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**Location-Based Services (LBS): An Emerging Innovative  
Transport Service Technology and A Research Agenda**

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# **Location-Based Services (LBS): An Emerging Innovative Transport Service Technology and A Research Agenda**

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## **I. Introduction**

It is widely believed that about 80 percent of public and private decisions are related to some sort of spatial consideration, leaving only few areas that are not affected by geographical considerations. The Internet puts an unprecedented amount of geographic information of all kinds at a user's fingertips, information that can be used for personal production activities in a mind-boggling variety of ways.

Untapped fields of study and new sources are being exploited, then brought together and merged with other branches of knowledge and used in common to provide extraordinarily useful information. The bank of knowledge and the new uses of geographic information thereby created open up new and vast horizons in areas outside the traditional geographical sphere, but, to be effective, these infinite possibilities now emerging need to be canalized.

Ambitious plans have been drafted, such as "e-Government" or, in Europe, "e-Europe", that aims to boost Europe's economy and make it the most competitive and dynamic economy in the world. In the context of this project, the urgent need for the field to exploit the opportunities of the new economy, and in particular the Internet, is fully recognized. Such concepts and ideas are spreading like wildfire, and it is no big effort of the imagination to see an "e-World" on the horizon. Geographic information is one key component of this, both as a basis for the making of decisions, as mentioned, but, more generally, as part of the content industry.

## **II. What is LBS?**

Location-based services (LBS) – sometimes called location-based mobile services (LBMS) – is an emerging technology combining information technology, GIS, and ITS. An enormous market can be foreseen in this field, including the market for tracking, route-finding and guiding, notification and alert services which would reach \$15 billion per year by 2005 (<http://www.isotc211.org/>). See Figure 1.

LBS combines hardware devices, wireless communication networks, geographic information and software applications that provide location-related guidance for customers. It differs from mobile position determination systems, such as global positioning systems (GPS), in that LBS provide much broader application-oriented location services, such as the following:

“You are about to join a ten-kilometer traffic queue, turn right on Washington Street, 1 km ahead.”

“Help, I’m having a heart attack!” or “Help, my car has broken down!”

“I need to buy a dozen roses and a birthday cake. Where can I buy the least expensive ones while spending the minimum amount of time on my way home from the office?”

## Emergence of Location Based Services

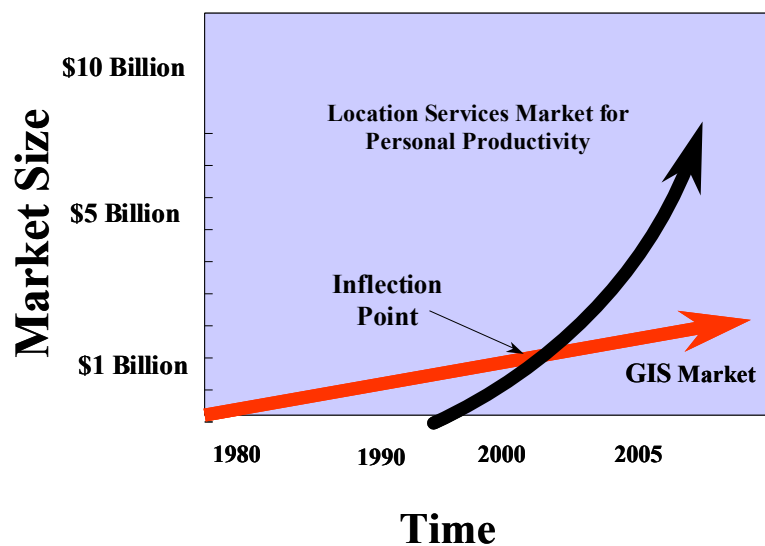


Figure 1: Emerging Market Location Services for Personal Productivity

### III. Research Agenda

The following are few sample issues that need to be researched for providing efficient and accurate location-based services for personal productivity:

1. Utilization of Real Time Data in Spatio-Temporal Context in GIS
2. Development of Spatio-Temporal Topology in GIS.
3. Development of Efficient Means to handle Large Data Set for LBS

4. Interoperability among Contents Providers and Interface Standardization for Efficient Request-Response Services.
5. Efficient and Cost-effective Means to collect Real-Time traffic data.
6. Development of Alternative Theories for utilizing Population Data vs Sample Data in GIS
7. Development of Heuristic Solution Algorithms for LBS

Among those, the following section describes issues related to providing services for request for routing and navigation in LBS and issues related to solving such complex functions in few seconds.

