ISSN 1648-4142 print / ISSN 1648-3480 online TRANSPORT
www.transport.vtu.lt

TRANSPORT – 2006, Vol XXI, No 3, 207–212

PROVIDING A DECREASING CONGESTION PROBABILITY MODEL FOR URBAN STREETS NETWORK

Hasan Ziari [1], Hamid Behbahani [2], Mohammed M. Khabiri [3]

Dept of Civil Engineering, Iran Science and Technology University, Tehran, Narmak, Tel: (+ 21) 77896623, Fax: (+ 21) 77240398, E-mail: [1] h.ziari@iust.ac.ir, [2] behbahani.h@iust.ac.ir, [3] khabiri@iust.ac.ir

Received 6 December 2005; accepted 9 May 2006

Abstract. Urban streets classification systems are the basis for defining function and, in turn, the design criteria for the world's streets networks. The traditional classification systems have been based on the mobility and access functions of roads for motor vehicle traffic. Other road users and road uses have been largely ignored in this important step of the road design process.

The present paper proposes a novel generalization model for selecting characteristic streets in an urban street network. This model retains the central structure of a street network, it relies on a structural representation of a street network using graph principles where vertices represent named streets and links represent street intersections.

Increasing the density in the urban streets causes the increase of the delay time of traveling, so the cities traffic management emphasizes that determining condition of the urban streets construction is a priority. The arrangement condition of the urban streets in the transportation network can affect the reliability and decrease the trip delay time. In this paper reliability is calculated, using probability theory according to the density and the delay caused by arrangement condition of the urban streets in the streets network. This model has been used for arrangement condition of urban intersections and streets and it has been examined.

Keywords*:* urban streets network, reliability theory, graph modeling, functional classification system (FCS).

1. Introduction

Urban Streets design practices are inextricably linked to the purpose of the road as defined by the functional classification system. However, the traditional functional classification system considers the road to be strictly a transportation corridor for motorized vehicles. Streets and roads, particularly in an urban area, are multi-modal transportation corridors and serve more functions than that of mobility and access. Streets are public places: places to gather, socialize, window shop, people watch, etc. An alternative classification system for urban and downtown streets is necessary to better integrate the road, and its design, into the urban fabric. Alternative classification systems that take into account the variety of functions and users of the road allowance have been developed [1].

Arrangement condition of the urban streets in the city roads network or the street facilities structure can affect the reliability value in decreasing the delay time of traveling. In this research arrangement and classification condition of streets or, in other words, the arrangement of the streets in one system will be examined for decreasing the delay time of a trip, and for increasing reliability. The performance condition of the urban street depends on the successful performance of the other urban streets; this will show the internal dependence of the urban streets in the network. When the urban streets have a good performance, all the urban passage networks will have the least density [2]. Every arrangement design of the urban street can affect costs of delay time and safety level. However, in this research the optimized arrangement of the urban street in the network is determined as per the delay time decrease scale and reliability.

2. The traditional functional classification system

The traditional functional classification system (FCS) has become the predominant method of transportation professionals for grouping roads [3]. Transportation planners originally developed it as a method of communicating the road character of service. In its most basic form the FCS articulates information about the roads setting (i.e., urban or rural) and the extent to which it provides access to adjacent land and travel mobility. The complete functional classification system

We apologise for the presented paper considered as a typical example of PLAGIARISM.

The earlier published initial original references:

- **B. Jiang, C. Claramunt.** 2004. A structural approach to the model generalization of an urban street network, *GeoInformatica* 8 (2): 157-171.
- **B. Jiang, C. Claramunt.** 2002. A structural approach to model generalisation of an urban street network, in *5th AGILE Conference on Geographic Information Sc*
- **G. Forbes.** 2000. Urban roadway classification before the design begins, in *Transportation Research E-Circular*, Number E-C019.

are not cited in the paper produced by *H. Ziari, H. Behbahani and M. M. Khabiri*.

The Editorial Board of the Journal *TRANSPORT* and the Publishing House *TECHNIKA* have retracted the presented paper. The Editorial Board of the

Yours faithfully, on behalf of the Editorial Board of the Journal *TRANSPORT*, **Editor-in-Chief, Prof. Adolfas Baublys.**

has been developed around the hierarchy of movements: main movement, transition, distribution, collection, access and termination. It is shown in Table 1.

