# Modified Betweenness Centrality for Predicting Traffic Flow

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## 1. Introduction

Centrality measures define the relationship between particular structural features of a network. Although network analysis has been utilized to express the most relevant physical, topological and static properties of networks, dynamic and temporal aspects are mostly disregarded. For example, in travel network studies the physical street network is assumed to be static, although it can have relevant dynamic and temporal constraints such as current traffic volume in comparison to capacity or night time closures.

Traffic flow can be defined as the process of physical agents moving along an urban travel network (Kazerani and Winter 2009). Since these agents are dynamic and purposeful, they have specific travel demands such as to leave an origin or reach a destination at a specific time. If the agents consider centrality of streets in their route planning, their route planning problem becomes essentially a dynamic one. Furthermore, their time dependent demands contribute to the dynamics of centrality measures. So the research question is how to modify conventional centrality measures by considering the time dependent travel demand.

So far, betweenness centrality (Freeman 1977) has been used as one of the prominent centrality measures for analyzing physical street network. In order to consider dynamic and temporal aspects of agents' travel demand in the street network a modified version of betweenness centrality will be developed to study people's origins and destinations in three different time periods of the day. The result will be compared to the traditional betweenness centrality of the street network to see the impact including these temporal and dynamic aspects on explaining traffic patterns.

## 2. Background

The nature of human movement has two aspects: the selection of a destination from an origin; and the selection of the intervening spaces that must be passed through to go from one to the other. The former is about *to-movement*, the latter *through-movement*. Therefore every trip is made up of a pair of origin-destination, or *to*-movement nodes, and a variable number of *through* movement nodes (Hillier and Iida 2005).

Centrality measures are frequently suggested to characterize patterns such as the flow of traffic on a street network (Porta et al. 2005; Crucitti et al. 2006; Jiang and Liu 2009). Betweenness is one of the most prominent measures of centrality and defines centrality in terms of the degree to which a node falls on the shortest path between others (Freeman 1977). It also characterizes transport and quantifies the importance of a node or an edge in a transportation network.

In a graph G = (N, E) consisting of N nodes and E edges, let $|SP_{jk}|$ denote the number of shortest paths between nodes $j, k \in$ N, and $|SP_{jk(i)}|$ the number of such paths leading through node $i \in$ N. Betweenness centrality of the node $i$ is defined as follows (1):

$$C_i^b = \sum_{\substack{j,k \\ j \neq k \\ j,k \neq i}} \frac{|SP_{jk(i)}|}{|SP_{jk}|}, \text{ or normalized: } C_i^b = \frac{\sum_{\substack{j,k \\ j \neq k \\ j,k \neq i}} \frac{|SP_{jk(i)}|}{|SP_{jk}|}}{(|N|-1)(|N|-2)/2} \quad (1)$$

An extension of betweenness to edges is obtained by replacing $SP_{jk(i)}$ in the definition of vertex betweenness by $SP_{jk(e)}$, the number of shortest paths from $j$ to $k$ containing the edge $e$.

In a previous paper (Kazerani and Winter 2009) we studied betweenness centrality for its potential to characterize traffic flow in street networks. We concluded that what was designed to characterize the design or outlay of physical networks is not suited for the dynamic processes going on in street network. A number of issues have been identified and addressed in this work in a modified version of betweenness centrality that applies to the dynamic processes. In the current work this modified version of betweenness centrality will be implemented and tested.

## 3. Implementation and Test

Since human movement is planned from a specific origin to specific destination and is not from every node to every other node, the number of visits to each edge or the travel demand of each edge can not be determined by the traditional edge betweenness centrality. Therefore, here a modified betweenness centrality which considers people's specific origins and destinations in different times of the day is considered in a synthetic network. This network includes a central business district (CBD) and seven suburbs around it. The network is shown in Figure 1 with streets as edges and intersections as nodes. The analysis methods applied run on any network.