#### **IV. Functional Forms for Estimating Routing Cost**

##### 4.1 A Use Case: Request and Response for Routing and Navigation Services

Let's take an example for a request for a navigation service: "find a route from my current position, stopping at a gas station for 10 gallons of gas, a pharmacy to pick up a bottle of Advil, and a flower shop for a dozen roses which must be the last stop before arriving at my Grandmother's home."

In this example, there are three types of costs involved: (1) the purchasing and stopping costs for needed items, (2) costs related to the time spent on the road, and (3) distance related costs such as gasoline used, and the wear and tear from the use of a car.

##### *4.1.1 Purchasing and Stopping Costs*

There are three items to shop and let's call it three activities, denoted by  $(B^m)$ , meaning that the activity one ( $B^1=10$ ) is to buy 10 gallons of gas, the activity two ( $B^2=1$ ) is to pick up a bottle of Advil, and activity three ( $B^3=12$ ) is to buy a dozen roses. Suppose that there are three gas stations, two flower shops and one pharmacy. The unit cost for gallon of gas for three different locations is denoted by  $(b_j^m)$ , meaning that cost per gallon at location 1 ( $j=1$ ) is denoted by  $(b_1^1)$ , at location two is denoted by  $(b_2^1)$ , and the other as  $(b_3^1)$ . Likewise, the unit cost for a rose at the flower shop at location one is denoted by  $(b_1^2)$  and the other as  $(b_2^2)$ . The unit cost of Advil at the pharmacy is  $(b_1^3)$ . If an item "m" is not available at stop "j", then  $b_j^m = \infty$  (unbounded). The matrix  $B_j^m$  represents the decision to purchase  $B$  amount of item  $m$  at stop  $j$ . Let  $s_j$  represents initial stopping costs that include parking costs once decided to stop at  $j$ . The marginal costs for stopping at location  $j$  for purchasing  $m$  is represented by  $s_j^m$  which include queuing and other added costs over the simple stop and go to purchase  $m$  at location  $j$ . The decision to stop at location  $j$  is given by  $d_j = 1$  if any

$B_j^m$  is non-zero. The decision to purchase item  $m$  at stop  $j$  is  $d_j^m = 1$  for all  $B_j^m$  that are non-zeros.

Thus, the total cost of purchasing needed items at location  $j$  ( $C_j$ ) including stopping costs in this example can be written as:

$$C_j = d_j s_j + \sum_m (b_j^m B_j^m + d_j^m s_j^m) \quad (1)$$

where  $d_j s_j$  is the cost of making an initial stop at  $j$  which includes parking cost,  $b_j^m B_j^m$  is the total cost of purchasing  $m$  at location  $j$ , and  $d_j^m s_j^m$  is the marginal cost incurred for purchasing item  $m$  including queuing at  $j$  shop.

Once shopping is done, the total items purchased should be at least the same as the original intention to buy ( $B^m$ ), i.e. 10 gallons of gas, a dozen roses and a bottle of Advil.

This is expressed as:

$$\sum_j B_j^m = B^m \quad (2)$$

#### 4.1.2 Time Costs

Time spent on the road to go to one of three gasoline stations, one of two flower shops and the pharmacy will depend on which one to shop and in which order.

Road network is represented by two types of elements: a set of points called nodes and a set of line segments connecting these points called links. Figure 1 depicts a set of network including five nodes connected by 11 links. Nodes are numbered by ordinary Arabic numeral, 1 to 5, and links are numbered by the alphabet, from  $a$  to  $n$ . The link travel time in minute is given within parenthesis, right after the link number.