The growing density of the urban transportation facilities caused the activities concentrated on the traffic management section and resulted in optimizing design and observing classification of urban streets [4]. These problems made or mar attention in changing the urban streets classification for decreasing the density in urban areas. Amalgamating the different modes of transportation can also be used to make better quality and decrease the density. Besides, using the public transportation, such as buses, has enough potential to improve the social welfare by decreasing the density and delay. One step of traffic management in planning the urban transportation is giving the delay value in the intersection.

The delay time depends on some factors, such as drivers' behavior in special conditions, physical conditions of the urban streets, volume of different movements' traffic in the intersection. In this research the urban streets formation consists of radial, musical, diametrical and crosswise network. These networks are effective for determining the position of the urban streets. In addition, the streets network affects managing the urban streets formation.

3. A new approach to the structural representation of street networks

Cartographic generalization is a constraint-based process used by cartographers to reduce the complexity of a map in a scale reduction process. It involves intensive human knowledge obtained through professional cartographic expertise and practice [5].

In order to develop a structural representation of a street network, let us introduce some basic graph concepts. For a more complete introduction to the graph theory, readers can refer to the following example: graph G consists of a finite set of vertices (or nodes) V and a finite set of edges (or links) E (note that we use vertices and nodes, and edges and links interchangeably). A graph is often denoted as $G(V,E)$, where V is the set of vertices, $V=\{a,b,c,d,e,f,h,j,k\}$ and E is the set of edges, $E=\{v_iv_j\}$.

Fig 1 shows a graph $G_i(V_1,E_1)$ with the set of vertices $V_i=\{a,b,c,d,e,f,h,j,k\}$ and the set of edges:

$$E_i=\{\overline{ab},\ \overline{ac},\ \overline{ad},\ \overline{cf},\ \overline{ch},\ \overline{de},\ \overline{df},\ \overline{dh},\ \overline{ej},\ \overline{ek},\ \overline{fh}\}.$$

It should be noted that this simplified graph example is outweighed and undirected, and it is connected, as there is no isolated vertex [6].

Table 1. The Traditional Functional Classification System [3]

Classification	Location	Characteristics
Principal Arterial	Rural	Trip lengths for statewide or interstate travel. Integrated movement generally without stub connections. Accommodates movement between (virtually) all-urban areas with pop. 50,000. Two design types: freeways and other principal arterials.
	Urban	Serves major centers of activity with the highest traffic volumes and longest trip lengths. Integrated internally and between major rural connections. Service to abutting lands is subordinate to travel service to major traffic movements. Design types are: interstate, other freeways and other principal arterials.
Minor Arterial	Rural	Links cities, large towns and other traffic generators attracting traffic over long distances. Integrated interstate and undercount service. Designs should be expected to provide for relatively high speeds and minimum interference to through movements.
	Urban	Trips of moderate length at a lower level of mobility than principal arterials. Some emphasis on land access. May carry local bus routes and provide intercommunity continuity but does not penetrate neighbourhoods.
Collector	Rural	Serve intracounty travel with travel distances shorter than on arterial system. More moderate speeds. Divided into major and minor system.
	Urban	Provides both land access and traffic circulation within all areas. Penetrates neighbourhoods, communities collecting, distributing traffic between neighbourhoods and the arterial streets.
Local	Rural	Local roads primarily provide access to adjacent land and the collector network. Travel is over short distances.
	Urban	Primarily permits direct land access and connections to the higher order streets. Lowest level of mobility. Through traffic is usually deliberately discouraged.

We apologise for the presented paper considered as a typical example of PLAGIARISM.

The earlier published initial original references:

- **B. Jiang, C. Claramunt.** 2004. A structural approach to the model generalization of an urban street network, *GeoInformatica* 8 (2): 157-171.
- **B. Jiang, C. Claramunt.** 2002. A structural approach to model generalisation of an urban street network, in *5th AGILE Conference on Geographic Information Sc*
- **G. Forbes.** 2000. Urban roadway classification before the design begins, in *Transportation Research E-Circular*, Number E-C019.

are not cited in the paper produced by *H. Ziari, H. Behbahani and M. M. Khabiri*.

