DEVELOPMENT OF LOCATION-BASED DYNAMIC ROUTE GUIDANCE SYSTEM OF KOREA HIGHWAY COOPERATION

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Abstract: For the last two years, Korean highway cooperation has developed a locationbased Dynamic Route Guidance System (DRGS). The target end users of the system are mobile-phone users in Korea. The service is scheduled to be commercialized in 2005. Spatially, the system covers all of the expressways which is about 2,800 km and some of the National highways of 500 km. This paper firstly discusses the procedures of travel timerelated data collection including node-link system, estimation link travel time etc. Secondly the study shows how to use real-time profile and historical profile in order to predict link travel time for the future time periods. Thirdly, path finding algorithms based on the predicted link travel times including multiple path finding algorithms and resource-constrained path finding method are summarized. Fourthly, the way of using XML language which realizes the proposed algorithms in the environment of the LBS is outlined. Lastly, the initial results of the proposed systems including the accuracy of the route travel time forecast and soundness of the suggested routes are discussed.

Key Words: Location Based System, Advanced Traveler Information Systems, Dynamic Route Guidance Systems, Geographic Markup Language

1. INTRODUCTION

For the last two years, Korean Highway Cooperation (KHC) has developed a location-based Dynamic Route Guidance System (DRGS). The target end users of the system are mobilephone and PDA users in Korea. The service is scheduled to be commercialized at the beginning of 2005. Spatially the system will cover all of the expressways which is 2,638 km and some part of the National highways of 484km in Korea, as shown in Figure 1.



Figure 1. Network Coverage of the System: Expressways and Part of National Highways in Korea

Basically the target services are as follows and described in Figure 2.

- Location-based routing services and navigation;
- Providing optimal path finding services for future time period
- Providing additional services relevant to highway route guidance

The project is also designed to provide following services through the web of KHC:

- Best route and its expected travel time when departing at present time;
- Best route and its expected travel time at the user-specified departure time;
- Navigation-related geographical and value-added information

The developed system is different from the existing ATIS in many aspects as follows:

- Based on the predicted traffic information rather than the real-time (current) traffic information;
- Location-based route guidance system using mobile phone and PDA;
- Providing multiple paths rather than a single path;
- More detail representation of the network.

The information flow of the system is shown in Figure 3.



Figure 2. Location-Based Routing Service



Figure 3. Information Flow of the System

This paper firstly discusses the network representation by links and nodes. Secondly, the procedures of network travel time-related data collection including node-link system, estimation link travel time etc are outlined. Thirdly, the study shows how to use real-time profile and historical profile in order to predict link travel time for the future time periods. Fourthly, path finding algorithms based on the predicted link travel times including multiple path finding algorithms and resource-constrained path finding method pair are summarized. Then, the way of using XML language which realizes the proposed algorithms in the environment of the LBS is outlined. Lastly, the initial results of the proposed systems including the accuracy of the route travel time forecast and soundness of the suggested route(s) are discussed, followed by concluding remarks.

2. NETWORK REPRESENTATION

The expressway network is divided into links based on following rules:

- Shorter link with heavier traffic and higher level of congestions;
- Shorter link with smaller loop spacing;
- Designating interchanges, junction, number of lane changing point, tunnel, service area, etc as nodes.

Using above rules, 1,721 links were defined. Among them 973 links represent basic expressway segments, and others do connectors of interchange, junction and service areas. The length of the links of the basic expressway segments ranges from about 3.0 km near metropolitan areas to 15.0km in rural areas.

3. TRAVEL TIME ESTIMATION AND FORECASTING

As shown in Figure 4, after observing raw traffic data, link travel times (i.e. real-time profile) are estimated. Then historical profile representing the average value of the observed link travel times over the certain past time periods are constructed. Then link travel times for the future time periods are predicted based on real-time profile and historical profiles. Lastly, optimal route for a given origin and destination pair is found and provided through mobile phone and/or PDA. The details of each step are as follows.

3.1 Collection of Raw Traffic Data

KHC operates 1,876 vehicle detectors (VDS: Vehicle Detector Systems) for traffic data collections and Toll Collection Systems (TCS) for toll collections. From VDS spot traffic information such as time mean speed and traffic volume is observed, and from TCS spatial traffic information such as space mean speed and travel time is collected. More than 90 percent of the expressways are covered by VDS. In this project, basically travel speed of 5 minutes duration from each vehicle detector is used in order to estimate link travel times. However, if VDS is not available, travel time information from TCS is applied.



