Realistic Flow Analysis Using a Simple Network Model

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ABSTRACT

Simple topological data structures consisting of links and nodes have often been used for modeling flows through a network because of their processing efficiency and ease of implementation. These representations of networks are typically assumed to be flat and metrical; links have the same cost of travel in either direction and no costs are associated with traversing nodes. This paper describes three additions to the common model that retain its advantages while offering a capability for much more realistic analysis of network flows.

The first enhancement of the simple network model is the assignment of separate costs for traversing a link in either direction. This simple modification allows consideration of physical constraints such as slope and temporal contraints such as traffic. Second, costs are associated with each link-to-link turn. This allows consideration of the delays experienced at network nodes from congestion and controls, and permits impossible turns (e.g. from an overpass) to be removed from paths of flow. Finally, it is shown through examples that integration of an enhanced network model with a relational database management system simplifies the assignment of appropriate travel costs enough that a single network can support realistic analyses that consider the unique characteristics of various types of links and nodes and flows across them in various congestion and control scenarios.

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A network is a weighted connected graph. That is to say a network is a series of connected links and nodes, where each link has associated with it data identifying its characteristics for allocation. Figure 1 shows the components making up a simple network. A prime example of a simple network is a street map (figure 2), the streets can be thought of as links and the intersections as nodes. Because street layouts are easily represented as networks, there is a lot of interest in optimizing flow through them. With that in mind, there has been a lot of work in devolving algorithms for modeling flow through networks. For the ever present reasons of speed and memory, simple networks are better suited for computer modeling of flow. Simple networks characteristically have only one link between any two nodes and assign a single impedance.

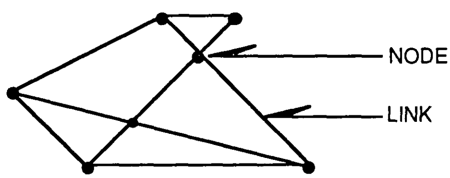

Figure 1.

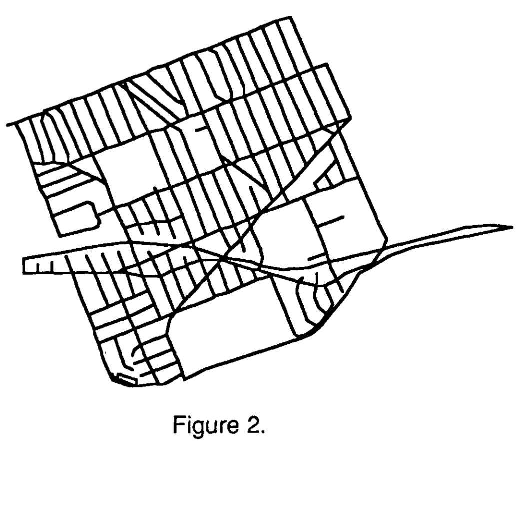

Figure 2.

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Allocation through a simple network model involves the growing out from one or more centers across the links. The method utilized at ESRI is a variation of Loubal's [1] extension of the well-known Moore [2] or Dijkstra' [3] Minimal Path Algorithm, but involves a heap structure to manage the selection of links. A heap is an ever sorted list, designed so that the next item off is always the smallest of all of the items currently kept within it. The heap is made up of link number and impedance pairs, where the impedance is the controling factor for the heap.

We are going to use the one center case within this paper; but keep in mind that the multiple center case uses the same heap structure, but each link keeps tract of which center it is allocated to. The one center case is illustraded by allocating traffic flow from or to a central point, while the multiple case is illustrated by allocating students to all of the schools within a city.

The heap starts out with an nonexistence link with a zero impedance whose next node to traverse is the center. Now starts the allocation process of taking the next link, called **L**, and its impedance, called **I**, from the heap. Once off the heap, all possible links directly reached from **L** are located together with their respective impedances. Each possible link is assigned a new impedance, which is the sum of its own impedance and **I**. The link is then placed back onto the heap. The allocation stops when the heap is finally empty. This method insures that each link is reached by the optimum path based solely upon impedance.

The simplicity of a non-directional network is due in part to the number of impedances that each link must maintain and incorporate in the model, and the fact that there is only one link connecting any two nodes. By always having only one impedance at the time of allocation assigned to each link, the framework for a simple network is maintained. The single impedance model affords easy implementation on the computer, but for the network that allows the same flow in both directions across a link, real-life traffic conditions cannot be easily handled if at all.