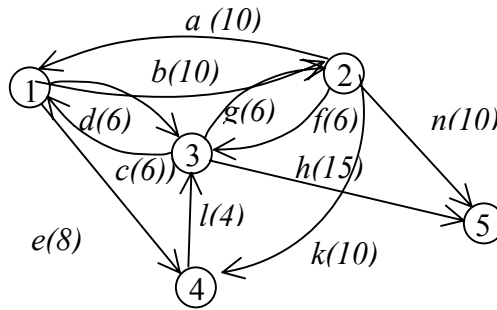


Figure 1: Sample Network with Fixed Link Travel Time

It is possible to reach node (5) from node (1) by several routes (or paths) through the network. In fact, there are (n-1)! possible routes if there no one way exists. A route is a sequence of directed links leading from one node to another. For example in above network, to get from node 1 to node 5, the following routes are available excluding those routes that require stopping the same node more than once.

- Route 1:  $1 \rightarrow b \rightarrow 2 \rightarrow n \rightarrow 5$  (total time  $(\sum_a t_a)$  to be on roads: 20 min)
- Route 2:  $1 \rightarrow b \rightarrow 2 \rightarrow f \rightarrow 3 \rightarrow h \rightarrow 5$  ( $\sum_a t_a$  is 31 min)
- Route 3:  $1 \rightarrow b \rightarrow 2 \rightarrow k \rightarrow 4 \rightarrow l \rightarrow 3 \rightarrow h \rightarrow 5$  ( $\sum_a t_a$  is 39min)
- Route 4:  $1 \rightarrow c \rightarrow 3 \rightarrow h \rightarrow 5$  ( $\sum_a t_a$  is 21 min)
- Route 5:  $1 \rightarrow c \rightarrow 3 \rightarrow g \rightarrow 2 \rightarrow n \rightarrow 5$  ( $\sum_a t_a$  is 22 min)
- Route 6:  $1 \rightarrow e \rightarrow 4 \rightarrow l \rightarrow 3 \rightarrow h \rightarrow 5$  ( $\sum_a t_a$  is 27 min)
- Route 7:  $1 \rightarrow e \rightarrow 4 \rightarrow l \rightarrow 3 \rightarrow g \rightarrow 2 \rightarrow n \rightarrow 5$  ( $\sum_a t_a$  is 28 min)

This is not all of the possible routes with stops. Several possible routes pass through two gas stations and would therefore give alternative routes. The ones not listed are not optimal, but that is not obvious *a priori*.

Let's assume that we know each traveler's unit cost of time in \$ per hour and denotes it as  $(\alpha^w)$  for traveler of the occupation type  $w$ , then the total travel cost in \$ for traveler type  $w$  ( $C^w$ ) is the unit cost of time  $(\alpha^w)$  multiply by the total time spent on roads  $(\sum_a t_a)$ , if link  $a$  is in route  $r$  between the origin (O) and destination (D) pair denoted by  $i$  and  $j$ . That is:

$$C^w = \alpha^w \sum_{a \in r_{ij}} t_a \quad (3)$$

where  $a \in r_{ij}$ : link  $a$  is in route  $r$  between the origin (O) and destination (D) pair denoted by  $i$  and  $j$

Assuming that a traveler's unit time cost  $(\alpha^w)$  is \$ 20/hour or 33 cents per minute, the total costs for taking route 1 is 33 cents times 20 minutes, i.e. \$6.60. If route 2 is the minimum

route and thus is chosen, then the total costs for taking route 2 is 33 cents times 31 minutes, i.e. \$10.23.

