Chicago is Rural: The Inconsistencies and Absurdities of Street Connectivity Indices

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Abstract

Various connectivity indices have been generated in an effort to insure a minimum standard of connectivity in newly developed street networks. While these metrics succeed at simplicity, they fail at consistency. Multiple analyses of the orthogonal street network in Chicago, Illinois will reveal the flaws built-in to the connectivity indices themselves. One such analysis, for example, pegs Chicago's street network as "rural." The findings of this study can carry over to many other metrics of street networks and ultimately point to the critical adoption of the simplest metric of all: block size.

Introduction

Many contemporary urban design metrics have been developed to quantify the connectivity of street networks. Municipalities and other authorities are beginning to realize the important characteristics of fine-grained street networks including street frontage, route options, and land use accommodation. The different metrics to describe these characteristics have been discussed extensively in Susan Handy's book *Planning for Street Connectivity: Getting from Here to There* (2003). Of these metrics, many are of a variety referred to as a *connectivity index*.

Connectivity indices attempt to distill the relative urban attributes of a street network into a ratio of street links to intersection nodes. If successful, this would prove an easy and efficient way to insure that future streets are developed with some minimum standard of block size and overall connectivity. However, as this paper will show connectivity indices have many internal flaws that render them ultimately inconsistent and ineffective. One of these metrics, in fact, gives downtown Chicago's street network a "rural" reading.

There are many versions of connectivity indices that can be found across the US. Three versions will be discussed in this paper from three different sources: the Virginia Department of Transportation; Cary, North Carolina; and Kannapolis, North Carolina. Each connectivity index utilizes the exact same ratio of street links over intersection nodes; however, the exact methods used to calculate the ratio varies. Figure 1 displays the three methods for counting nodes and links that will be studied in this paper.
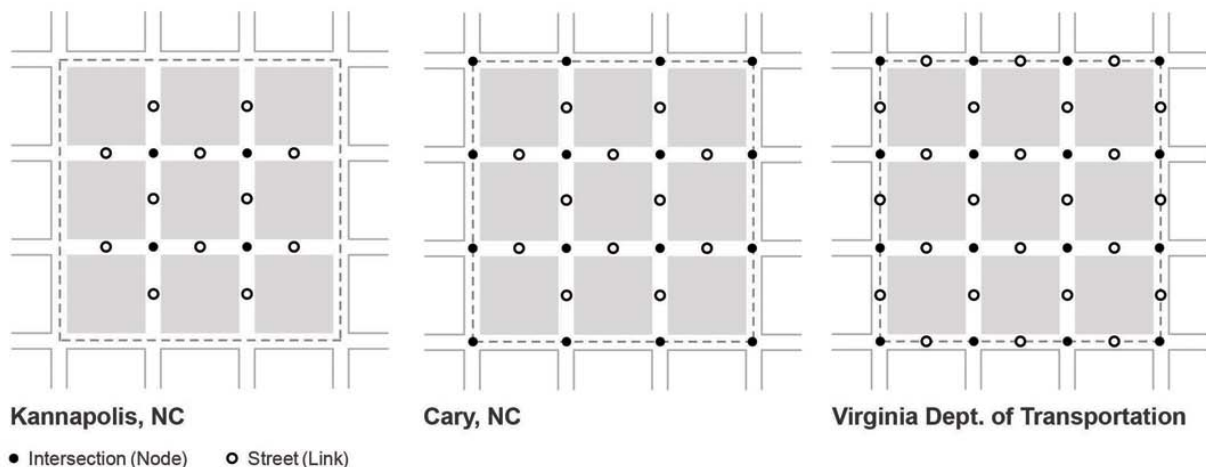

● Intersection (Node)   ○ Street (Link)

Figure 1: Methods for counting nodes and links for use in the calculation of a connectivity index.

The Virginia Department of Transportation (VDOT) has developed a connectivity index to guide development across the entire state of Virginia (2010). The quantitative readings of this metric are broken up into three qualitative categories: rural, suburban, and compact. The compact category is based on an index value of 1.60

or greater and describes areas with high levels of street grid densities. The "suburban" category is set up to have an index between 1.40 and 1.60. This allows for street networks to develop with a smaller level of connectivity. Finally, the rural reading is a category with no index requirement. Areas in Virginia under this category can be developed without meeting any index standard.

