Characterization of Street Networks in Turkish-Islamic Urban Form

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Abstract

A Turkish-Islamic street network is characterized by discriminant functions of several space-syntax-related indices as well as image-analysis and graph-theoretical indices. A set of space syntactic indices is found to be powerful enough to distinguish an Islamic network. Axial ringiness in particular characterizes Islamic network patterns, implying that formation of larger blocks is a typical feature. Relative abundance of cul de sac edges is another important feature of Islamic network. Most of the areas in Istanbul are judged to be non-Islamic from the network patterns.

A battery of measures shows that it is possible to develop a linear discriminant function. Similarly, cities can be separated from the other cities by highlighting the traditional Turkish and Islamic characteristics of their street plans.

Keywords: Islamic towns, discriminant analysis, street networks

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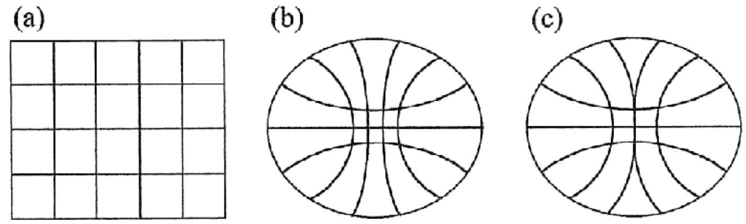
1. Introduction

Islamic street networks are said to possess certain features discernible from cities in other cultural background. Typical features include an abundant amount of "organic" networks having a large number of cul-de sac, winding and narrow roads (of human scale) and a lack of main streets. Several cities, such as Venice and Sienna, which are outside Islamic influence, however, have such features. Then what is the "true" feature of Islamic street networks? Motivated by this problem, the present paper quantitatively seeks the indices or combination of indices to measure Islamic characteristics revealed in street network patterns.

To this end, several cities in Turkey possessing (Turkish) Islamic characteristics are selected as case study cities. Moreover, some cities in Turkey, which do not possess Islamic characteristics, are also selected for comparison purposes. Still some more cities are selected from all over the world, which are studied by Asami, Kamiya and Shimazu (1999). These are all listed in Section 2.

A number of indices have been proposed to characterize the network patterns. Notable examples may be several indices applied with a graph-theoretical notion: a index, b index and g index among others (Kansky, 1963). Graph-theoretical indices are useful, when we focus on topological feature of networks. A casual consideration, however, reveals that topological features are not sufficient to characterize our notion of road network patterns. Figure1 exemplifies this (Asami, Kamiya and Shimazu, 1999). Two networks (a) and (b) are topologically the same, while (b) and (c) are topologically different. However, (a) may be labeled as a grid pattern, while (b) and (c) may be labeled as radial patterns. This example illustrates one important fact in recognizing our road network classifications, namely, that we are more concerned about the curvature and shape of network segments. In the context of Islamic characteristics, the abundance of winding roads cannot be expressed solely by graph-theoretical indices.

Figure 1. Three road networks



To overcome the limitation of graph-theoretical indices, we may introduce some concepts developed in image analysis. Network patterns can be represented as an image by showing parts of networks in black and others parts in white. In such a black-white image, street networks are not lines in a mathematical sense, but a thick line represented by black pixels. Streets are typically shown as thick black areas. To get a "skeleton" of the streets, i.e., a centerline of the street, thinning operations are often used in image analysis. Thinning operations peel off boundaries of networks gradually, so that the streets are connected by pixels, until no more peeling off is possible. The resultant image shows the thinnest network, which is topologically the same as the original one. In this operation, we can count the number of "peeling off" operations necessary for each edge, which yields the width of each edge. Using such an operation, we can measure the average width of streets, and the ratio of distance along an edge to the distance of two end nodes.

Another important group of indices has been developed with the concept of "space syntax". The framework of this methodology is based on two basic tools called *convex* and *axial* maps, to model and capture several syntactic properties of networks quantitatively (Hillier, 1996; Hillier and Hanson, 1984). Indices, based on graph-theory and image analysis are described in detail in Section 3.

Given such indices at hand, the present paper seeks efficient discriminant functions. A discriminant function is a function of indices, which most differentiates the Islamic cities from other cities. A typical function is a linear function of indices with proper coefficients. A discriminant function for Islamic characteristics will have the largest (positive) value for the most "Islamic" city judged by the indices of street networks, and the least (negative) value for the least "Islamic" city. Ideally, functional value is greater than a certain threshold value for all Islamic cities and is less than the threshold value for all non-Islamic cities. Such a discriminant function can completely distinguish the Islamic cities. Given this framework, several interesting questions arise: What are the most important features for (Turkish) Islamic street networks? Which city has the most Islamic features? Which index is the most powerful in discerning the Islamic characteristics? Are space-syntax-related indices effective in discerning the Islamic characteristics? Section 5 reports the results of discriminant function analysis, and answers such questions. Discriminant functions derived in Section 6 are applied to some historical parts of Istanbul. The summary of results in addition to concluding remarks is stated in the last section.

2. Islamic Cities and Non-Islamic Cities

To construct the discriminant functions, we need to collect several cities of Islamic and non-Islamic characteristics. For effective analysis, street patterns of study areas should have almost the same precision. Aru (1998) has a good collection of street networks for Turkish cities. We chose the following cities for our analysis:[1]

Adana, Adiyaman, Diyarbakir, Erzurum, Eskisehir, Izmir, Iznik, Kayseri, Konya, Kutahya, Manisa, Sivas, Tokat and Urfa

These street networks are depicted in Figure 2. Amongst them, Adana, Adiyaman, Diyarbakir, Erzurum, Kayseri, Konya, Kutahya, Sivas, Tokat and Urfa are classified as Islamic cities. Eskisehir, Izmir and Iznik do not reflect Islamic patterns, for they have been fully influenced by the transformations of 20th century planning. Hence they are classified as "not Islamic" cities. Manisa cannot be classified on this basis, and is left as "not classified", since it will be classified by the resultant discriminant functions.

For comparison purposes, cities outside Turkey are also collected. We have utilized networks from Asami, Kamiya and Shimazu (1999):

Amsterdam, Barcelona, Bombay, Edinburgh, London, Melbourne, New York, Osaka, Paris, Rome, Seoul, Sienna, Sydney, Taipei and Venice

These street networks are depicted in Figure 3. All cities in this category are classified into non-Islamic cities. As is seen in this selection process, no Islamic cities outside Turkey are used, accordingly, the term "Islamic" implies "Turkish Islamic" in this analysis.

