and distance	0.336 (p=0.0001) (n=905)	-0.005	0.038	0.409	0.150	0.271	0.194

Table 5

Traffic volumes, population density, non-residential development density, street width, reach and distances from City Hall – Only streets wider than 34.8 feet are included; Table 5a*: Linear correlation coefficients between logged AADT (2001) values and spatial variables – wider streets;* Table 5b*: Multiple regression models with logged AADT (2001) as dependent variable, and population and non-residential development densities, width, distance and a measure of reach as independent variables – wider streets*

Thus, by taking density into account we further reinforce the distinction between the logic of wide streets and the logic of narrow streets. Traffic on wide streets seems unaffected by local conditions, while traffic in narrow streets seems determined by local conditions, with configurational variables exercising the primary role and density the secondary.

4. Discussion

We have shown that in a an area of 13 counties within the Atlanta Metropolitan region, street width alone explains 41% of the variance of Average Annual Daily Traffic volumes and that when configure-tional variables are added this is increased to more than 50% of the variance. Furthermore, we have drawn a distinction between narrow and wide streets and associated it with a distinction between local and global traffic. We can explain more than 30% of the variance in AADT for narrow streets with configurational variables exercising the strongest influence, followed by measures of urban density. We can also explain more than 30% of the variance in AADT for wider streets, but in this case neither urban density nor configuration seem to play a significant role. Rather, the variance of AADT for wider streets is explained by street width and distance from the City Hall of Atlanta. These findings point to a need for a theory of urban hierarchy that recognizes that the patterns of movement traversing an area may be dissociated from local conditions, both local patterns of street connectivity and local patterns of land development. The development of such theory is beyond the scope of this paper.

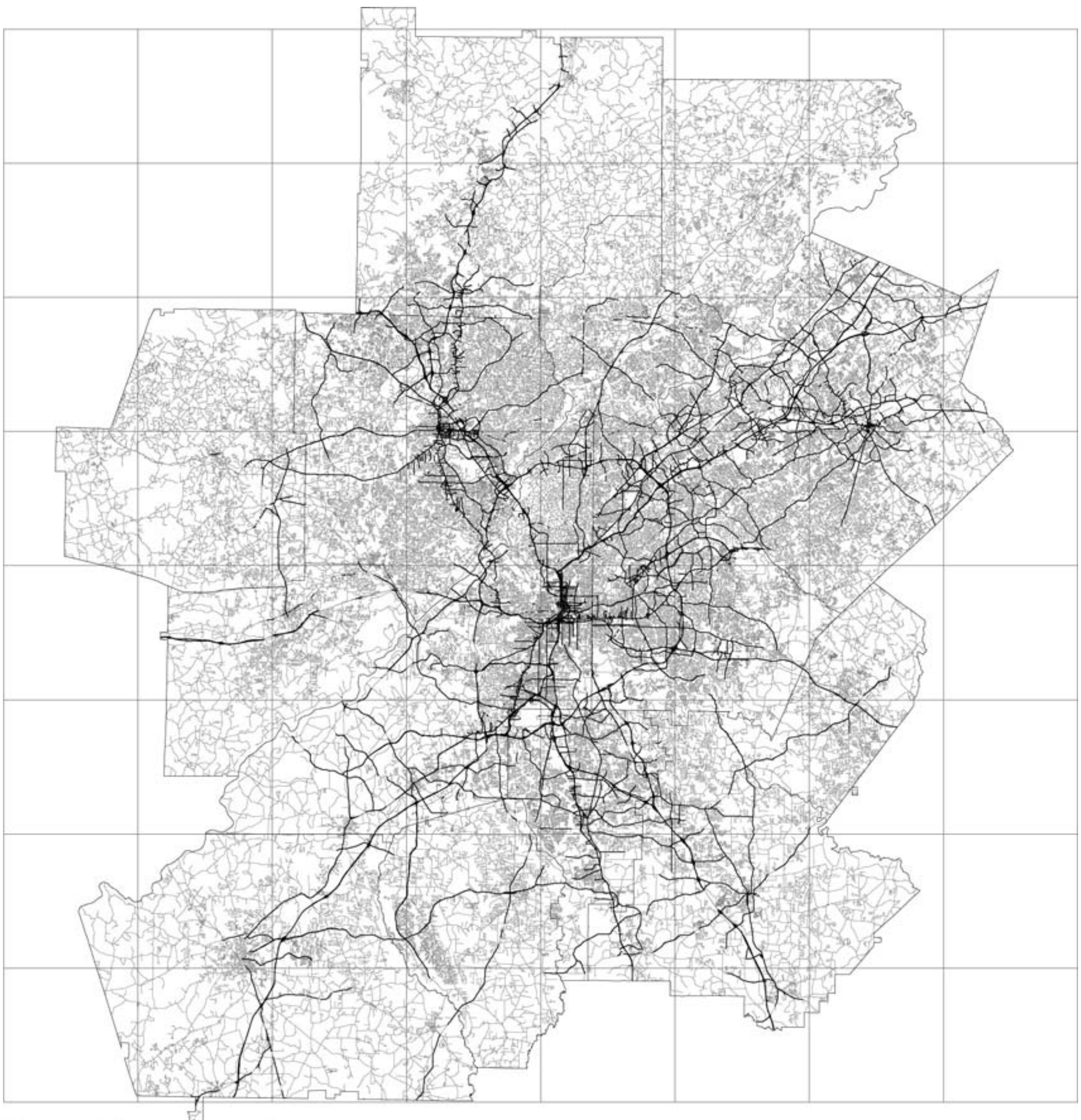


Figure 3: Atlanta - 13 counties
Street segments with directional reach
greater than 351 miles (Top decile)

Figure 3

Our analysis also raises questions regarding the interplay of configurational variables from a cognitive point of view. Betweenness measures the potential of each street as a shortcut, a potential that implies extensive familiarity with the surroundings. From this point of view, our analysis would seem to be particularly taxing, because at this stage we can only compute global betweenness values rather than values adjusted to local ranges. However, the fabric of Atlanta, with its characteristic fragmentation, and patterns of enclaves and cul-de sacs, is such that global metric betweenness is likely to correlate with metric betweenness for local ranges. In such a fabric, only a small minority of streets extend to make global connections. The majority function as local branching distributors or as perimeters of enclaves. Thus, betweenness may be easier to intuit once an area has been initially explored. Directional reach, on the other hand, is a measure of density biased to straight connections. Measures of density pick the focal points to which the urban fabric converges. From a cognitive point of view it is easier to intuit because it is readily linked to perceptual inputs – the alignment of streets.