Figure 1 shows VDOT's method for counting street links and nodes. Within the study boundary and along the edges of the study boundary every street link and node is taken into account. Existing streets are included in the calculation if they connect to the proposed streets.

Cary, North Carolina has adopted a similar connectivity index (2010). They have established a value-standard of 1.20 or greater for all future developments. However, the methodology Cary employs for counting links and nodes differs from VDOT's method. While intersection nodes are counted interior and exterior to the study boundary, street links are only counted on the interior of the boundary (Figure 1).

Finally, Kannapolis, North Carolina has established yet another approach (2009). While a 1.60 index reading is only desired for maximum connectivity, all new street networks must meet an index of 1.40 or higher. While these are the same thresholds as found in VDOT's guidelines, the methodology Kannapolis employs for counting links and nodes differs from both VDOT and Cary. Only those links and nodes fully within the interior of the boundary are counted. No links or nodes are counted along the boundary perimeter or along any connecting street exterior to the boundary (Figure 1).

While the similarities between these connectivity indices may seem to overtake the differences, the behaviors of the metrics vary drastically. In the following sections each metric will be used to analyze Chicago's street network.

Establishing Variables

In order to easily test various connectivity indices under different street network circumstances a system of variables and equations must be developed. To begin, the orthogonal block will be used as the base-element for this analysis (Figure 2). Each orthogonal block can be geometrically defined by the lengths of its two independent sides (*a* and *b*). Surrounding each block is a half-width right-of-way. As blocks are appended to each other to form a larger street network their half-width rights-of-way will combine to form full-width rights-of-way at the seams. The dimensions of these rights-of-way are set as another controllable variable (*r*). Finally, the number of blocks of the generated street system in the horizontal and vertical direction are established as variables (*p* and *q*).
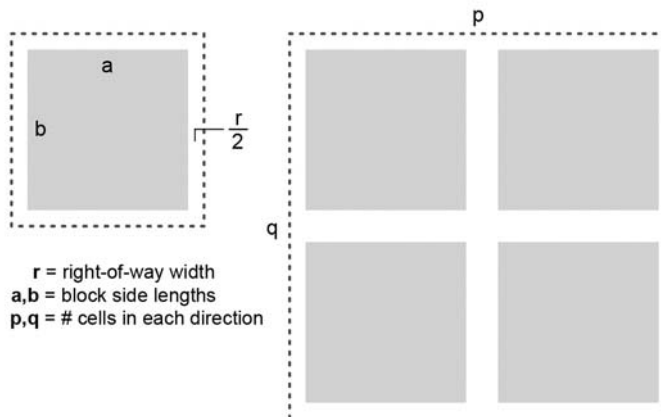

Figure 2: The block as the basic unit for this analysis. The variables as they are defined allow for control of different geometric aspects of the block and the block system.

Now that the variables have been established, equations can be generated with these in order to model the behaviors of each connectivity index. In the interest of space and time the derivation of the equations for the connectivity indices will not be shown, but this is done through a simple process in pattern finding. The equations are as follows:

Connectivity Index (VDOT) $= (p(q+1)+q(p+1)) / ((p+1)(q+1))$
Connectivity Index (Cary) $= (p(q-1)+q(p-1)) / ((p+1)(q+1))$
Connectivity Index (Kannapolis) $= (p(q-1)+q(p-1)) / ((p-1)(q-1))$

The analysis can begin by taking each of these metric equations and inserting into them certain parameters of block arrangements. For the purposes of this paper, a p x p square matrix of blocks (for example, 2x2 blocks, 3x3 blocks, and so on) will be used. Because the square matrix arrangement sets q equal to p this simplifies the equations even further:[1]

Connectivity Index (VDOT) $= 2p / (p+1)$
Connectivity Index (Cary) $= (2p^2 - 2p) / (p+1)^2$
Connectivity Index (Kannapolis) $= 2p / (p-1)$

Testing in Chicago

Block sizes in downtown Chicago vary, but in general they are approximately 320 feet by 380 feet on their sides. Chicago rights-of-way are approximately 60 feet wide. While it is important to establish these specific parameters for sizes, it will be noticed that their associated variables (a, b, and r) do not appear in any of the metric equations above. This is significant and will be explained later on.