#### 4.1.3 Distance Related Costs

Assuming that distance related costs such as gasoline used, and the wear and tear from the use of a car, denoted by  $d$ , is \$0.20 per mile, and the total distance traveled is denoted by  $(d_a)$ , then the total distance related costs ( $C^d$ ):

$$C^d = d \sum_{a \in r_{ij}} d_a \quad (4)$$

where  $a \in r_{ij}$ : link  $a$  is in route  $r$  between the origin (O) and destination (D) pair denoted by  $i$  and  $j$

#### 4.1.4 Total Costs for Shopping and Routing

The total cost for traveler type  $w$  ( $W$ ) for stopping at a gas station for 10 gallons of gas, a pharmacy to pick up a bottle of Advil, and a flower shop for a dozen roses before reaching at Grandmother's home now can be calculated by summing up the minimum purchasing costs ( $C_j$ ) over all location  $j$ , the minimum routing costs ( $C^m$ ) and the minimum distance costs ( $C^d$ ), subject to that all items are successfully purchased.

The solution of the problem for type  $w$  traveler can be found by minimizing the total costs. i.e.

$$W = \sum_j \sum_m (d_j s_j) + (b_j^m B_j^m + d_j^m s_j^m) + \alpha^w \sum_{a \in r_{ij}} t_a + d \sum_{a \in r_{ij}} d_a \quad (5)$$

subject to equation (2)

This is a typical Linear Programming (LP) problem. Solving an LP with tens of thousands links and nodes is not a trivial issue. Many scholars, however, have found efficient algorithms solving it differently than solving it as an LP problem.

Let's define that  $h_{a \in r_{ij}}^{m,w}$  is costs for taking link  $a$  to purchase  $B$  amounts of items  $m$  at location  $j$  including purchasing costs ( $b_j^m B_j^m$ ), initial stopping costs ( $d_j s_j$ ), marginal stopping costs ( $d_j^m s_j^m$ ), time costs ( $t_{a \in r_{ij}}$ ), and distance related cost ( $d_{a \in r_{ij}}$ ) where link  $a$  belongs to the shortest route chosen between origin  $i$  and destination  $j$  for a traveler type  $w$ . That is:

$$h_{a \in r_{ij}}^{m,w} = (d_j s_j + b_j^m B_j^m + d_j^m s_j^m) + \alpha^w (t_{a \in r_{ij}}) + d(d_{a \in r_{ij}}) \quad (6)$$

In another words,  $h_{a \in r_{1,1}}^{1,2}$  indicates the cost for purchasing item 1 (10 gallons of gasoline) by taking link  $a$  which is within the shortest route connecting origin 1 to destination 2. Let's look at our problem again. Suppose that a gas station exists in each node of 2, 3 and 4, and a flower shop is available in each of nodes 2 and 4. One pharmacy is located at each node of 3 and 4. The unit costs are assumed as:

Gasoline costs:	Gas station at node 2, i.e.	$b_2^1 = \$1.5/\text{gallon}$
	Gas station at node 3, i.e.	$b_3^1 = \$2.0/\text{gallon}$
	Gas station at node 4, i.e.	$b_4^1 = \$1.3/\text{gallon}$
Flower costs:	Flower shop at node 2, i.e.	$b_2^2 = \$2.0/\text{rose}$
	Flower shop at node 4, i.e.	$b_4^2 = \$2.5/\text{rose}$
Pharmacy costs:	Advil at node 3, i.e.	$b_3^3 = \$1.0/\text{bottle}$
Pharmacy costs:	Advil at node 4, i.e.	$b_4^3 = \$10.0/\text{bottle}$

Ignoring stopping costs and the distance related cost at the moment (it is easy to include them in the actual estimation, however), and assuming that traveler's unit time cost ( $\alpha^w$ ) is \$0.33 per minute, the travel time and purchasing cost by taking various links are as shown in Figure 2. In it, link travel time costs are shown next to each link. Costs for purchasing item  $m$  at  $j$  are shown within boxes. For instance,  $[3^1: \$20]$  indicates that it costs \$20 to purchase 10 gallons of gasoline ( $m=1$ ) at location 3. As one can see within boxes, I assigned a pseudo node number to each available shop with the same node number, but with different superscript numbers indicating different shops available in node  $j$ . For instance,  $2^1$  is gasoline station located in node 2 and  $2^2$  indicates a flower shop located in node 2.  $2^0$ ,  $3^0$  and  $4^0$  indicate nodes with no shops indicating that they are for passing nodes with no stopping for shopping.