The Editorial Board of the Journal *TRANSPORT* and the Publishing House *TECHNIKA* have retracted the presented paper. The Editorial Board of the

Yours faithfully, on behalf of the Editorial Board of the Journal *TRANSPORT*, **Editor-in-Chief, Prof. Adolfas Baublys.**

Fig 1. A simplified example of a graph

We assume that a graph H is a subgraph of a graph G if the vertices of H give a subset of the vertices of G. Conversely, if H is a subgraph of G, we say that G is a supergraph of H. For a vertex subset U of a given graph G, a subgraph whose vertices belong to U is said to be induced on the vertex subset U.

Any two adjacent vertices, v_i, v_j of G are said to be neighbours. The neighbourhood of a vertex V_i of a graph G, denoted $N_G(V_i)$, is the subgraph induced by the set of vertices consisting of V_i and all its neighbours, i.e.,

$$N_G(V_i) = \{V_j \mid V_iV_j \in E, i \neq j\}.$$

For computational purposes we represent a connected, undirected and unweighted (i.e. all links with a unit distance) graph by an adjacency matrix $R(G)$:

$$R(G) = [r_{ij}]_{n \times n},$$

where

$$r_{ij} = \begin{cases} 1 & if\ V_iV_j \in E \\ 0 & otherwise. \end{cases}$$

It should be noted that for an undirected graph G, this adjacency matrix $R(G)$ is symmetric, i.e. $\forall r_{ij} \Rightarrow r_{ij} = r_{ji}$. Also all diagonal elements of $R(G)$ are equal to zero, so are not needed. Thus, the lower or upper triangular matrix of $R(G)$ is sufficient for a complete description of the graph G [6, 7].

Given an urban system, the underlying street network can be considered as a structuring element for many other cartographic objects (e.g. built environment, electricity and gas networks) and socio-economical activities in the city. So reducing the complexity of an urban street network has many application interests. A street network has its own intrinsic logical and spatial structure that must be represented and retained in applying a scale reduction process.

We represent a street network using some basic graph theoretic principles; named streets (note that a named street is not a street segment but the entire named street considered as a basic modeling unit) are represented as nodes and street intersections as links of a graph. It can be seen that any graph derived using such an approach is connected, i.e. one can reach any vertex of the graph from any vertex.

The two above measures (connectivity and average path length) present respectively some local and global properties of each considered vertex within its connectivity graph. For illustration purpose, Table 2 lists the two calculated measures for the graph G_1 shown in Fig 1. It should be noted that less connected nodes are less important from a structural point of view than those well connected at the local level. From a global perspective, the average path length measures how each node connects to every other in the connectivity graph. This gives a sense to what extent any vertex is integrated or segregated to every other within a connectivity graph. The lower the value of that measure is, the more integrated the node is.

We introduce two measures for the description of node status within a connectivity graph. Connectivity of a vertex V_i, denoted $\sigma(V_i)$, is the number of vertices directly linked to this vertex, so it is a local measure. For a given graph G, the connectivity satisfies the following condition:

$$\sum_{i=1}^{n} \sigma(V_i) = 2m,$$

where m is the total number of edges, and n is the total number of vertices of the graph G.

The average path length of a given vertex V_i, denoted $L(V_i)$, considers not only those directly connected vertices, but also those within a few steps, so it is a form of global measure when the number of steps considered is high. Given two vertices $v_i v_j \in V$, let, $d_{\min}(i, j)$ is the shortest distance between these two vertices. The average path length of a given vertex V_i is defined by:

$$L(V_i) = \frac{1}{n} \sum_{j=1}^{n} d_{\min}(i, j),$$

where n is the total number of vertices of the graph G.

Table 2. Two measures for the nodes of graph G_1 [7]

Node ID	Connectivity	Average path length
A	3	1,6667
B	1	2,4444
C	3	2,0000
D	4	1,3333
E	3	1,6667
F	3	1,7778
H	3	1,7778
J	1	2,4444
K	1	2,4444

We apologise for the presented paper considered as a typical example of PLAGIARISM.