Table 1 organizes the results of each metric on Chicago's urban qualities and quantities. By comparing each finding it is easy to see that inconsistencies are present. The metrics not only produce contradictory readings relative to each other, they produce contradictory readings relative to themselves.
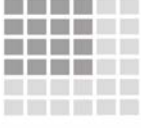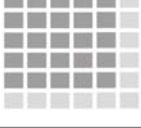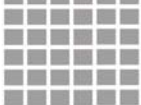
Chicago Block System (320' x 380' Blocks)	Number of Blocks	Connectivity Index (VDOT)	Connectivity Index (Cary)	Connectivity Index (Kannapolis)
	2 x 2	1.33 "RURAL"	0.44 "FAIL"	4.00 "PASS"
	3 x 3	1.50 "SUBURBAN"	0.75 "FAIL"	3.00 "PASS"
	4 x 4	1.60 "COMPACT"	0.96 "FAIL"	2.67 "PASS"
	5 x 5	1.67 "COMPACT"	1.11 "FAIL"	2.50 "PASS"
	6 x 6	1.71 "COMPACT"	1.22 "PASS"	2.40 "PASS"

Table 1: Comparisons between the values and readings of each connectivity index over various block arrangements in Chicago, Illinois.

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[1] One may be interested to learn that for all of these connectivity index equations the limit as p approaches infinity is equal to exactly 2. This means that as larger and larger areas of grid street networks are counted their streets will outnumber their intersections two-to-one.

The ways in which these metrics *should* be behaving is entirely different than the ways they are *actually* behaving. The results in Table 1 should contain a column of constant numbers and readings. While one may have expected each metric to have different *magnitudes* of readings relative to the other metrics due to the different counting methods of links and nodes, it is not immediately understood why the readings should be displaying different *rates of change*. VDOT's connectivity index, for example, changes from "rural" to "suburban" to "compact" successively within just three data points. A reading that passes Cary's regulation is not obtained until one analyzes a 6x6 block system; until then, the street network in Chicago would not pass Cary's requirement. Finally, Kannapolis appears to exhibit successful and consistent qualitative readings, but the quantitative component tells a different story.

A further visualization of Chicago's block system under the connectivity indices is shown in Figure 3. The inconsistent and variable behavior of each metric is easily seen. Rather than appearing as constant horizontal lines as they should, the metric values instead appear as decreasing or increasing relative to the size of the study area. As the number of blocks (or total study area) increases along the x-axis, the reading of each connectivity index varies non-linearly on the y-axis. This shows that for every metric a substantially different reading will be obtained simply by looking at different area sizes.
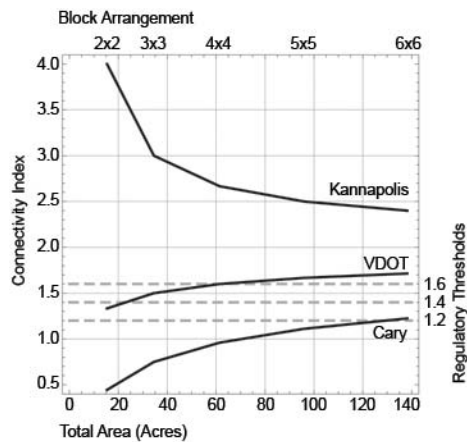

Figure 3: Graph comparing the behaviors of the three connectivity indices. The lines should be perfectly horizontal if the metrics were to be consistent across all areas, but this is not what is occurring. The metrics themselves change their own readings as the area under consideration increases. This contrasts with the rigid regulations (dashed lines in the graph) at the specified thresholds.

This type of non-linear relationship between the connectivity indices and study area is not sustainable for consistent results in reality because project sizes vary from the small to the large. A connectivity index value at one project size cannot be carried over to another project size. However, this is exactly the intention behind the metrics as adopted by all development authorities referred to in this paper. Because these development authorities have established constant thresholds of connectivity for all developable areas, the actual realization of these metrics on the ground will deviate substantially from this idealized regulation.