All the street networks are "cut off" by a square window of 1.25km edge, with the same scale.

3. Graph-theoretical and image-analysis based indices for characterization of network patterns

Islamic cities tend to have the same features in street networks: abundant closed ends, large blocks (resulting from the abundance of closed end edges), less number of intersections with four or more connected streets, narrow width of streets (of human scale), winding streets, difficulty in grasping and perceiving the entire patterns, etc. To express such features, the following indices are selected and measured, all of which are based on graph theory or image analysis.

I. Graph-theoretical indices:

(I-1) rate of cul-de-sac edge (e1e)

An entire network can be decomposed to nodes and edges. *Nodes* are intersections of streets or closed end points. *Edges* are parts of streets connecting two neighboring nodes. Number of edges connecting to a node is called *order* of the node. Intersection of two streets is a node of order four. A closed end point is a node of order one.

Rate of closed end edge is the rate of the number of edges, which are connected to nodes of order one, to the number of all edges. Since street networks of the study areas are parts of networks cut off from the actual networks, the nodes on the boundary are not in many case nodes in the reality. To avoid the distortion from this boundary effect, all the edges connected

[1] Street networks of Turkish cities are taken from Aru (1998), except for Iznik (from Eyice (1987), see Kubat (1997)), and Eskisehir, Izmir and Manisa (from "Kijima collection" stored now in Asami's research unit).