Figure 4. Conceptual Diagram of Traffic Data Processing

3.2 Link Travel Time Estimation (Real-time Profiling)

Link travel time (speed) for each time period is estimated by weighted mean of the VDS's speeds by cell lengths as follows:

$$s(h) = \frac{\sum_{j=1}^{V-1} \left(v_j(h) + v_{j+1}(h) \right) / 2 \times d_{j,j+1}}{\sum_{j=1}^{N-1} d_{j,j+1}}$$
(1)

where s(h) = travel speed of time interval h of a link;

 $v_j(h)$ = spot speed of detector j of time interval h; $d_{i,j+1}$ = distance from detector j to detector j+1 (length of cell);

 \vec{N} = number of detectors in a link

For the expressway segments where normal and HOV lanes co-exist, two travel speeds are estimated for both normal lane and HOV lanes. In case of travel time estimation from the TCS, the arithmetic mean from the all vehicle's travel time excepting outliers is used as a representative mean. For link travel time estimation, 10 minutes interval is used based on the study (Park et al., 2004).

After estimating link travel time for each time interval, the simple exponential smoothing method is applied in order to remove noise or randomness and capture the travel time changing pattern as follows:

$$S_{T} = S_{T-1} + \alpha (y_{T} - S_{T-1})$$

= $\alpha \cdot y_{T} + (1 - \alpha)S_{T-1}$
= $\alpha \cdot y_{T} + \alpha (1 - \alpha)y_{T-1} + \alpha (1 - \alpha)^{2} y_{T-2} + \dots$

where S_T = smoothed travel speed of time interval T of a link;

 y_T = observed travel speed of time interval T of a link;

 α = smoothing factor (0~1).

3.3 Construction of Historical Profile

When constructing HP, a number of questions must be answered. One of them is about how many HP should be constructed. That is, the necessity of weekly differentiation needs to be checked. In order to answer to this question, this study conducted a statistical test (comparing two means) using the link travel time data from 30 links (from Seoul to Daejeon) on the Kyungbu expressway in Korea. The travel time data were collected from the Loop detectors from March to August, 2003 (yielding 180 days' data). The link travel times were aggregated into 10 minutes intervals so that there are 144 interval for a day (6 interval/hour ×24hour). It was found that each day of week has different link travel times. Particularly, the portions of intervals where link travels on Sunday are equal to those of other day of week was found to ranges from 1/3 to 1/2. In the case of comparison between Saturday and other days of week, the portions of intervals where link travels are the same ranges from 1/2 to 2/3. Based on these findings, it was recommended that each day of week should have each one's HP (see Park et al.(2004) for details).

3.4 Link Travel Time Forecasting under Non-Incident Condition

This project designed so that link travel times are predicted every 10 minutes as shown in Figure 5. For this, future time periods were divided into 10 minutes interval.



Time	Link							
interval	1	2	3	4				
h	$tt_1(h)$	$tt_2(h)$	$tt_3(h)$	$tt_4(h)$				
h+1	$tt_1(h+1)$	$tt_2(h+1)$	$tt_3(h+1)$	$tt_4(h+1)$				
<i>h</i> +2	$tt_1(h+2)$	$tt_2(h+2)$	$tt_3(h+2)$	$tt_4(h+2)$				
•	•	•	•	•				
•	•	•	•	•				
•	•	•	•	•				
•	•	•	•	•				
•	•	•	•	•				
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Link travel time forecasts at time period "*h*"

Time Link interval 1 2 4 3 h+1 $tt_1(h+1)$ $tt_2(h+1)$ $tt_{3}(h+1)$ $tt_4(h+1)$ $tt_1(h+2)$ $t_{2}(h+2)$ $t_{3}(h+2)$ h+2 $tt_4(h+2)$ $tt_1(h+3)$ $tt_{2}(h+3)$ $tt_{3}(h+3)$ $tt_{4}(h+3)$ h + 3• •

Link travel time forecasts at time period "h+1"

Figure 5. Conceptual Framework of Link Travel Time Forecasting

The project relies on artificial neural networks (ANN) in order to forecast link travel time for future time periods. After comparing different input sets, the best structure of the ANN models was found as follows:

- Input: tt(h-7), tt(h-6), tt(h-5), tt(h-4), tt(h-3), tt(h-2) from target and downstream links
- Output: tt(h), tt(h+1), tt(h+2), tt(h+3), tt(h+4), tt(h+5) of target link

where tt(h) = travel time of time period h;