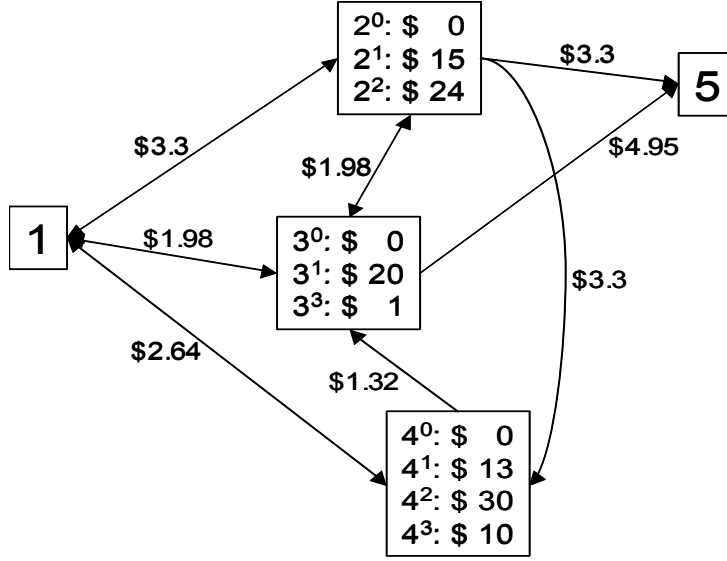


Figure 2: Travel Time and Purchasing Costs at Different Locations

For a typical traveler  $w$ , travel time and purchasing cost,  $h_{a \in r_{i,j}}^m$ , can be rearranged as the Node-Node Adjacency Matrix representation of the network given in Figure 2 as shown Table 1. In Table 1, the rows and columns in the matrix correspond to the nodes on the network. A non-zero element in the  $i$ th row and  $j$ th column in the matrix represents the cost for link travel time and purchasing costs at the end node. A zero element in the matrix indicates that there exists no link going from node  $i$  to node  $j$ .

	1	2 <sup>0</sup>	2 <sup>1</sup>	2 <sup>2</sup>	3 <sup>0</sup>	3 <sup>1</sup>	3 <sup>3</sup>	4 <sup>0</sup>	4 <sup>1</sup>	4 <sup>2</sup>	4 <sup>3</sup>	5
1	0	3.3	18.3	27.3	1.98	21.98	2.98	2.64	15.64	32.64	12.64	0
2 <sup>0</sup>	3.3	0	15.0	24.0	1.98	21.98	2.98	3.3	16.3	33.3	13.3	3.3
2 <sup>1</sup>	3.3	0	0	24.0	1.98	21.98	2.98	3.3	16.3	33.3	13.3	3.3
2 <sup>2</sup>	3.3	0	15.0	0	1.98	21.98	2.98	3.3	16.3	33.3	13.3	3.3
3 <sup>0</sup>	1.98	1.98	16.98	25.98	0	20.0	1.0	0	0	0	0	4.95
3 <sup>1</sup>	1.98	1.98	16.98	25.98	0	0	1.0	0	0	0	0	4.95
3 <sup>3</sup>	1.98	1.98	16.98	25.98	0	20.0	0	0	0	0	0	4.95
4 <sup>0</sup>	2.64	0	0	0	1.32	21.32	2.32	0	13.0	30.0	10.0	0
4 <sup>1</sup>	2.64	0	0	0	1.32	21.32	2.32	0	0	30.0	10.0	0
4 <sup>2</sup>	2.64	0	0	0	1.32	21.32	2.32	0	13.0	0	10.0	0
4 <sup>3</sup>	2.64	0	0	0	1.32	21.32	2.32	0	13.0	30.0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0

Table 1: Node-Node Adjacency Matrix indicating Costs for Travel Time and Purchasing  $B$  amounts of items  $m$  between Pair of Nodes