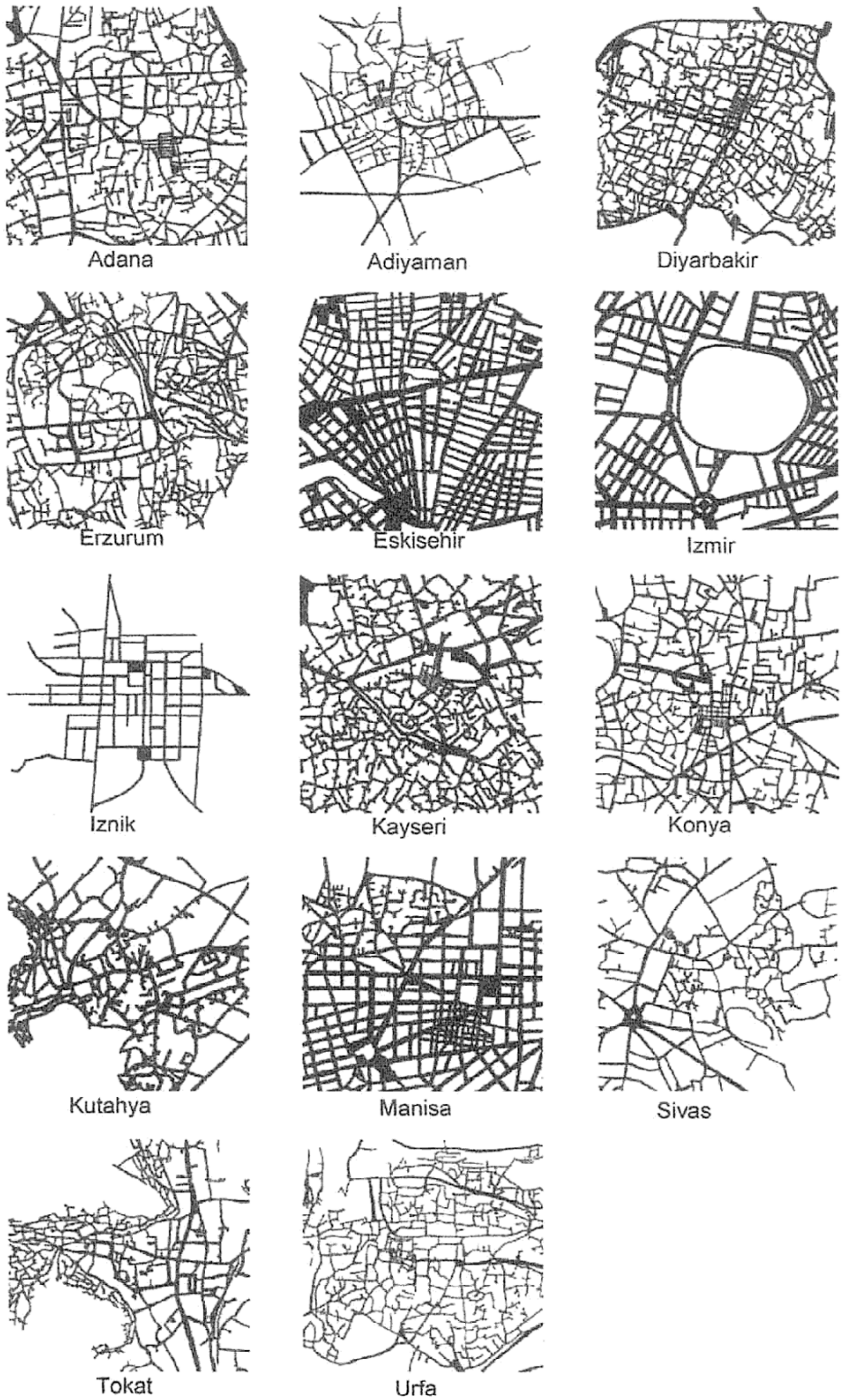


Figure 2. Street networks of selected Turkish cities

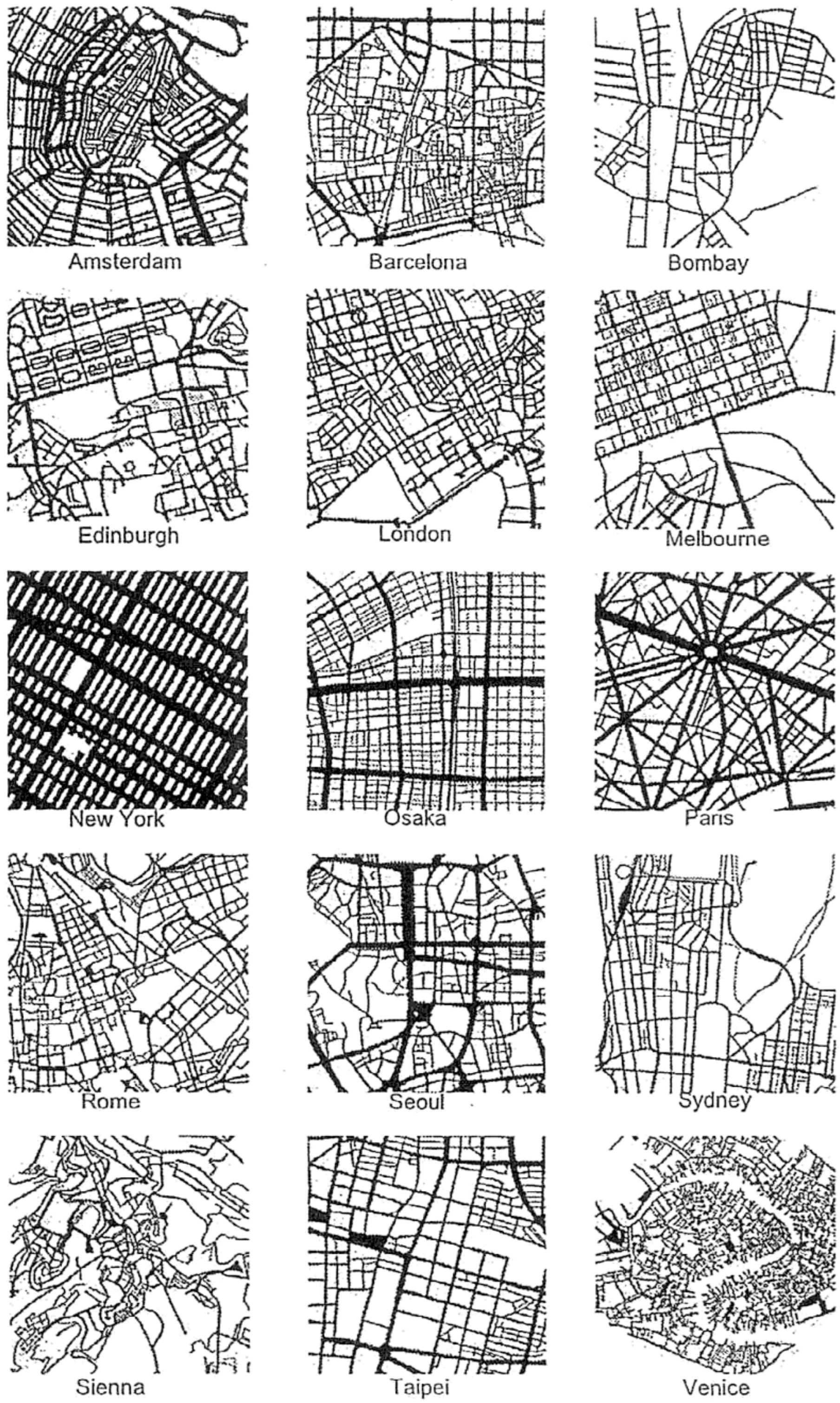


Figure 3. Street networks of selected World cities

to the boundary of the cut-off window are not included in counting the number of edges. This index measures the abundance of dead-end points, and is expected to be larger for Islamic cities. This index will be abbreviated as *e1e*.

(I-2) rate of closed end node (n1n)

Another simple measure of the abundance of closed end points is the rate of closed end nodes. This is given by the rate of the number of nodes of order one to the number of all nodes. To avoid the boundary effect again, all the nodes on the boundary of the cut-off window are not included in counting the number of nodes. This measure is also expected to be larger for Islamic cities. This index will be abbreviated as *n1n*.

(I-3) density of faces (blocks) in the district (face)

In Islamic cities, urban blocks tend to have some cul-de-sacs as approaches to houses. This may similarly imply that blocks tend to be relatively larger than the blocks in non-Islamic cities. To measure such effects, density of outer edges (i.e., surface surrounded by connected edges), or blocks in the region are calculated. Since the study area is the same for every city, only the number of outer edges is calculated. This measure is abbreviated as *face*, is expected to be smaller for Islamic cities.

(I-4) average order of node (avorder)

As described in the previous section, the average order of nodes is expected to be smaller for Islamic cities. This index is abbreviated as *avorder*.

II. Image-analysis related indices:

(II-1) rate of area covered by road to the entire district (roadcov)

Simple indices derived from image analysis will be used. The first index abbreviated as *roadcov*, measures the rate of an area covered by roads to the entire district and is expected to be smaller for the Islamic cities.

(II-2) mean distance along the edge to the distance between the nodes (dd)

Streets tend to be winding for Islamic cities. If an edge is winding, then the distance along the street tends to be larger than the straight-line distance between two neighboring nodes. This measure abbreviated as *dd* will define the mean distance along the edge, to the distance between the nodes. This index is expected to be larger for Islamic cities.

(II-3) average width of road (avwidth)

Streets tend to be narrow in Islamic cities. To represent this feature, the average width of roads, abbreviated as *avwidth* will be defined. This measure only signifies the average width of road over the total length of roads, and is expected to be smaller for Islamic cities.

4. Space Syntax based indices for characterization of network patterns

To characterize the fundamental feature of space structure, the methodology of the "Space Syntax" model is adapted (Hillier, 1996; Hillier and Hanson, 1984). The methodology is used to describe and quantify the structural properties of buildings and urban layouts in the Unit of Architectural Studies, The Bartlett Graduate School of Architecture and Planning. The configuration properties are based on the computer program (*Axman PPC 2.5*, written by Sheep T Iconoclast, 1992; *NewWave 1.0*, written by Sheep T. Iconoclast, 1985).

In terms of this terminology, the following indices are used in the present analysis.

III. Space-syntax related indices:

(III-1) Thoroughfare/DE (*through*)

This measure is related to a reciprocal of graph-theoretical index, e1e. The main difference lies in that thoroughfare, i.e., the number of edges, now counts edges connecting to the boundary of the cut-off window. DE is the number of closed end edges. This index is given by thoroughfare divided by DE. Islamic cities are expected to exhibit small values.

(III-2) Grid axiality (*gridax*)

(III-3) Axial ringiness (*axring*)

(III-4) Correlation coefficient of the global and local integration values (*rofii3*)

(III-5) Intelligibility (*intellig.*)

(III-6) Mean connectivity (*meanconn*)

(III-7) Mean depth (*meandpth*)

(III-8) Mean axial length (*meanaxlg.*)

All these indices are summarized in Table 1.