The directional network which allows different flow in either direction across a link offers a solution to the modeling of most traffic conditions; however, it poses still more problems on the handling of the differing impedances that each link can have. By associating the network with a relational database management system, the problem is reduced in magnitude to a level that allows for easy implementation.

The relational database allows the impedances assigned to each link to be selected, changed, or easily modified before each allocation. The model can now support multiple impedances that reflect the various traffic conditions associated with different times of the day; consequently the same network model can be used without modification to perform mulitple allocations of differing traffic scenarios.

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The allocation process itself assigns direction of travel to each link once it is added to the tree structure, and therefore the correct impedance for the link, based solely upon the direction of travel, can be assigned. In this way, the single impedance network model is still maintained. With the addition of directional impedance, the model now more closely reflects the actual flow of traffic through the network. The model can now handle the real-life conditions; while maintaining the speed normally associated with allocating flow through a simple network. Figure 3 displays a model of travel time during rush hour traffic conditions; while figure 4 displays the same model, but with traffic flowing toward the center instead of away from the center.

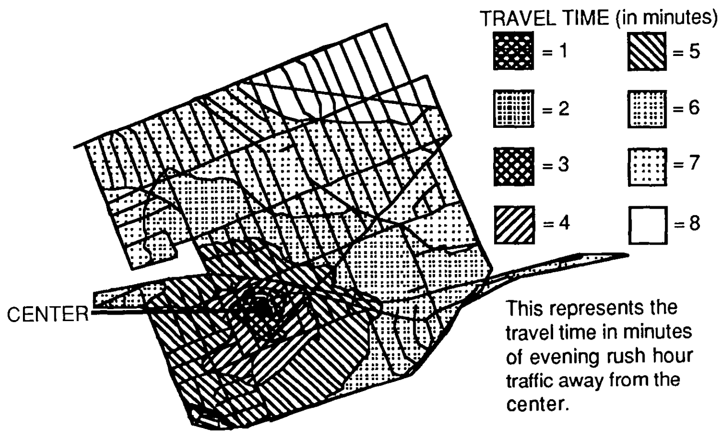


Figure 3.

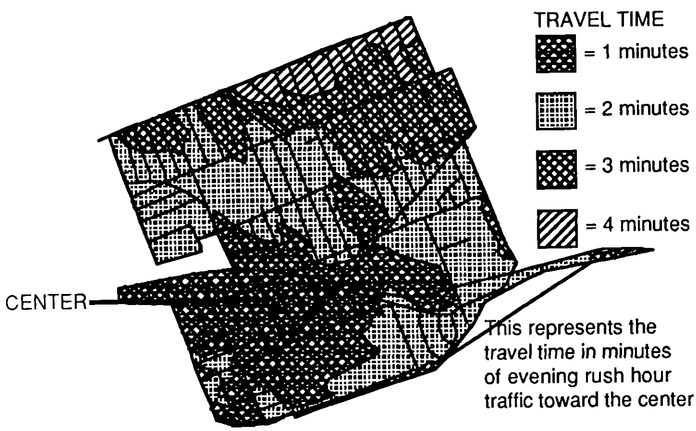


Figure 4.

Since the model is closely linked to a relational database management system, another impedance can be easily added to the model. This impedance, called turn impedance, controls the rate of travel from one link onto another. This still does not imply that the simple network approach can no longer apply. The single impedance assigned to each link, in addition to its appropriate directional impedance, will also reflect the impedance of the turn needed to travel onto the link.

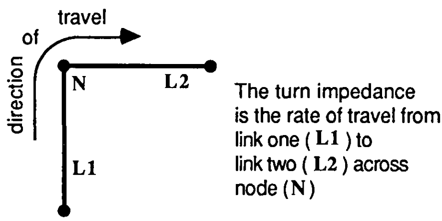


Figure 5.

The turn impedance is the cost of traveling from one link across a node onto another link (figure 5). These impedances are maintained in the same relational database, offering easy selection and modification before allocation. With the addition of turn impedance, the model now closely reflects the actual flow of traffic through the network. The model can now handle restricted flow through the nodes without having to stop all flow. This incorporates such network considerations as: Overpasses, Underpasses, Highway on and off ramps, Turning from or onto one-way streets, U-turns, Left-hand versus right-hand turns, etc...

Figure 6 is an example of using turn and directional impedances to perform route evaluation. In figures 6, 7, 8, and 9; left hand turns were assigned an impedance of 5 minutes, right hand turns an impedance of 10 seconds, no turns an impedance of 30 seconds, and U-turns were disabled. Figure 9 brings together all of the impedances, in order to solve an real-life traffic scenario. For this example figure 8 shows the route without the addition of an accident, which completely disables the intersection. The difference of impedances between figures 6 and 7, illustrates how directional impedances alter the allocation process based upon the direction of travel along the links.