Once arranged the travel time and purchasing costs as shown in Table 1, there exist many efficient solution algorithms for this type of problems. Zahn (1997) and Zhan and Noon (2000) rearranged this type of data structure by the Forward Star and the Reverse Star representations. The Forward Star representation of data can be used to efficiently determine the set of arcs outgoing from any node. On the flip side, the Reverse Star representation is a data structure that provides an efficient means to determine the set of incoming arcs for any node. The Reverse Star representation of a network can be constructed in a manner similar to the Forward Star representation. The only difference is that *incoming* arcs at each node are numbered sequentially. Past research has demonstrated that the Forward and Reverse Star Representation is the most efficient among all existing network data structures for representing a network (Ahuja et al. 1993; Cherkassky et al. 1993; Zhan 1997; Zhan and Noon 2000). Zhan and Noon (1996) evaluated 15 different algorithms for solving this type of problems (see Table 2) and recommended the following:

1. The fastest algorithms for computing shortest paths on real road networks are:
  - a. the Pallottino's graph growth algorithm implemented with two queues (TWO-Q) and
  - b. the Dijkstra's algorithm implemented with approximate buckets (DIKBA).
2. Avoid the Bellman-Ford-Moore implementations (BF and BFP) and the naïve implementation of Dijkstra's algorithm (DIKQ).

Abbreviation	Implementation Description	Complexity	Additional References
BF	Bellman-Ford-Moore basic implementation	$O(nm)$	Bellman (1958)
BFP	Bellman-Ford-Moore with parent-checking	$O(nm)$	
DIKQ	Dijkstra's - naive implementation	$O(n^2)$	Dijkstra (1959)
DIKB	Dijkstra's using buckets structure - basic implementation	$O(m + nC)$	Dial (1969)
DIKBM	Dijkstra's using buckets structure - with overflow bag	$O(m + n(C/\alpha + \alpha))$	Cherkassky <i>et al.</i> (1993)
DIKBA	Dijkstra's using buckets structure - approximate buckets	$O(m\beta + n(\beta + C/\beta))$	
DIKBD	Dijkstra's using buckets structure - double buckets	$O(m + n(\beta + C/\beta))$	
DIKF	Dijkstra's using heap structure - Fibonacci heap	$O(m + n \log(n))$	Fredman and Tarjan (1987)
DIKH	Dijkstra's using heap structure - $k$ -array heap	$O(m \log(n))$	Corman <i>et al.</i> (1990)
DIKR	Dijkstra's using heap structure - $R$ -heap	$O(m + n \log(C))$	Ahuja <i>et al.</i> (1990)
PAPE	Incremental Graph - Pape-Levit implementation	$O(n2^n)$	Pape (1974)
TWO-Q	Incremental Graph - Pallottino implementation	$O(n^2m)$	Pallottino (1984)
THRESH	Threshold Algorithm	$O(nm)$	Glover <i>et al.</i> (1984, 1985)
GOR	Topological Ordering - basic implementation	$O(nm)$	Goldberg and Radzik (1993)
GOR1	Topological Ordering - with distance updates	$O(nm)$	

Notation:  
 $n$  is the number of network nodes.  $m$  is the number of network arcs.  
 $C$  is the maximum arc length in a network.  $\alpha$  and  $\beta$  are input parameters.

Table 2: Summary of 15 Shortest Path Algorithms (Zahn and Noon, 1996)

The next question is how can we obtain the link travel time ( $t_a$ ).

#### 4.2 Functional Forms for Estimating Link Travel Time, $t_a$

Estimating link travel time will depend on whether real time traffic data including volume and speed can be obtained and be made available for service brokers/users or not.

##### *4.2.1 When Real Time Link Speed is available*

When real time speed data on each link is available, then we can easily estimate the link travel time by the following equation:

$$t_a = (60 \text{ minutes} \times \text{link distance in mile}) / [\text{Speed (mile/hour)}] \quad (7)$$

For example, if the current speed on the link  $a$  is 30 miles/hour and the link length is 2 miles, the current link travel time is  $(60 \text{ min} \times 2) / 30 \text{ m/h} = 4 \text{ minutes}$ .