Note that in a real forecasting environment, tt(h-1) representing link travel time from -10 minutes to current time of day (0 minute) cannot be used as input variable for the ANN because it cannot be observed at the time when ANN is applied. Table 1 shows the ANN results of the selected links from Kyoungbu expressway. Among 33 days' data in March and April, 2003, 20days were used for ANN training, and 7days and 6 days' data for calibration and validation, respectively.

			le rolecast	ing Error r	IOIII AININ					
Link	Historical		ANN (MAPE: %)*							
	Profile	tt(h)	tt(h+1)	tt(h+2)	tt(h+3)	tt(h+4)	tt(h+5)			
Seocho-Yangjae	4.0	1.4	1.9	2.4	2.9	3.3	3.8			
Yangjae-Dalraenae	2.7	1.8	2.6	3.4	4.1	4.7	5.2			
Seoul TG-Chukjeon	8.2	2.2	3.0	3.9	4.7	5.5	6.4			
Chukjeon- Shingal JC	4.1	1.8	2.6	3.3	4.1	4.9	5.7			
Ohsan-Wongok JC	3.6	1.8	2.1	2.3	2.8	3.0	3.4			
Wongok JC- Anseong	5.6	1.5	1.9	2.3	2.6	3.0	3.3			
Namee-Chungwon	4.9	2.1	2.7	3.2	3.6	4.0	4.4			
Chungwon-Chukam	5.4	2.0	2.7	3.2	3.8	4.2	4.5			
Hwaeduk JC- Daejeon	3.6	1.7	2.2	2.6	3.0	3.3	3.6			

Table 1. Travel Time Forecasting Error from ANN

* Mean absolute percent error

When applying ANN for travel time forecasting, the appropriate number of ANN models should be decided. In other words, the spatial transferability should be checked. Table 2 shows the results of the spatial transferability of ANN for travel time forecasting. It is observed that spatial transferability is very low and therefore ANN model should be developed for each link. Accordingly, ANN model is designed for each link in this project.

Link used for Link used for Spatial		Forecasting Error from ANN(%)							
ANN Calibration	Transferability Test	tt(h)	tt(h+1)	tt(h+2)	tt(h+3)	tt(h+4)	tt(h+5)		
	Yangjae-Seocho	1.4	1.9	2.4	2.9	3.3	3.8		
Yangjae- Seocho	Daraenae-Yangjae	6.4	10.0	14.0	18.0	21.6	24.5		
	Chukjeon-Seoul TG	7.0	8.2	9.7	11.3	12.9	14.4		
Wongok- Anseong	Wongok-Anseong	1.8	2.1	2.3	2.8	3.0	3.4		
	Anseong-Wongok	3.4	3.6	3.8	3.8	4.1	4.3		
	Chungwon-Namee	6.5	6.8	7.1	7.3	7.4	7.5		

Table 2. Results of Spatial Transferability of ANN Model

Other important issue to be cleared with respect to travel time forecasting is about "how many days data should be used for ANN calibration (i.e. optimal data size for calibration)" and at the same time "how open the ANN model should be calibrated (optimal calibration frequency)". To answer for these two questions, this project tested a different set of "optimal data amount for calibration" and "optimal calibration frequency "as shown in Table 3.



Figure 6. Optimal Calibration Cycle

Table 3. Scenario	s for Choosing Optim	al Data Size and Calibr	ation Frequency
Data Size for		Calibration Frequency	
Calibration	30 days	60 days	90 days
30 days	30-30	30-60	30-90
60 days	60-30	60-60	60-90
90 days	90-30	90-60	90-90

To test 9 different scenarios, 180 days' data collected from March to September, 2003 were used. Among 9 scenarios, the 30-90 model was the worst and the 90-30 model was the best. However, the results of the 90-30 model were not much different from those from the 30-30 and 60-30 models. Therefore considering the calibration time and data storage, the 30-30 model was chosen, implying that the ANN calibration for each link is done every month using previous month's real-time profile (see KHC(2004) for details).

3.5 Link Travel Time Forecasting under Incident Condition

One of the most important and challenging information for the successful real-time routing system is the reliable link travel time forecast under incident condition. Considering a number of weaknesses of the incident-related data collection system of KHC, this project applied "shock-wave theory" for this purpose. The input and out of the model are as follows:

- Input: Incident location, time, number of lanes blocked, vehicle type, number of vehicles, incident duration, traffic volume of upstream, capacity of incident location, etc.
- Output: Link travel speed forecasts of each incident related links for future time periods (from the beginning of the incident and to the end of incident-induced queue)

The detail procedures for the travel speed forecasting under incident are as follows:

- [Step 1] Estimation of Backward forming shockwave speed
- [Step 2] Estimation of Backward recovery shockwave speed
- [Step 3] Estimation of Clearance time of queue
- [Step 4] Estimation of maximum queue length
- [Step 5] Estimation of traffic state of each link for each time interval (consisting of normal state before incident, queue state by incident, recovered state after incident clearance)
- [Step 6] Estimation of link speed of each link for each time interval (by the weighted average speed considering temporal and spatial occupation of each state in a link)

The incident duration is predicted by the cross-classification model calibrated using 2003's data (about 7000 incidents). The detail description is available in KHC(2004).