Explaining the Inconsistencies

Why do these inconsistencies exist in and between connectivity indices? Why do the readings deviate based simply on the size of the study area of the exact same block system? What are the internal flaws?

The primary factor behind all of these questions is in the combining-patterns of street links and intersection nodes. An example of this is in Figure 4 where each block contains 4 intersections and 4 streets. The expansion of a block system grows block-by-block. The calculation of the total number of intersections and streets within a block system can be done in one of two ways: the naive way and the studied way. The naive method is to simply multiply the number of links and nodes by the number of blocks. In this case, a 2x2 block system would contain 16 links and 16 nodes as 4 links and 4 nodes are each multiplied by 4 blocks. However, it is easily shown that this is not in fact the case. The studied approach to this problem recognizes that links and nodes cancel out with other links and nodes as blocks agglomerate together. A 2x2 block system actually contains 12 links and 9 nodes (not 16 links and 16

nodes). The ratio of links to nodes will obviously differ between these two counting methods. One gives a false connectivity index value of 1.00 (16 links / 16 nodes) while the other yields a true reading of 1.33 (12 links / 9 nodes).
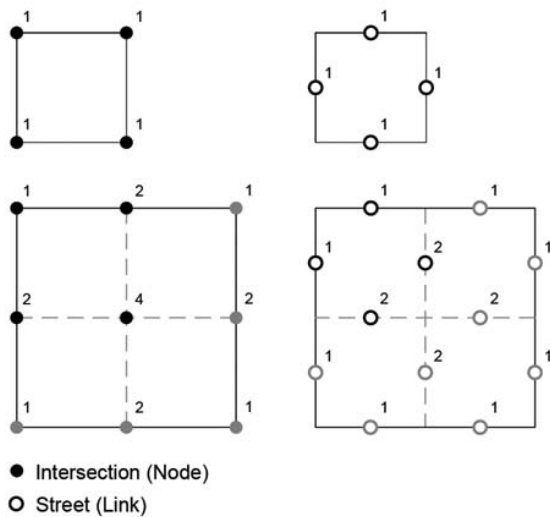

● Intersection (Node)
○ Street (Link)

Figure 4: Diagram displaying links and nodes that are over-counted during block agglomeration. Simple multiplication of links and nodes by block number will cause links to be over-counted by up to 2 and nodes to be over-counted by up to 4.

The three connectivity indices analyzed in this paper cannot be rectified against the effects of over-counting. The combination patterns of links and nodes will differ not just with area but also geometry. The problems exhibited with these metrics are systemic to the metrics themselves. Because of the physical reality of dimensions the ratio of links to nodes will be in constant flux as one analyzes large or small areas of street networks.

Summary and Conclusion

It has been shown that three connectivity indices from the Virginia Department of Transportation; Cary, North Carolina; and Kannapolis, North Carolina all exhibit radically different behaviors when applied to the exact same orthogonal street system. The metrics have been shown to be non-linear functions of area. Due to the simple change in study area, each metric's reading changes substantially. In the case of Chicago, its street network was found to be "rural", "suburban", and "compact" simultaneously.

There are many conclusions that can be drawn from this analysis. The first and most direct is the inability of connectivity indices of all varieties to consistently quantify urbanism. The drastic changes in values over various block arrangements are a testament to this problem. Further, the indices fail to take area into account directly. The same number of street links and intersection nodes can describe drastically different block sizes. A 200-foot block will have the exact same connectivity index as a 2,000-foot block because they both have 4 intersections and 4 streets. This is made apparent when looking at the equations for the connectivity indices above: the only variables included are the number of blocks in the horizontal and vertical directions. Block size never makes its way into the equations.

Second, the failure of connectivity indices points toward a general failure of ratio-based urban design metrics in general. This is due to the over-counting problem discussed earlier. An analysis of other metrics including intersection density (Aurbach 2005) and street grid density (Council 2007) has been done in another paper[2] by the author with similar results.