Table 1A. Values of Image-Aanalysis indices

image-analysis/graph-theory related indices

	I-1	I-2	I-3	I-4	II-1	II-2	II-3
	ele	nln	face	avorder	roadcov	dd	avwidth
Adana	0.213	0.267	223	2.451	0.263	1.032	8.54
Adiyaman	0.235	0.292	98	2.475	0.111	1.022	6.28
Diyarbakir	0.159	0.22	327	2.72	0.279	1.039	8.19
Erzurum	0.166	0.218	275	2.578	0.277	1.038	8.15
Eskisehir	0.011	0.018	339	3.147	0.467	1.011	15.26
Izmir	0.015	0.023	168	2.783	0.338	1.014	16.82
Iznik	0.064	0.098	61	3.028	0.099	1.017	8.72
Kayseri	0.195	0.256	260	2.558	0.347	1.042	10.4
Konya	0.167	0.224	229	2.607	0.24	1.037	8.31
Kótahya	0.175	0.233	161	2.631	0.27	1.04	13.39
Manisa	0.068	0.106	294	2.959	0.412	1.014	15.24
Sivas	0.216	0.271	119	2.403	0.153	1.035	7.43
Tokat	0.173	0.228	194	2.558	0.172	1.042	7.47
Urfa	0.21	0.264	210	2.481	0.162	1.042	5.22
Amsterdam	0.015	0.024	396	3.059	0.509	1.015	15.14
Barcelona	0.054	0.083	469	2.978	0.3	1.016	7.96
Bombay	0.02	0.039	154	2.92	0.163	1.012	8.81
Edinbourgh	0.133	0.184	212	2.704	0.328	1.052	12.35
London	0.024	0.04	387	2.942	0.346	1.026	10.45
Melbourne	0.093	0.131	260	2.736	0.247	1.021	9.56
New York	0.012	0.02	226	3.051	0.743	1.001	33.67
Osaka	0.01	0.018	509	3.325	0.36	1.003	9.91
Paris	0.01	0.016	255	2.995	0.465	1.007	17.96
Roma	0.024	0.04	423	2.929	0.287	1.022	7.95
Seoul	0.016	0.024	290	2.968	0.354	1.026	13.43
Sienna	0.082	0.122	261	2.8	0.231	1.092	7.66
Sydney	0.031	0.047	232	2.926	0.217	1.023	8.61
Taipei	0.002	0.003	237	3.009	0.312	1.009	13.07
Venice	0.225	0.289	630	2.52	0.289	1.06	5.39

	space-syntax related indices							
	III-1 through	III-2 gridax	III-3 axring	III-4 rofii3	III-5 intellig	III-6 meanconn	III-7 meandepth	III-8 meanaxlg
Adana	3.37	0.054	0.195	0.523	0.255	3.195	14.94	30.71
Adiyaman	1.56	0.064	0.145	0.534	0.257	3.02	7.73	27.1
Diyarbakir	6.65	0.05	0.219	0.53	0.185	3.431	5.55	25.97
Erzurum	4.15	0.049	0.187	0.446	0.165	3.34	12.4	28.06
Eskisehir	36.83	0.167	0.722	0.582	0.392	5.577	5	77.43
Izmir	40.5	0.169	0.52	0.516	0.387	3.964	5.76	65.58
Iznik	4.17	0.296	0.563	0.667	0.705	4.032	4.89	115.32
Kayseri	2.42	0.054	0.215	0.502	0.271	3.516	7.23	30.63
Konya	3	0.061	0.216	0.493	0.352	3.323	10.15	31.71
Kótahya	2.62	0.08	0.233	0.517	0.331	3.869	7.31	38.17
Manisa	4.15	0.147	0.603	0.535	0.5	5.692	7.36	64.66
Sivas	3.96	0.056	0.135	0.412	0.241	3.117	9.8	29.13
Tokat	3.81	0.049	0.159	0.362	0.247	3.247	16.05	23.4
Urfa	3.53	0.04	0.137	0.357	0.141	2.898	13.33	22.86
Amsterdam	28.85	0.106	0.498	0.489	0.249	4.505	7.47	131.16
Barcelona	7.64	0.086	0.444	0.567	0.287	4.448	6.41	51.54
Bombay	21.25	0.149	0.43	0.458	0.269	4.281	5.78	75.4
Edinbourgh	9.69	0.092	0.323	0.551	0.259	3.363	4.85	55.13
London	41.44	0.108	0.509	0.604	0.403	4.032	4.89	47.73
Melbourne	3.4	0.119	0.452	0.715	0.319	3.559	5.21	58.9
New York	9	0.625	2.253	0.748	0.812	8.84	4.16	307.94
Osaka	21.44	0.228	1.211	0.657	0.664	7.119	4.5	122.21
Paris	45.75	0.18	0.675	0.741	0.688	5.583	3.07	99.29
Roma	22.19	0.087	0.424	0.546	0.254	3.943	12.5	50.39
Seoul	27.92	0.103	0.415	0.613	0.388	4.15	5.06	58.78
Sienna	11.28	0.052	0.2	0.288	0.181	3.077	15.01	32.6
Sydney	9.63	0.126	0.448	0.539	0.414	3.922	6.43	67.89
Taipei	174	0.184	0.661	0.663	0.582	4.674	5.28	94.54
Venice	1.56	0.034	0.214	0.237	0.113	3.203	20.34	15.87

Table 1B. Values of Space Syntax indices

5. Discrimant Functions

The procedure of discriminant analysis is complicated for those who have not conducted this analysis. For those who are not familiar with this method, the procedure is detailed here.

(1) Transformation of indices:

Discriminant functions are typically linear (to be precise, affine, i.e., linear function plus constant term). This is valid when the variables approximately follow normal distribution. Several indices used in the analysis do not follow normal distribution. To remedy this situation, the distribution of the index values is transformed, so that the transformed values approximately follow normal distribution.

The normality of distributions can be tested in several ways. We adopted two tests, i.e., test by Skewness and Geary's test.

Skewness is the third moment around the mean standardized by 3/2 power of variance. This value is zero if the distribution is completely normal. Let T be the standard deviation of sample skewness provided that the theoretical distribution is normal, and that variables fluctuate due to the probabilistic variation.

Geary's test compares variance and mean deviation (average of absolute values of deviation). Let the mean be M and standard deviation be S provided that the theoretical distribution is normal, and that variables fluctuate due to the probabilistic variation.