4. PATH FINDING ALGORITHM IN DYNAMIC TRAFFIC NETWORK

4.1 Identifying Optimal Path and Estimating Expected Route Travel Time

In order to find an optimal path and estimate the expected travel time of the path, the following equation was used:

$$E(l_{j}) = \min_{i \neq j} \left\{ E(l_{i}) + E(c_{ij}(E(t_{i}))) \right\}, \qquad l_{o} = departure \ time \ at \ origin$$

where $E(l_i)$ = expected travel time from origin to node *j*

Strictly speaking, the Bellman's Principle of Optimality does not hold in a dynamic and stochastic traffic network (Patanamekar et al. (2003)); therefore, the conventional labeling approach based on the notion of Equation 10 may produce erratic results. However, this project relies on Equation 10 for path finding because the probability of identifying non-optimal path as an optimal path is very low (see Patanamekar et al. (2003) for detail).

When identifying optimal or alternative paths in a interrupted traffic flow such as National highways in Korea, U-turn and P-turn should be considered as shown in Figure 11. However,

the conventional node-based labeling approach violates Bellman's Principle of Optimality, resulting in erratic path. In this context, this project bases on the link-based labeling approach rather than node-based one.



Figure 7. Link-based Labeling Approach for U-turn and P-turn Movements

4.2 Identifying Multiple and Reasonable Alternative Routes

Drivers prefer to be provided with a multiple number of reasonable alternative paths rather than a single optimal path. For this, this project uses the definition of "reasonable alternative paths" of Park et al. (2002) as follows:

A path is a "reasonable alternative path" if it not only has "acceptable attribute value(s)" but is also "dissimilar" in terms of the links used with respect to previously identified paths

For this, this project uses the efficient vector labeling (EVL) algorithm (Park et al. 2002). Modified from the conventional label-setting based K-shortest path algorithm, the EVL algorithm deletes a sub-path which cannot satisfy the constraints in terms of overlapping between and/or among routes and attribute's constraint such as travel time and toll.

5. WEB GIS SERVER

GML (Geographical Markup Language) is an enabler of geo-spatial web services and integration. It is an XML language for modeling, encoding, transmission, and storage of all forms of geographic data. It provides structure and primitives to define application specific geographic objects or vocabulary. It handles rich set of primitives, including those for features, geometry, topology, coverage, coordinate reference systems, units of measure, feature styling, time, and observations.

This project applied GML and GIS in order to create geographical DB, which is required for location –based geo-spatial web services. Figure 8 shows the procedure of building GML DB.



Figure 8. GML DB Building Process

Road network was presented by the GDF(Geographic Data Files) road network model. Level 1 network (simple feature) describing on/off ramps, basic links and connecting links, etc. is used for navigation, while level 2 network (complex feature) such as interchanges, toll plazas and links for travel information displaying, etc is used for routing. Figure 9 shows the image sample for navigation service.



Image Sample for Exit Guidance Service



Image Sample for Routing Instruction in Navigation Service

Figure 9. Navigation Image Sample

6. GEO-MOBILE APPLICATION

System Architecture of the Information Dissemination Web-service consists of four parts: web-server, web application server, traffic data processing system, and web GIS server. Figure 10 shows the relationships among these fours parts. The web-server enables users to access services through internet by mobile phones, passes the request of users to web application servers, and transfer the corresponding service to users through internet. The web application server consists of routing process, SMS process, Mapping process, Map image process and JSP engine. The traffic data processing system has two components: traffic data server which preprocesses traffic data coming from traffic information center, and routing

engine which identifies an optimal path under prevailing and predictive traffic condition. The main function of web GIS sever is to provide web map service and route-related information based on the routing-related calls from users.



Figure 10. System Architecture of the Information Dissemination Web-service

7. INITIAL RESULTS OF THE SYSTEM

7.1 Experimental Study Design

To test the accuracy of the travel time forecasting processes and the reasonableness of the path finding algorithm, 182 origin-destination pairs were chosen from the expressway network shown in Figure 1. The average route distance is about 170 km. To test the impact of the level of congestion (i.e. time of day), seven different departure times (i.e. 07:00, 08:00, 09:00, 12:00, 16:00, 17:00, 18:00) were chosen. Accordingly, overall 2,548 (182 OD pairs \times 7 departure times) path searches were performed.