The earlier published initial original references:

- **B. Jiang, C. Claramunt.** 2004. A structural approach to the model generalization of an urban street network, *GeoInformatica* 8 (2): 157-171.
- **B. Jiang, C. Claramunt.** 2002. A structural approach to model generalisation of an urban street network, in *5th AGILE Conference on Geographic Information Sc*
- **G. Forbes.** 2000. Urban roadway classification before the design begins, in *Transportation Research E-Circular*, Number E-C019.

are not cited in the paper produced by *H. Ziari, H. Behbahani and M. M. Khabiri*.

The Editorial Board of the Journal *TRANSPORT* and the Publishing House *TECHNIKA* have retracted the presented paper. The Editorial Board of the

Yours faithfully, on behalf of the Editorial Board of the Journal *TRANSPORT*, **Editor-in-Chief, Prof. Adolfas Baublys.**

This property can be illustrated in Fig 2, where all nodes are arranged in terms of how far (shortest distance) every other node is from the two nodes: *a* and *d* respectively. We can observe that node *d* is better integrated to every other than node *a* is. Conversely, we can remark that node *a* is relatively "far from" every other, while node *d* is "close to" every other.

The connectivity structure of the graph is important in deriving node *a* series of subgraphs which retain the main structure of initial graph. For instance, the node *d* should have a higher probability than node *a* to be kept during the processing of the reduction scale algorithm, as it is better integrated to every other node at the global level, and also better connected to other nodes at the local level.

The above example illustrates how connectivity gives a sense on nodes' integration with immediate neighbours (local level); while the average path length reflects the way each node is integrated to its *k*-neighbours (global level). Overall, a relevant structural approach to model generalization of urban street network should keep alliterated nodes (or in other words to eliminate less integrated nodes). Logically we can remark that ellconnected and – integrated streets tend to be more important from a structural point of view than those less connected and integrated [8].

4. Theory principles of probability to be used

For arranging the streets in the urban network the model how to calculate the performance success value in the urban network for a determined arrangement design will be examined. Decreasing delay in every arrangement design, especially for the streets arrangement performance, is effective in assessing every arrangement design as per the performed predictions in decreasing delay.

If P_i is the probability of the free flow in street i for the serial arrangement condition, then the successful performance probability of network or, in other words, reliability of lack of happening delay (R_s) is calculated as per relation [9]:

$$R_s = P_1 \times P_2 \times P_3 \times ... \times P_n \prod_{i=1}^{n} P_i \ .$$

If P_i is the probability (free flow time ration to total time) of free flow presence in street, in parallel arrangement condition of streets network, that is to say, in the streets network until no streets become dense, the general network stays immediately.

Relation calculates performance probability without delay or being sure to free flow of the traffic in the network:

$$R_s = 1 - (1 - P_1)(1 - P_2)...(1 - P_n) = 1 - \prod_{i=1}^{n} q_i \ ,$$

where: $q_i = 1 - p_i$.

Considering that a network has a serial arrangement, reliability is calculated by relation. To increase the presence probability of free flow delay, the parallel networks can be provided from the sequential streets. Fig 3 shows a sample of arrangement of these streets network. If one of the parallel systems delays, the other system will act without delay and free flow probability of one of two parallel subsystems is calculated as per flowing relation. General sureness scale of network depends on that at least one of two subsystems does not have delay:

$$R_s = 1 - \left(1 - \prod_{i=1}^{n} P_i \right)^2 .$$

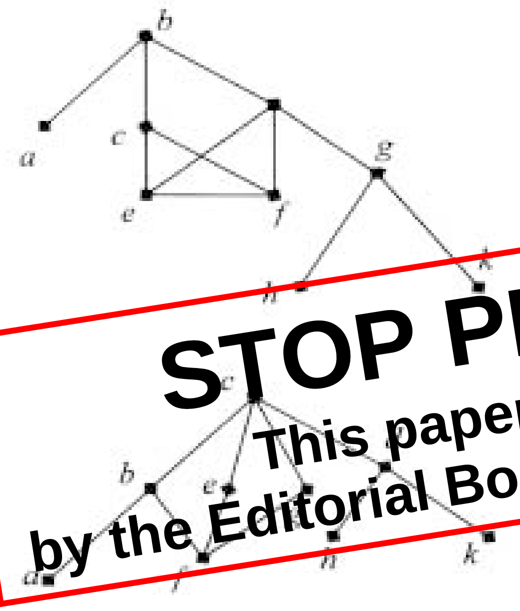


Fig 2. Respective integration/connection of nodes *a* and *b*

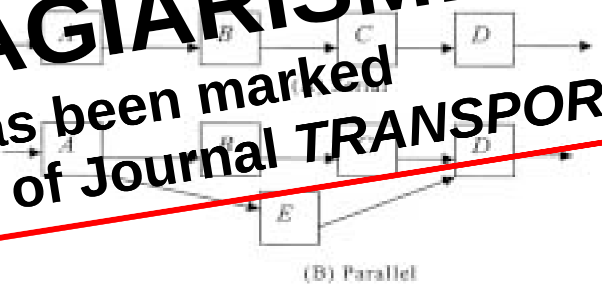
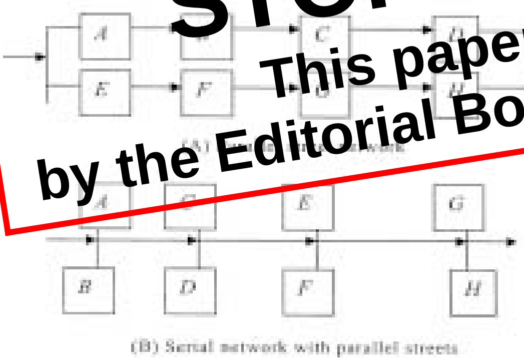


Fig 3. Showing two kinds of urban street arrangement conditions: serial (A) and parallel (B)

To increase the reliability an auxiliary parallel street can be arranged for each street individually, Fig 4 shows an example of this system arrangement.



(B) Serial network with parallel streets

Fig 4. Systems with auxiliary section: (A) parallel street network, (B) serial

5. Reliability model to calculate decreasing delay of an urban street

When k -rows of the urban streets are arranged sequentially and in series, and if every line acts without delay, then the system will have a successful performance. To decrease the density, the urban streets are arranged in parallel condition, and this situation is called an auxiliary system, because in every line, only one of the streets will have free flow and other streets will have density with a lot of delay.

To provide a model be made of a parallel and serial arrangement, reliability is calculated by free flow as per relation:

$$R_S = \prod_{i=1}^{k}\left(1-q_i^n\right).$$

Delay value in the streets have a traveling time equal to C_i, general delay value and traveling are equal to $C_i N_i$, where N_i shows the quantity of the arranged streets in one line in parallel condition. The purpose of this model is to determine the optimized design of arrangement so that the general delay value is decreased, B is considered as traveling time with max. density in the streets and the model is designed as follows [9]:

$$\text{purpose function: } \max\prod_{i=1}^{k}\left(1-q_i^{ni}\right);$$

$$\text{under restriction: } \sum_{i=1}^{k} n_i c_i \le B .$$

A sample of applying this model will be examined. In mosaic network of the urban streets, three parallel rows of the urban streets are arranged, so that, there is only one street in the third row (without any intersection and low delay), and density rate in the streets of the first line is 0,1 with an average trip time of 10 minutes, and in the streets of the 2nd row this rate is equal to 0,3 and with an average traveling time of 15 minutes, and in the street of the 3rd row in which the density rate is 0,1, the delay time will be 5 minutes.

According to this model determining the quantity of the intersections (quantity of streets caused by intersection) are considered in the first and second lines. So, the general delay value is minimized as much as possible. Max. trip time with max. density and delay are equal to 15 minutes. This model is given as follows:

$$R_S = \left(1-q_1^{n_1}\right)\left(1-q_2^{n_2}\right)\left(1-q_3^{n_3}\right) = \left(1-0.1^{n_1}\right)\left(1-0.3^{n_2}\right)\left(1-0.1^{1}\right);$$

$$n_1c_1 + n_2c_2 + n_3c_3 \le B \text{ or}$$

$$600n_1 + 900n_2 + 300n_3 \le 3000 .$$

Steps of determining N_1 and N_2 are given in Table 3.

Optimized values N_2 and N_1 are determined by error and try or line planning method $N_1=1$ and $N_2=2$, and reliability is equal to 73,19 % for the presence of free situation in network.