The distribution was transformed by a *Box-Cox transformation* (Goodman, 1978; Linneman, 1981) with a shift parameter. Let x be the original value and X be the transformed value. The Box-Cox transformation is expressed as:

$$X = \frac{(x+b)^a - 1}{a}$$

where a is the exponent parameter and b a shift parameter which should be larger than – (minimum of x). This is an increasing function as far as a is finite. When a is zero, then it is defined as $\log(x+b)$. The following expression is minimized

max [(transformed skewness)/T, {(transformed Geary's index)-M}/S]

with respect to a and b. The optimal transformation in this sense is derived for each variable (using the *solver* of the MS-Excel). The resulting variables may exhibit very small variation. To avoid the computational difficulty due to this, subtracting its mean and then dividing by its standard deviation, and finally adding 3 to get positive values standardizes each transformed index. The symbol "#" will be put at the end of the variable name hereafter to indicate that the variable is optimized with this procedure.

(2) Discriminant function

Discriminant analysis is conducted with the statistical software called SPSS. This software typically gives us the following form of the discriminant function:

$$a+b_1X_1+b_2X_2+\ldots+b_nX_n$$

where a and b_i's are coefficients and X_i's are variables signifying the space syntax or image analysis related indices of a specific city. If the value is larger than a certain value, then the city is judged as Islamic, otherwise not Islamic.

(3) Islamic cities

Twenty-nine cities, described in Section 2, are classified in view of their Islamic feature as follows: Islamic cities (10 cities):

Adana, Adiyaman, Diyarbakir, Erzurum, Kayseri, Konya, Kutahya, Sivas, Tokat, Urfa

Manisa is in-between. Others are not Islamic.

(4) Optimal transformations for each indices

The optimization procedure described in (1) yielded the optimal transformation parameters a and b for each index (summarized in Appendix 1).

(5) Standardization of variables

After the Box-Cox transformation with parameters in (5), indices are standardized (as is described in Appendix 2).

(6) Correlation coefficient of indices

In view of Pearson's coefficient of correlation (usual coefficient of correlation), the following variables have a very high coefficient (greater than 0.6 or less than -0.6) compared to the Islamic dummy variable.

through#: -0.651, *axring*#: -0.610, *e1e*#: 0.673, *n1n*#: 0.674

In view of *Spearman rank correlation coefficient* (non-parametric coefficient of correlation, see Siegel (1956), the following variables have a very high coefficient (greater than 0.5 or less than -0.5) compared with the Islamic dummy variable.

> *through*#: -0.538, *axring*#: -0.502, *meanaxlg*#: -0.516, *e1e*#: 0.557, *n1n*#: 0.557, *avorder*#: -0.537

These coefficient values indicate that (Turkish) Islamic networks are characterized by an abundance of dead-end edges, larger blocks, narrower (and hence of human scale) roads and an abundance of T-type intersections.

(7) Islamic discriminant function with space-syntax related variables only

Discriminant analysis can be run in two modes: stepwise or simultaneous inclusion. The stepwise inclusion introduces variables one by one in the order of significance, and this also discards variables, which become insignificant. Stepwise run yields the following result:

$$-5.237+1.162*\mathit{gridax}\#+1.928*\mathit{axring}\#-1.331*\mathit{intellig}\# \qquad \text{(SS)}$$

If this value is less than –0.698, then a city is classified as Islamic. As a result, 26 cities out of 28 cities (92.9%) are classified correctly with this function. The value of *intellig*# is negative which is against the simple relationship between *intellig*# and Islamic, probably the result of the modification of *gridax*# and *axring*#. This implies that the larger the block sizes and the greater the information from the orthogonal grid patterns, the more intelligible the network is.

To derive a little more precise function, we ran the analysis in the stepwise mode again, this time with lower threshold values of F, thus including more variables into the function:

$$-6.217+2.463*\mathit{axring}\#-1.225*\mathit{intellig}\#+0.614*\mathit{through}\#+1.519*\mathit{gridax}\#-1.300*\mathit{meanconn}\#$$

If this value is less than –0.773, then a city is classified into Islamic. Overall, 28 cities out of 28 cities (100%) are classified correctly. Cross validation tests do not improve at all, however, from the result above (both being 92.9%). [Cross validation here means that we conduct the following test for each city. "Excluding the city, we construct a discriminant function. Then try to see if the city is classified correctly."] The signs of *intellig*# and *meanconn*# are against the simple relationship between those and Islamic. The first equation means that Space Syntax (SS) above is recommended for use, as it has high discriminating power with less explanatory indices.

(8) Islamic discriminant function with non space-syntax related variables only

A Stepwise run yields the following result.

$$-4.472+2.254*\mathit{e1e}\#-0.758*\mathit{dd}\# \qquad \text{Image Analyses (IM)}$$

If this value is greater than 0.637, then a city is classified into Islamic. Overall, 26 cities out of 28 cities (92.9%) are classified correctly with this function. The sign of *dd*# is negative which is against the simple relationship between *dd*# and Islamic, this probably serves as a modification of *e1e*#.

To derive a little more precise function, we ran in the simultaneous mode to include all the variables. The resulting function can still discriminate 26 cities correctly, and no refinement is observed. Accordingly, equation (IM) is recommended for this case.

(9) Islamic discriminant function with all the variables

Stepwise run yields the following result.

-1.407-2.543**n1n#*+1.809**dd#*-1.800**avorder#*-
1.549**avwidth*+2.724**axring#*
+1.813**meanaxlg#*

If this value is less than –0.919, then a city is classified into Islamic. Overall, 28 cities out of 28 cities (100%) are classified correctly with this function. Cross validation result shows that 27 cities are correctly classified out of 28 cities. The sign of *dd#* is negative which is against the simple relationship between *dd#* and Islamic, this probably serves as a modification of *e1e#*.

A Stepwise run indicated the following order of inclusion of variables:

axring#, *avwidth#*, *n1n#*, *dd#*, *meanaxlg#*, *avorder#*

Only *axring#* discriminates 25 cities (89.3%). The first two variables discriminate 27 cities (96.4%). The first three variables discriminate 26 cities (92.9%) (worse than the two-variable case!). The first four variables discriminate 28 cities (100%), but cross-validation gives 96.4% precision. The first five variables can discriminate 28 cities (100%), but cross validation gives 96.4% precision. The smallest number of variables with the maximum power of discrimination is attained with four variables. The resulting discriminant function is:

-0.940+1.864**axring#*-0.783**avwidth#*-1.618**n1n#*+0.852**dd#*
All Analysis (AL)

If this value is less than –0.778, then a city is classified into Islamic. *Avwidth#* and *dd#* are different from the simple relation with Islamic, and they serve as a modification. Existence of larger blocks and winding roads characterize the Islamic network in this order.