##### *4.2.2 When Real Time Link Traffic Volume is available*

Many cities now have installed devices such as loop detectors to obtain real time traffic volume on certain links. In such a case, real time link speed may not usually obtainable from loop detectors, but real time link traffic volume can be. We can convert real time link volume to link travel time by using a function such as the BPR function as shown below:

$$t_a = t_a^0 [1 + \eta(v_a/c_a)^\lambda] \quad (8)$$

where  $t_a$  = current link travel time

$t_a^0$  = uncongested free flow travel time on link  $a$

$v_a$  = real time traffic volume on link  $a$

$c_a$  = capacity of link  $a$  in number of vehicles per lane (refer to the Highway Capacity Manual (HCM) by the Federal Highway Administration (FHWA) or visit [www.bts.gov/tmip/papers/general/](http://www.bts.gov/tmip/papers/general/))

$\eta$  = a coefficient to be calibrated. The usual value used for US city roads is 0.88 as can be seen in [www.bts.gov/tmip/papers/general/ch10.htm](http://www.bts.gov/tmip/papers/general/ch10.htm)

$\lambda$  = a coefficient to be calibrated. The usual value used for US city roads is 5.5 as can be seen in [www.bts.gov/tmip/papers/general/ch10.htm](http://www.bts.gov/tmip/papers/general/ch10.htm)

For example, assume that there is a link of which uncongested link travel time ( $t_a^0$ ) is 40 miles/hour for 2-mile link (or 3 minute link travel time), and has two lanes with the capacity of handling 1,600 passenger car-equivalent units (PCU) per lane. Further assume

that loop detectors indicate that there are 4,000 PCUs passing by in that link now, then the estimated link travel time is:

$$t_a = 3 \text{ min } [1 + 0.88 (4,000/3,200)^{5.5}] = 12 \text{ minutes.}$$

If there are only 1,000 PCUs traveling, then link travel time is:

$$t_a = 3 \text{ min } [1 + 0.88 (1,000/3,200)^{5.5}] = 3 \text{ minutes.}$$

For detailed descriptions on the other type of link travel time functions, see Suh, Park and Kim (1990).

### 4.3 Estimating Spatio-Temporal Link Travel Time

In either situation described above, the more accurate link travel time for a given origin-destination pair can be estimated by using a spatio-temporal function. If the current traffic volume and speed indicate that it would take 10 minutes to travel on link  $a$  connected from node 1 to node 2 in Figure 1, travel time on link  $n$  connecting from node 2 to node 5 has to be estimated since what we have now is the current link travel time, not the link travel time 10 minutes later. Figure 2 illustrates the situation.