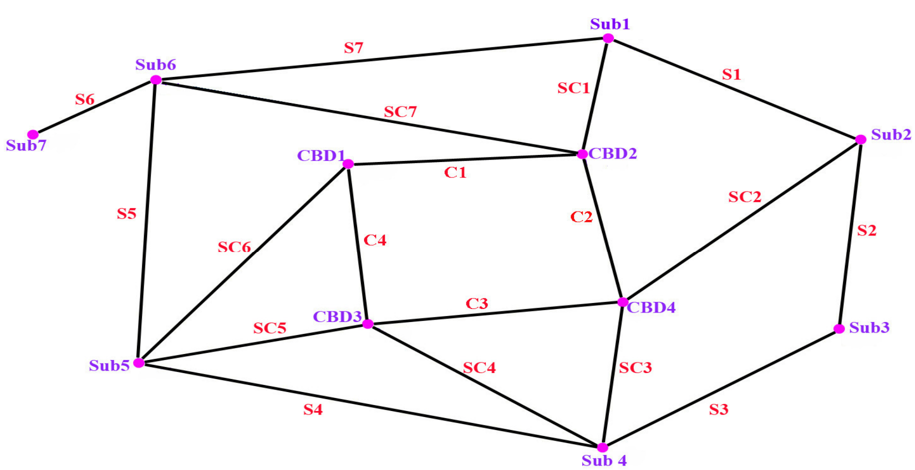


Figure 1. A network with Central Business District (CBD) and suburbs

Specific origins and destinations are considered in three different time periods of the day. Although this is not driven from actual data, it is the dominant travel behaviour in the city during these times of the day on a smaller scale:

1- In the morning when people leave home for destinations like work, school and shopping centres. Usually people's homes are located in suburbs and work, school and shops are located more centrally. Table 1 (left) shows an artificial data set reflecting such a distribution of origins and destinations for Figure 1.
2- During the day when they go for lunch or shopping or any other activity. Since people are expected to be at more central places, these travels usually happen within a CBD. Table 1 (centre) shows a data set reflecting this predominant pattern of movements.
3- In the afternoon when People would travel mostly back to home. This behaviour is reflected in the data set of Table 1 (right).

| Origin | Destination |
|---|---|
| Sub7 | CBD4 |
| Sub2 | CBD1 |
| Sub6 | Sub2 |
| Sub3 | CBD3 |
| Sub6 | CBD1 |
| Sub1 | CBD3 |
| Sub1 | CBD4 |
| Sub5 | CBD2 |
| Sub5 | Sub3 |
| Sub4 | CBD2 |

| Origin | Destination |
|---|---|
| CBD1 | CBD3 |
| CBD3 | CBD2 |
| CBD2 | CBD4 |
| CBD1 | Sub6 |
| CBD4 | CBD1 |
| CBD3 | Sub4 |

| Origin | Destination |
|---|---|
| CBD4 | Sub3 |
| CBD3 | Sub6 |
| Sub6 | Sub7 |
| CBD4 | Sub6 |
| CBD1 | Sub2 |
| CBD2 | Sub4 |
| CBD2 | Sub5 |
| Sub4 | Sub2 |
| CBD3 | Sub1 |
| CBD1 | Sub4 |

Table 1. Origins and destinations of people in the morning (left), during the day (centre), and in the afternoon (right), with respect to Figure 1.

Since people's travel demands are distributed along each edge and not necessarily from node to node, edge betweenness centrality can be a more reliable measure for this analysis. Apart from that defining the prominence of an edge in terms of betweenness is more useful in terms of predicting traffic flow than prominence of nodes.

In order to compute the modified edge betweenness centrality in a network of travel demands, igraph package version 0.6[1] (Csardi 2005), which is an open source library for network analysis, is employed in GNU R statistical environment[2].

## 4. Discussion of the Results

The results of applying the modified edge betweenness centrality for characterizing people's travel demand in three time periods of the day is presented in Table 2, together with conventional edge betweenness for comparison. Figure 2 compares the results in a chart. Betweenness is referred to as *btwns* here.

1 http://cneurocvs.rmki.kfki.hu/igraph

2 (http://www.r-project.org/)