(10) Conclusion of discriminant analyses

The results above can be summarized as follows:

(a) Space Syntax (SS) could discriminate 92.9% cities with three variables, IM 92.9% with two variables, and AL 100% with four variables. We may say that space-syntax indices perform well in distinguishing the Islamic cities from others. This may further indicate that space syntax can be a quite powerful tool in describing the fundamental characteristics of the street networks.
(b) To concisely distinguish the Islamic characteristics, the SS or IM function will be good enough. For more complete distinction, AL can be used.

For Islamic characteristics, one can use either SS or IM for handy use. Variables in SS can be computed provided that one has space syntax programs provided from the Center for Advanced Spatial Analysis (Space Syntax Laboratory, The Bartlett, UCL). Otherwise it may be difficult. The variable *e1e#* in IM can easily be calculated, if the number of edges with closed ends and the total number of edges. The other variable, *dd#*, is, however, difficult to compute without the calculations of all the length of edges. If a street network is already represented as vector data by Geographic Information Systems (GIS), then this is easy to calculate. If GIS data has already been put into use, we would recommend the use of IM. For the complete analysis, AL is superior. Over all, the global measures of space syntax do not appear to be powerful enough to discriminate Islamic cities. This is expected because of the cut-out operation for sample areas, and therefore the global measures do not express the global character of the city.

It should be also noted that the transformation is quite important to conduct the analysis. Moreover, single precision is not enough for an accurate Box-Cox transformation in accuracy.

Table 2 summarizes results of discriminant functions SS, IM and AL. As is seen in this table, Manisa is judged non-Islamic by all discriminant functions. Cities misclassified by SS are Diyarbakir and Sienna. Since the discriminant function SS makes much of larger blocks and deformation from the orthogonal grid pattern, these cities are apt to be misclassified. Discriminant function IM misclassified Melbourne and Venice, for it emphasizes the abundance of closed end edges.

Table 2. Results of classification of cities by discriminant functions

		SS-discriminant function			IM-discriminant function			AL-discriminant function		
cities	**Islamic**	**value**	**judge**	**rank**	**value**	**judge**	**rank**	**value**	**judge**	**rank**
		<-0698			>0.637			<0.778		
Adana	Yes	-2.24	Y	6.00	2.52	Y	2.00	-2.98	Y	5.00
Adiyaman	Yes	-3.87	Y	2.00	3.18	Y	1.00	-4.74	Y	2.00
Diyarbakir	Yes	-0.61	N*	11.00	1.49	Y	11.00	-1.45	Y	10.00
Erzurum	Yes	-1.16	Y	9.00	1.64	Y	9.00	-2.32	Y	8.00
Eskisehir	No	2.09	N	26.00	-1.86	N	25.00	1.83	N	22.00
Izmir	No	1.94	N	25.00	-1.80	N	24.00	1.57	N	18.00
Iznik	No	1.81	N	24.00	0.06	N	15.00	1.58	N	19.00
Kayseri	Yes	-1.89	Y	7.00	1.91	Y	5.00	-2.36	Y	6.00
Konya	Yes	-2.45	Y	5.00	1.70	Y	7.00	-1.68	Y	9.00
Kótahya	Yes	-1.37	Y	8.00	1.72	Y	6.00	-2.34	Y	7.00
Manisa	?	1.20	N	18.00	0.41	N	14.00	0.15	N	13.00
Sivas	Yes	-4.38	Y	1.00	2.44	Y	3.00	-4.83	Y	1.00
Tokat	Yes	-3.57	Y	3.00	1.61	Y	10.00	-3.06	Y	4.00
Urfa	Yes	-2.95	Y	4.00	2.09	Y	4.00	-3.43	Y	3.00
Amsterdam	No	2.27	N	27.00	-1.87	N	26.00	1.72	N	20.00
Barcelona	No	1.23	N	19.00	-0.19	N	16.00	1.74	N	21.00
Bombay	No	2.58	N	29.00	-1.47	N	18.00	2.10	N	23.00
Edinbourgh	No	0.98	N	15.00	0.59	N	13.00	0.09	N	12.00
London	No	0.90	N	14.00	-1.96	N	27.00	2.67	N	27.00
Melbourne	No	1.60	N	22.00	0.80	Y*	12.00	0.78	N	15.00
New York	No	2.35	N	28.00	-1.31	N	17.00	0.48	N	14.00
Osaka	No	1.69	N	23.00	-1.53	N	20.00	2.37	N	25.00
Paris	No	1.16	N	17.00	-1.73	N	21.00	1.41	N	17.00
Roma	No	1.58	N	21.00	-1.77	N	23.00	2.87	N	29.00
Seoul	No	0.61	N	13.00	-2.34	N	29.00	2.23	N	24.00
Sienna	No	-0.99	Y*	10.00	-1.76	N	22.00	1.20	N	16.00
Sydney	No	0.99	N	16.00	-1.52	N	19.00	2.68	N	28.00
Taipei	No	1.42	N	20.00	-2.26	N	28.00	2.33	N	26.00
Venice	No	0.32	N	12.00	1.68	Y*	8.00	-0.40	N	11.00