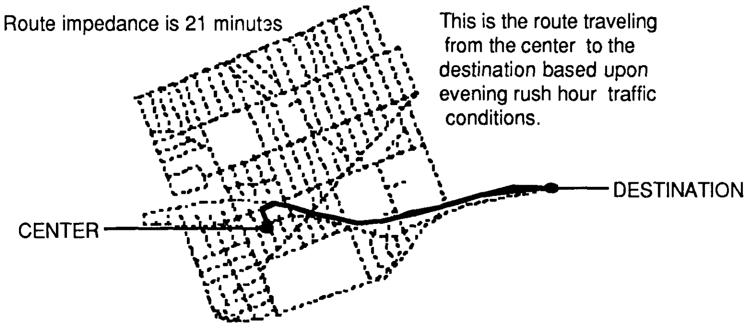
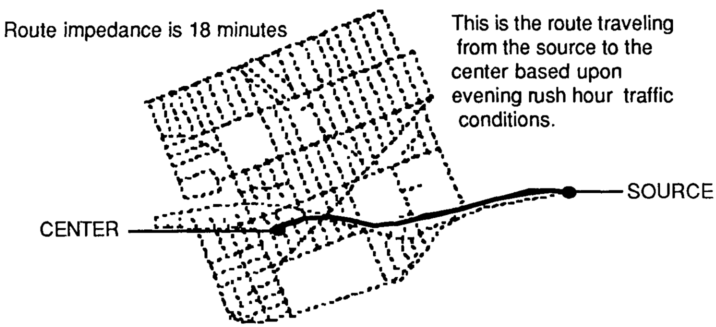


Figure 6.



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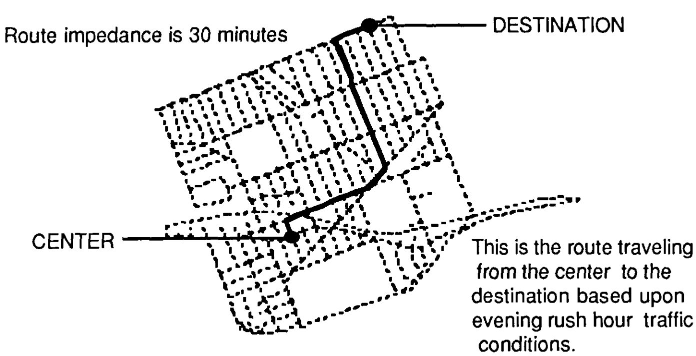

Figure 8.

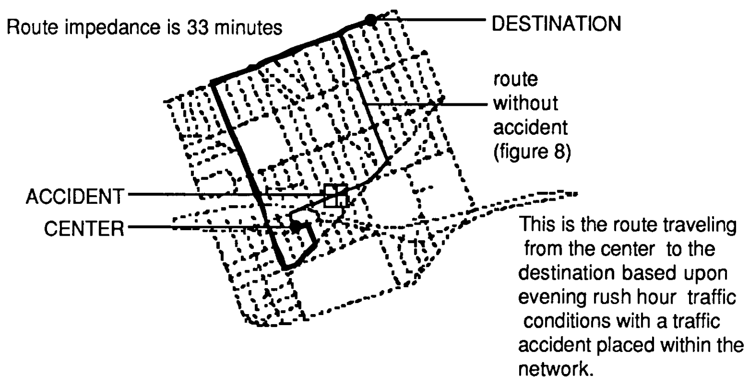

Figure 9.

The flow through the network can now be modeled in such a way that it closely follows real-life traffic conditions. The speed of the allocation process is still preserved by virtue of the fact that the heap structure must only maintain the two items of link number and cumulative impedance.

The methods of allocation brought forth in this paper, as illustrated by traffic flow through a street network, may be applied equally well to most flow analysis modeling problems.

REFERENCES:

1) P. S. Loubal, A Procedure for Allocating Resources Over a Network.

2) E. F. Moore, The Shortest Path Through a Maze, *Proc. Int. Symp. on the Theory of Switching,* Harvard University, Cambridge, Massachusetts, 1-3 (1963).

3) E. W. Dijkstra', A Note on Two Problems in Connection with Graphs, *Numerische Mathematik*, 1, 269-271 (1959).