| Edge | Conventional edge b*twns* of the physical network | Edge *btwns* of travel demand in the morning | Edge *btwns* of travel demand at noon | Edge *btwns* of travel demand in the evening |
|---|---|---|---|---|
| C1 | 0.04 | 0.014 | 0.01 | 0.01 |
| C2 | 0.054 | 0.023 | 0.014 | 0.018 |
| C3 | 0.034 | 0.006 | 0.008 | 0.006 |
| C4 | 0.026 | 0.004 | 0.014 | 0.008 |
| SC1 | 0.032 | 0.01 | 0 | 0.006 |
| SC2 | 0.044 | 0.01 | 0 | 0.014 |
| SC3 | 0.034 | 0.007 | 0 | 0.014 |
| SC4 | 0.022 | 0.007 | 0.008 | 0.004 |
| SC5 | 0.03 | 0.002 | 0 | 0.008 |
| SC6 | 0.026 | 0.007 | 0.004 | 0.008 |
| SC7 | 0.04 | 0.015 | 0.004 | 0.01 |
| S1 | 0.056 | 0.015 | 0 | 0.004 |
| S2 | 0.038 | 0 | 0 | 0.008 |
| S3 | 0.05 | 0.015 | 0 | 0.008 |
| S4 | 0.054 | 0.007 | 0 | 0.004 |
| S5 | 0.076 | 0.009 | 0.004 | 0.012 |
| S6 | 0.074 | 0.007 | 0 | 0.008 |
| S7 | 0.05 | 0.009 | 0 | 0.002 |

Table 2. Conventional and modified edge betweenness centrality values

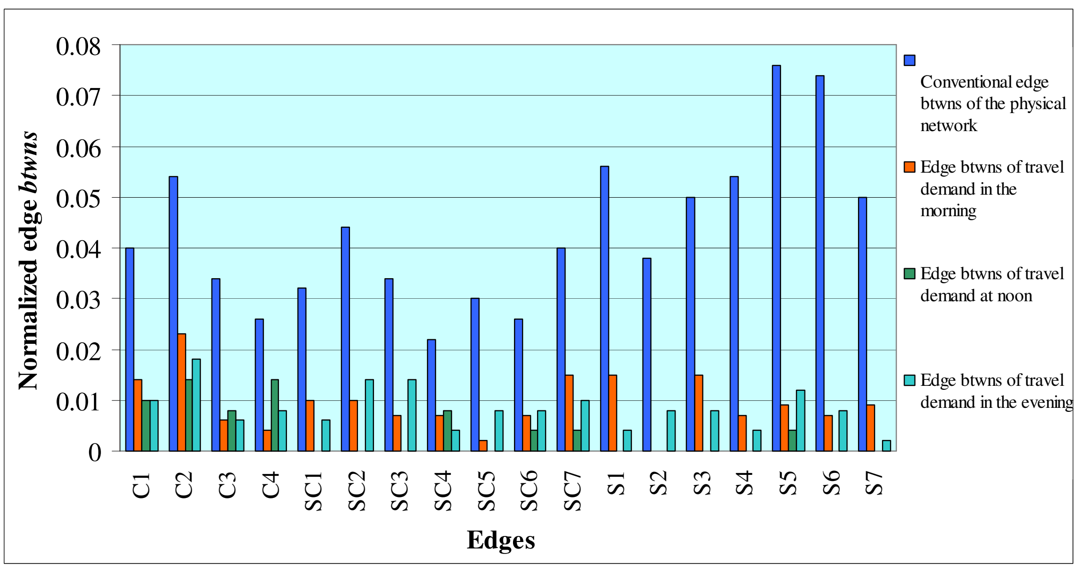


Figure 2. Comparison of conventional and modified edge betweenness centrality in three time periods of the day

Figure 2 shows a considerable difference between conventional and modified edge betweenness centrality. For example edge S5 has the highest score in conventional betweenness but almost a low score in travel demand network in all three time periods of the day. The opposite case can be seen on edge C2. That is because in the conventional way of computing edge betweenness, some of the constraints like population of different parts of the city, concentration of business locations and demands of people would not be considered.

Even a noticeable difference among edge betweenness of travel demand in different periods of time through out the day exists. For instance, SC2 is a prominent edge in terms of betweenness in the morning and evening, but has a zero value at noon. The reason is that in the morning and also evening people need to pass the edges which are between suburbs and CBD, but at noon they would be more in central areas and rarely pass other edges.

## 6. Conclusion

In this work, dynamic and temporal aspects of people's travel demand were studied by implementing a modified version of betweenness centrality. By approaching the hypothesis, the result showed a significant difference between traditional betweenness which was used to be utilized for traffic flow prediction and the so called modified betweenness centrality. Considering the dynamic and temporal nature of human's travel demand will lead to an improved traffic flow prediction and also transport capacity. The next step could be implementing this method in a larger scale on real travel demand.

## 7. Acknowledgment

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