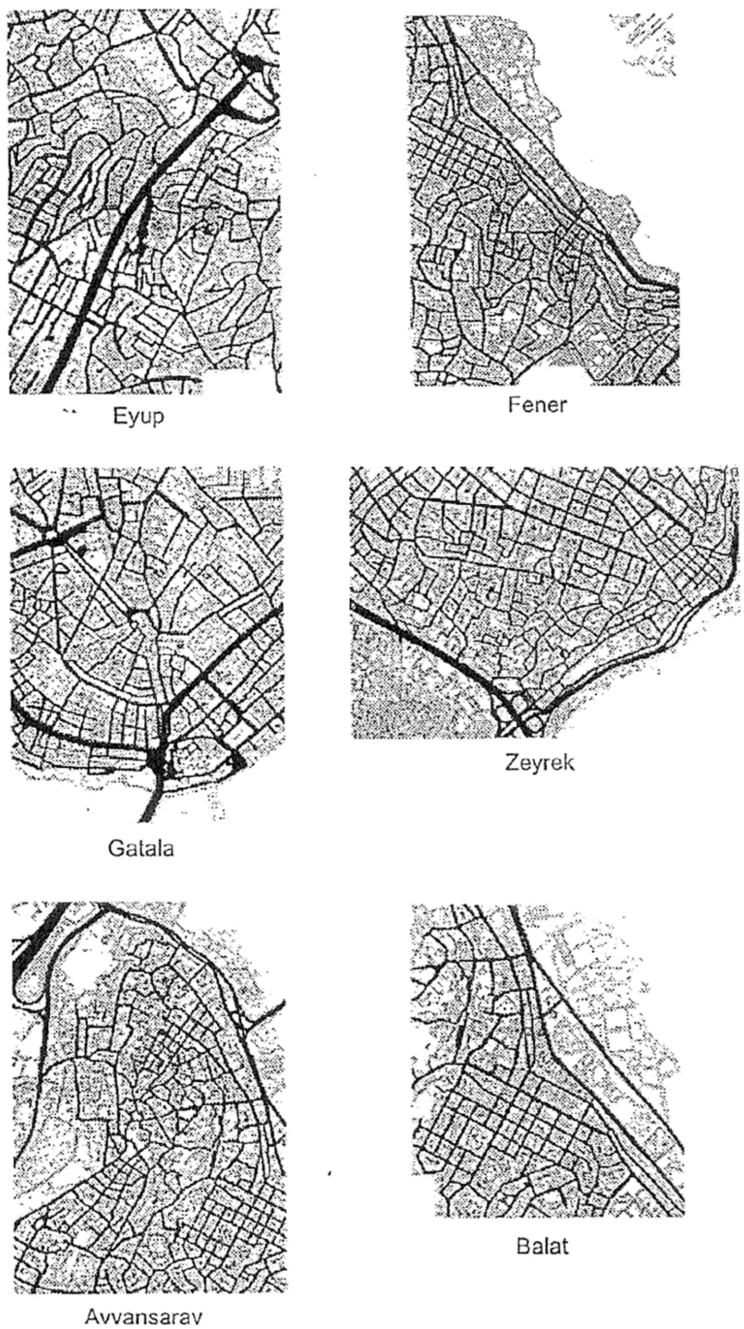
(Y or N "*" indicates mis-classification according to the discriminant function)

The ranking cities in terms of Islamic networks are rather robust. Sivas is the most Islamic by SS and AL, which is the third Islamic by IM. Adiyaman is the most Islamic by IM, which is the second Islamic by SS and AL. The robustness of the judgement, by several discriminant functions suggests the reliability of the judgement as well as potential transferability of the functions to other contexts. To test the transferability, the discriminant function SS will be applied to some areas of Istanbul in the following section.

6. Application of discriminant function to some areas in Istanbul

Several areas of Istanbul are selected to apply the discriminant functions derived. The study areas are Eyup, Fener, Galata, Zeyrek, Ayvansaray and Balat (See Figure 4). They have some inheritance from Islamic culture, and parts of the street network are found to possess Islamic traditional patterns. They all are situated in the center of the city and exhibit exceptional urban potential.

Figure 4. Street networks from Istanbul



Surrounded by Byzantine city walls from the 5th century AD, Fener, Balat, Zeyrek, and Ayvansaray districts of Fatih constitute one of the oldest residential districts of the historical center. Focal point of the social and cultural lives of Greeks, Armenians, Jews and Muslims in the past, the Fener, Balat, Zeyrek and Ayvansaray districts are presently inhabited by a mostly Muslim population that immigrated from rural areas. Outside the walls, the Muslim neighborhood of Eyup on the Golden Horn was developed according to the fundamental goal of the conqueror to create a Muslim city in which the communities could live in accordance with the philosophy of Islam. Galata on the opposite side of the Golden Horn had been the non-Muslim center of the capital after the conquest. As the empire gradually submitted to the economic dominance of Western powers, Galata naturally became the first place to accommodate European tradesmen, while Istanbul preserved its traditional and predominantly Muslim character.

The discriminant function (SS) derived in the preceding section is applied to these areas. The results are shown in Table 3. The result shows that the patterns of the selected samples are mostly judged as areas not reflecting the Islamic characteristics except Galata. The dense pattern of Galata confirms the lines of topography and forms an irregular urban block thus reflecting the organic texture. In particular, Balat is judged the farthest from Islamic, as it does not reflecting the organic pattern. Its grid pattern is still traditional.

Table 3. Islamic characteristic of Istanbul judged by Discriminant Function.

area	gridax	axring	intellig	DF	Islamic
Eyup	0.0568	0.1577	0.089	-0.042	No
Fener	0.0655	0.1887	0.1487	-0.242	No
Galata	0.0852	0.2431	0.3144	-0.89	Yes
Zeyrek	0.0688	0.214	0.1564	0.391	No
Ayvansaray	0.069	0.2123	0.1578	0.323	No
Balat	0.1436	0.2982	0.2429	1.854	No

Thus far, judging from Islamic characteristics of Istanbul can be interpreted as the indication of the superiority of non-Islamic influence in the city. Its architectural and urban heritage reflects several cultures and a pattern of “mosaic of peoples, cultures and religions” is still observable in Istanbul. This colorful mosaic, related to religious and residential architecture, also affected the urban morphology. Its transformation from the Christian tradition to the sacred city of Islam produced unparalleled configurations in its urban form. In addition, large-scale and destructive fire disasters and earthquakes ruined the city, which was mostly redeveloped with Western-inspired planning principles. Moreover, the piece-meal planning after fire disasters was paralleled by construction and regularization activities of the street patterns.

Even though irregular streets still exist in the areas, new roads and new squares have been opened, cul de sacs have almost disappeared, a large section of the waterfront (Halic-Golden Horn) has been regularized, modern transportation has penetrated to even the most isolated and traditional neighborhoods, and much of the built fabric has been converted to concrete. Because of these reasons, the city of Istanbul that absorbed and reflected the cultural heritage of eastern Orthodox Christianity followed by Islamic Ottoman civilization cannot be accepted as an Islamic city at all. It is proved by the application of the discriminant function on sample regions of Istanbul.

Istanbul has duality in its morphological structure. It reflects traditions of many cultures as well as Muslim. We should not expect from the analyses of this city to reflect the same results of the other Islamic cities. Balat, for example, does not have an organic pattern, it is a grid but is still traditional.