Third, each implementation of the connectivity index makes the conceptual mistake of equating high street grid densities with high population and land use densities. The authorities using these connectivity indices are doing so in an attempt to control for population growth. However, this is simply not shown to reflect reality. The

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[2] The paper, *The Metrics of Street Networks: Their Inconsistencies*, has been submitted to the editors of the *Journal of the American Planning Association* and is currently under review for publication as of this writing.

subdivision of territory should be established independent of any perception of population or land use. A set of the exact same 400-foot blocks can accommodate all varieties of land uses and population densities (Figure 5). This is an argument that cannot be fully made in this paper, but it is one that gets to the heart of the issue of controlling for street networks.

Finally, this paper has shown that some indirect regulations cannot successfully be used for direct results. If the goals of connectivity indices are to ultimately reduce block size then block size is what needs to be regulated, not the by-products of block size. Rather than summing links and nodes in all configurations at all sizes and scales the simplest metric, the size of the block, will take care of everything. *"The size of a block shall be no more than 600 feet on a side with a perimeter of no more than 2,400 feet"* is a simple example of a very powerful metric. This metric gets straight to the heart of the matter and cannot be gamed. This metric does not just help to insure walkability, connectivity, and consistency: it guarantees it.
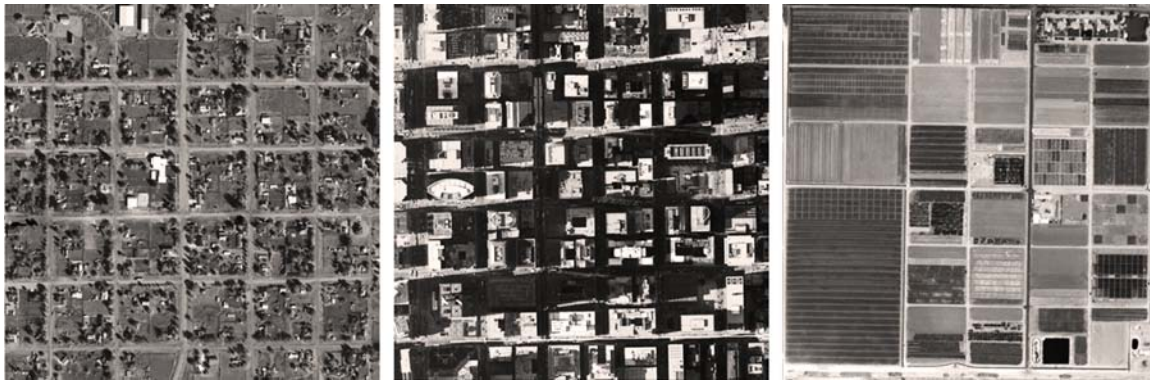

Figure 5: Comparison of the exact same 400-foot block system successfully operating across land use intensities and population densities. From left to right: small town of Paragonah, Utah; commercial downtown of Chicago, Illinois; and farms in Arizona. (Images obtained from GoogleEarth).

References:

Aurbach, Laurence. 2005. TND Design Rating Standards: Version 2.2: TND Town Paper.
    http://www.tndtownpaper.com (accessed August 19, 2010).
Council, U.S. Green Building. 2007. LEED for Neighborhood Development Rating System: Pilot Version: U.S.
    Green Building Council. http://www.usgbc.org (accessed January 16, 2010).
Handy, Susan, Robert G. Paterson, and Kent Butler. 2003. *Planning for Street Connectivity: Getting from Here to
    There*. Chicago: American Planning Association.
Kannapolis, City of. 2009. Unified Development Ordinance. http://www.cityofkannapolis.com/dept_pz_udo.asp.
Town of Cary, North Carolina. 2010. Land Development Ordinance.
    http://www.amlegal.com/pdffiles/Cary_pdf/LDO_CH07.pdf.
Transportation, Virginia Department of. 2010. *Secondary Street Acceptance Requirements: Guidance Document for
    the Commonwealth Transportation Board's Secondary Street Acceptance Requirements (24VAC30-92)*.
    Commonwealth of Virginia: Virginia Department of Transportation.