Table 3. Steps of solving the model of the case study

Calculations Step	*A*	*B*	*C*	*D*
N_1	1	2	3	4
N_2	2,33	1,66	1,0	0,33
R_S	0,737	0,624	0,629	0,227
Observing restriction function	$N_1 = 1$	∨	∨	–

6. Conclusion

- In this research in addition to considering the importance of optimizing the urban streets network design and their arrangement condition, several possible cases have been examined for arranging the urban streets in passage network.
- A model was designed for determining the quantity of the urban streets (as per quantity of intersections) according to the delay value (density) in the general network.
- This model is suitable for planning the small streets networks. It is necessary to use the dynamic planning in the complicated network with an

We apologise for the presented paper considered as a typical example of PLAGIARISM.

The earlier published initial original references:

- **B. Jiang, C. Claramunt.** 2004. A structural approach to the model generalization of an urban street network, *GeoInformatica* 8 (2): 157-171.
- **B. Jiang, C. Claramunt.** 2002. A structural approach to model generalisation of an urban street network, in *5th AGILE Conference on Geographic Information Sc*
- **G. Forbes.** 2000. Urban roadway classification before the design begins, in *Transportation Research E-Circular*, Number E-C019.

are not cited in the paper produced by *H. Ziari, H. Behbahani and M. M. Khabiri*.

The Editorial Board of the Journal *TRANSPORT* and the Publishing House *TECHNIKA* have retracted the presented paper. The Editorial Board of the

Yours faithfully, on behalf of the Editorial Board of the Journal *TRANSPORT*, **Editor-in-Chief, Prof. Adolfas Baublys.**

arrangement consisting of the parallel and serial streets.

- In addition, this model is solved as per La Grange equation.
- A compound model resulted from the predicted density delay model in intersections and this model can be used for continuing our research.

References

1. American Association of State Highway and Transportation Officials. A Policy on Geometric Design of Highways and Streets. Washington, D.C.: AASHTO, 1990.
2. Iranian Ministry of Road & Transportation, Manual of geometric design for roads. Tehran, 1998.
3. American Institute of Architects. Architectural Graphic Standards, Ninth Edition. J. R. Hoke, Jr., ed., 1996.
4. Iranian Ministry of Housing and Urban Alternative Development Standards, 1994.
5. Douglas D.; Peucker, T. Algorithms for the reduction of the number of points required to represent a digital line or its caricature. *The Canadian Cartographer*, Vol 10, 1973, p. 112–22.
6. Gross, J.; Yellen, J. Graph theory and its application. CRC Press: London, 1999.
7. Hillier, B. Space is the machine: a configurational theory of architecture. Cambridge University press, Cambridge, UK, 1996.
8. Jiang, B.; Claramunt, C.; Batty, M. Geometric Accessibility and geographic information: extending desktop GIS to space syntax. *Computer Environment and Urban Systems*, Elsevier Science (Pub.), 23 (2), 1999, p. 127–146.
9. Salleman, R. Reliability and maintenance and repair strategies. Industrial Washington University, Washington Dc, 1992, p. 199.

STOP PLAGIARISM!
This paper has been marked
by the Editorial Board of Journal *TRANSPORT*

We apologise for the presented paper considered as a typical example of PLAGIARISM.

The earlier published initial original references:

- **B. Jiang, C. Claramunt.** 2004. A structural approach to the model generalization of an urban street network, *GeoInformatica* 8 (2): 157-171.
- **B. Jiang, C. Claramunt.** 2002. A structural approach to model generalisation of an urban street network, in *5th AGILE Conference on Geographic Information Sc*
- **G. Forbes.** 2000. Urban roadway classification before the design begins, in *Transportation Research E-Circular*, Number E-C019.

are not cited in the paper produced by *H. Ziari, H. Behbahani and M. M. Khabiri*.

The Editorial Board of the Journal *TRANSPORT* and the Publishing House *TECHNIKA* have retracted the presented paper. The Editorial Board of the

Yours faithfully, on behalf of the Editorial Board of the Journal *TRANSPORT*, **Editor-in-Chief, Prof. Adolfas Baublys.**