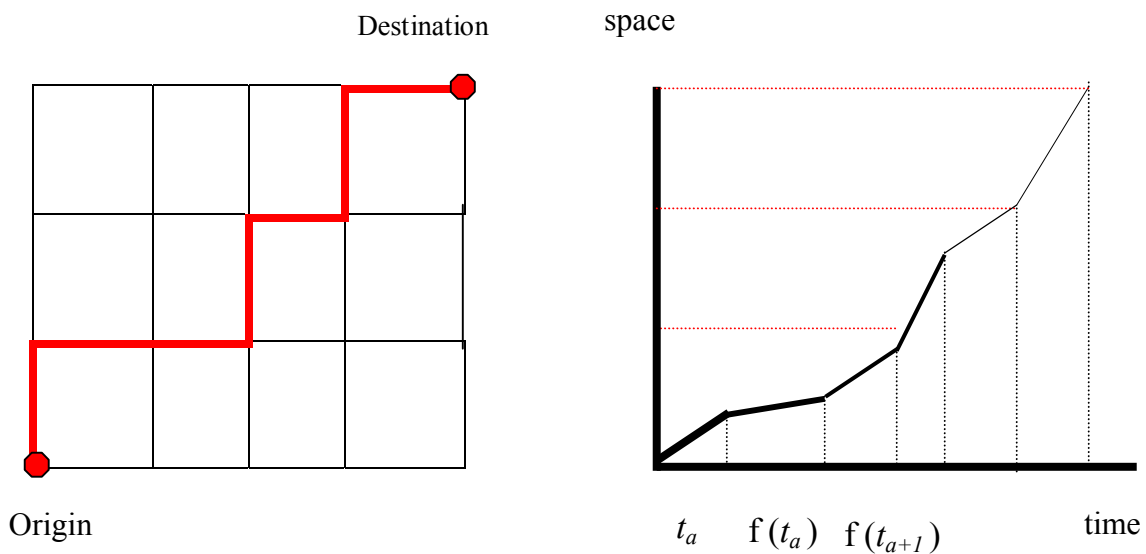


Figure 3: Forecasting Spatio-Temporal Link Travel Time with Real Time Data

A general spatio-temporal function can be written as follows:

$$t_{a+1} = f(t_a) \tag{8}$$

Evaluation on various link travel time forecasting methods as well as design and implementation of a link travel time forecasting model has been well described in You and Kim (2000), a copy of which I have sent to all members of AGLBS before the Liege meeting.

#### 4.3.1 When Real Time Traffic Data are not available

In the absence of real time link speed and volume, we could construct link travel time based on the past link time data. I would suggest at least three link travel time tables be made. These are:

- (1) Peak-hour link travel time table fro weekdays,
- (2) Non Peak-hour link travel time table for weekdays, and
- (3) Link travel time table for weekends.

Each link time then can be used in any functions described above, depend on the time of the day and time of the week. In case travel between origin and destination is involved in both peak and non-peak hours, both peak and non-peak tables from the past data can be used as shown in Figure 3 below.

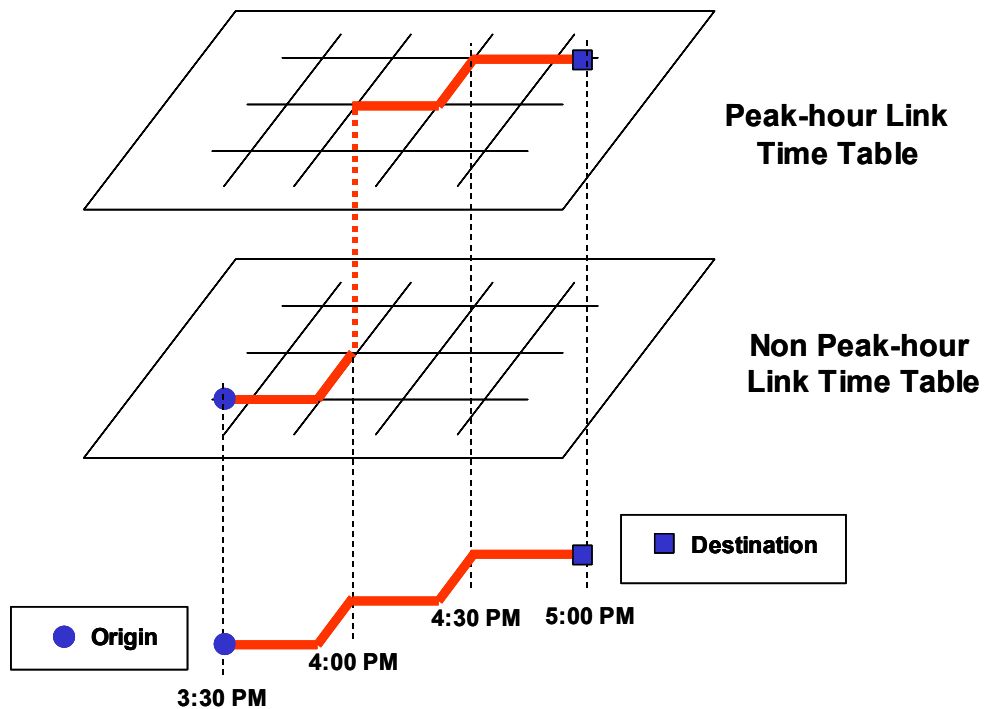


Figure 4: Estimating Spatio-Temporal Link Travel Time with Past Data

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