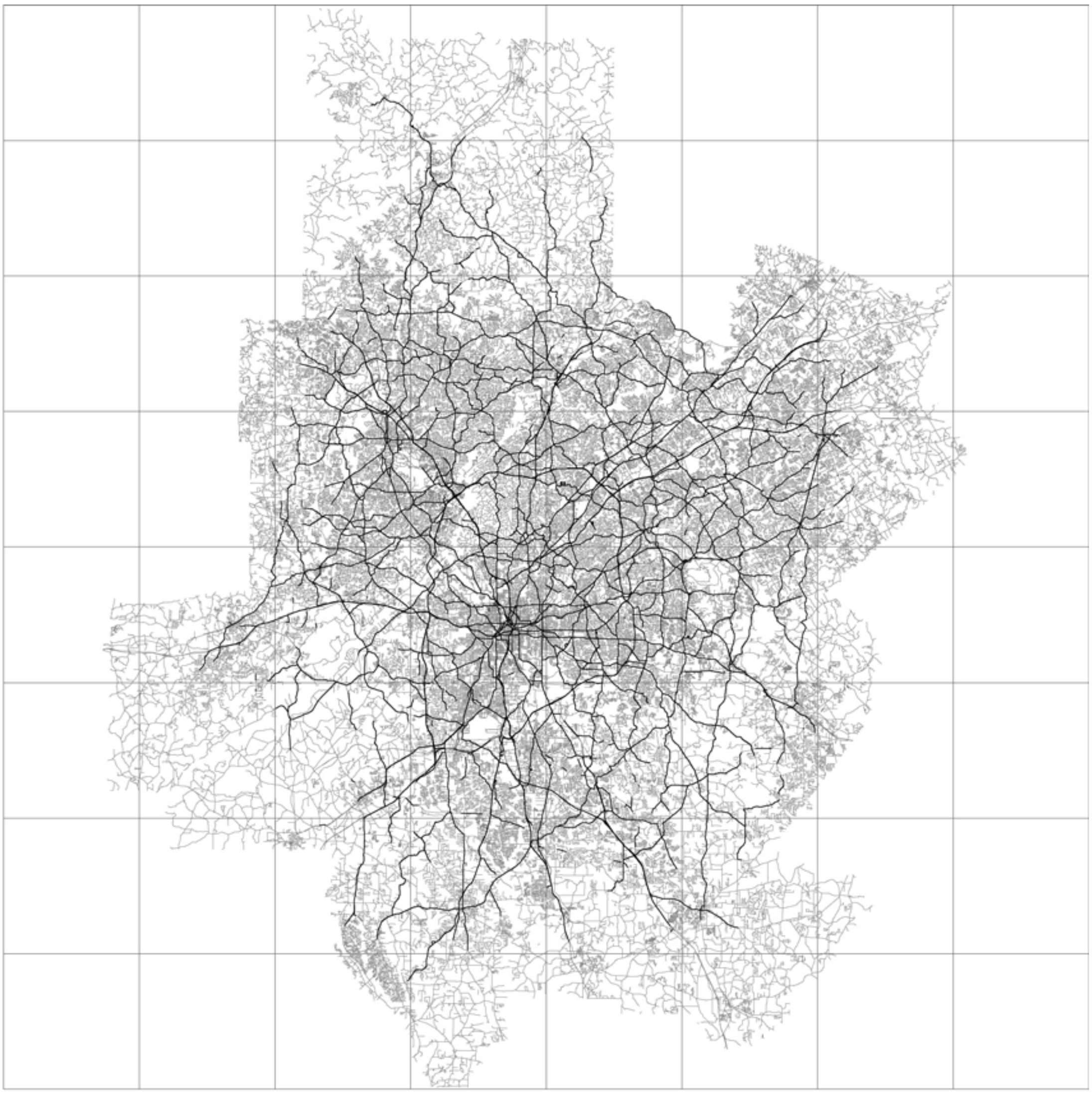


Figure 4: Atlanta - 10 counties
Street segments with metric betweenness greater than 21.8 (Top decile)

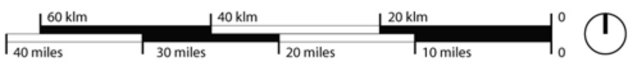


Figure 4

Further research is needed to sort out how these two principles balance out: the sense of convergence and the sense of shortcut. The first seems inherently centrifugal, the second inherently centripetal. We still have little understanding of how the structure of urban areas pulls together or draws apart the shortcuts and the foci of convergence. In our sample, the correlation between betweenness and the measures of reach is low and no more than 10% of the variance of one variable can be accounted for by the variance of the other. And yet, understanding vehicular traffic requires that we approach the interplay between convergence and shortcut with more urgency than when we deal with pedestrian movement. The reason for this is simple: vehicular traffic spans much greater distances. This allows "shortcuts" and "foci of convergence" to vary in relation to one another in much more complicated ways, as well as at very different scales of urban organization.

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