Istanbul has a Byzantine heritage and reflects the mosaic of different communities. Accordingly, the city does not and can not, reflect an Islamic character. If we put aside Galata, which was initially a Christian city, the others are affected from the Armenian, Rum, Jewish or Caramanian cultures and also from Muslim traditions. The Turks came afterwards, and they of course caused some changes in the urban fabric. The different communities used to live together, and each other affect them all in their culture and behavior. Only Eyup was initially developed as an Islamic neighborhood but deteriorated afterwards by renovation projects. Zeyrek became more Islamic than the others did by the Conqueror's policies after the 15th century to convert the nation to Turkish nature. The large-scale fires and earthquakes affected physical structure of the sample regions and these regions were renovated several times in history according to Western inspired planning principles. Also these all caused the urban pattern of historical Istanbul to become far from Islamic.

Some passages from several published documents explaining Istanbul's cultural and religious heritage confirm this interpretation:

> "Istanbul was the capital of a Muslim empire and Muslim culture, nevertheless, Istanbul always had, in its composition, a Western element, not only in its cosmopolitan character, but also in its geography and underlying Romano-Byzantine heritage"(Kuban,1996,page 5)

> "The form of the main street, the general and unchanging structure of the basic elements of the city, the main forums, the sea shores, the walls, the harbours, the palace and the spatial distribution of vital functions remained in place after the Turkish conquest"(Kubat,1999, p.34).

> "Contemporary Istanbul has an evocative landscape where the weight of history is strong". Monuments of great cultural value enhance the magnificent site. "The elements of the pre-Islamic past and the unique silhouette of a Muslim capital are surrounded by late Roman city walls, all of them are eloquent manifestations of a most varied cultural history" (Kuban, 1996, page 5).

> "19th century Istanbul was not a Muslim city according to the simplicistic definition of the ideologically oriented historians. It was the 19th century metropol with a Muslim past and a mixed society. Similarly, Istanbul today is a city inhabited by Muslims but it does not correspond to the definition of a Muslim city. Istanbul as a unique city has defined its own concepts of urban environment. Certainly many principles of life were regulated by religion but there were many others, historically, ethnically, topographically or geopolitically defined, and understandable only in these contexts" (Kuban, 1996, page 207)

> "In recent times, the communication network of the city has improved, new roads and new squares have been opened, cul de sacs have almost disappeared, a large section of the waterfront has been regularized, modern transportation has penetrated to even the most isolated neighborhoods, and much

of the built fabric has been converted to concrete. However, many irregular street patterns still exist; the waterfront along the Golden Horn is crowded with factories, warehouses, and workshops" (Celik, 1993, p.162).

"The city is still symbolic although Islamic traditions are applied in the architecture and urban tissue of the city. Although the Byzantine and Roman cities were more symbolic and the Islamic cities were more instrumental, the morphology of the historical core of Istanbul did not shift from a symbolic character to instrumental. The main spine and the dominant axis of the old city were still in existence in the Ottoman period and it still is today. The city still maintained its symbolic character as the capital city of the two great civilizations: the Byzantine Empire and the Ottoman Empire. Time does not affect the architecture of cities as it affects the architecture of buildings. City form-morphology tends to change less rapidly than many human institutions. The main thoroughfares of modern Istanbul follow quite closely the course of the Roman roads built more than fifteen centuries ago" (Kubat, 1999, page 40).

7. Conclusion

The present paper derived discriminant functions for Islamic characteristics revealed in the street networks. To do so, space syntax related indices and other indices (based on graph theory and image analysis) were utilized. Space syntax related indices are shown to discriminate powerfully the Islamic characteristics. This result indicates that indices developed in the space syntax are efficient enough in characterizing the network patterns.

The functional forms derived in the paper suggest that Islamic street networks can be most characterized by large size of blocks, larger difference from the orthogonal grid patterns and dominance in cul de sac edges. These features are pointed out many times in literature. The contribution of the present analysis does not lie only in confirming quantitatively the well-said feature, but in the success in ordering the elements of basic features by applying the analyses of discriminant functions.

The function was applied to several traditional areas in Istanbul. Since Istanbul has been influenced by a number of large conversions in city structure, it can be said that these areas are duly judged to be non-Islamic (except one area, Galata).

Concerning the judgement about Galata, the authors are somewhat skeptical as to the validity of the discriminant function. Galata reflects the organic texture of the roads which conforms to the steep topography. Since the discrimnant function does not take the topography into account, it is hard to distinguish between the natural organic pattern and the organic pattern induced by topographical reasons. This may be the limitation of the current discriminant function. To remedy this defect, indices related to topographical information should be included in the construction of the discriminat function.

Note

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Appendices

Appendix 1. Optimal transformation parameters a and b.

Table 4. Optimal transformation parameters. (Indices with '*' at right exhibit still distribution significantly different from normal after the transformation).

indices	a	b
ele	-9.96	1.32*
nln	-5.46	1.52*
face	-0.71	1000.00
avorder	-8.21	2.40
roadcov	-12.43	3.12
dd	-21.24	1.01*
avwidth	-3.70	19.98
through	-3.49	39.22
gridax	-19.02	2.20
axring	-15.93	1.64
rofii3	-5.63	8.60
intellig	-14.42	2.76
meanconn	-6.05	3.47
meandpth	-4.48	20.42
meanaxlg	-2.59	154.74*

Appendix 2. Standardization of indices.

Note: With notational convention, all the variables without # below indicate transformed variables.

e1e# = (e1e-0.09682)/0.0017813+3
n1n# = (n1n-0.17036)/0.0041504+3
face# = (face-1.39304)/0.0005741+3
avorder# = (avorder-0.12183)/0.00000006564+3
roadcov# = (roadcov-0.08043)/0.000000008389+3
dd# = (dd-0.04708)/0.000000002634+3
avwidth# = (avwidth-0.27027)/0.0000004010+3
through# = (through-0.28653)/0.0000002296+3
gridax# = (gridax-0.05259)/0.000000003226+3
axring# = (axring-0.06279)/0.000002266+3
rofii3# = (rofii3-0.17761)/0.00000008460+3
intellig# = (intellig-0.06935)/0.000000004105+3
meanconn# = (meanconn-0.16527)/0.0000006172+3
meandpth# = (meandpth-0.22301)/0.00000003861+3
meanaxlg# = (meanaxlg-0.38572)/0.0000001461+3