7.2 Comparison between Predicted and Observed Route Travel Times

Table 4 shows the comparison results of the predicted and observed route travel times on October 29 (Friday) and 31 (Sunday) in 2004. In case of October 29 (Friday), the mean absolute error (MAE) and mean percentage error (MPE) are 3.3km/h and 2.4%, respectively. The probability that MAE is less than or equal to 10 minute is 92.9%, while the probability that MPE is less than or equal to 10 % is 97.0%. It was also found that the afternoon departure times gave higher errors than the morning departure times. The test of October 31 (Sunday) gave worse results than that of October 29 due to the weekend congestion. However, the MAE and MPE are still less than 10 minutes and 10%, respectively.

	Departure time							
	mean	07:00	08:00	09:00	12:00	16:00	17:00	18:00
Mean Absolute Error (MAE) (min)	3.3	2.7	2.6	3.0	3.8	3.9	3.7	3.4
Mean Percentage Error (MPE) (%)	2.4	2.2	2.0	2.3	2.6	2.4	2.5	2.6
Probability that MAE is less than or equal to 10km/h	92.9	94.5	94.0	94.0	89.6	89.6	90.1	96.2
Probability that MPE is less than or equal to 10%	97.0	96.7	96.7	95.6	95.6	97.8	98.4	97.8

Table 4. Predicted and Observed Route Travel Times (October 29, 2004, Friday)

* Average route travel time of all cases is 158.0 minutes

Table 5. Predicted and Observed Route Travel Times (October 31, 2004, Sunday)								
				Departu	re time			
	mean	07:00	08:00	09:00	12:00	16:00	17:00	18:00
Mean Absolute Error (MAE) (min)	7.8	2.5	2.9	2.8	2.9	12.6	14.4	16.1
Mean Percentage Error (MPE) (%)	4.3	2.0	2.4	2.3	2.4	6.1	7.1	7.9
Probability that MAE is less than or equal to 10min	79.0	100.0	94.5	97.8	96.2	56.0	54.9	54.4
Probability that MPE is less than or equal to 10%	85.0	98.4	96.2	97.3	97.8	73.6	69.8	64.8

* Average route travel time of all cases is 165.7 minutes

7.3 Other Results

The project tested following three aspects to check the soundness of the path finding algorithms:

- Probability that the suggested path is the same with the true optimal path;
- Probability that the suggested path satisfies constraint;
- The portion of path (length) overlapped with other alternative path

For this, the EVL algorithm was used to identify two alternative paths, and maximum overlaps between paths was set as 30%. On the other hand, maximum route travel time of the 2^{nd} fastest path was set as 110% of the fastest path.

Tables 6 and 7 show the results on October 29 and 31. It may be seen that the probability of the suggested path to be the true optimal path is about 90%. Similar to the previous section, afternoon and Sunday gave a little bit worse results than morning and weekday. It is also observed that the EVL algorithm always satisfies constraint. The average overlaps between paths were found as about 40%.

Table 6. Other Tests on October 29, 2004 (Friday)								
				Departu	re time			
	mean	07:00	08:00	09:00	12:00	16:00	17:00	17:00
Probability that the suggested path is the same with the true optimal path (%)	89.0	96.2	92.9	85.7	86.8	82.3	88.5	86.8
Probability that the suggested path satisfies constraint (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
The portion of path (length) overlapped with other alternative path (%)	40.8	40.4	40.2	39.9	39.3	41.1	42.7	41.9

Table 7. Other Tests on October 31, 2004 (Sunday)								
				Departu	ure time			
	mean	07:00	08:00	09:00	12:00	16:00	17:00	17:00
Probability that the suggested path is the same with the true optimal path (%)	88.3	96.7	91.2	82.4	90.1	90.1	81.9	85.2
Probability that the suggested path satisfies constraint (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
The portion of path (length) overlapped with other alternative path (%)	41.3	40.8	40.3	40.2	41.3	42.1	42.0	42.3

1000 7.0000 10000 31,2001 (builduy)	Table 7.	Other	Tests c	on October	31, 2004	(Sunday
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8. CONCLUDING REMAKRS

This paper introduced the location-based dynamic route guidance system developed by Korea Highway Cooperation (KHC). The service is scheduled to be commercialized in 2005. One of the important next step of this project is to include the remaining parts of national highways and urban transportation networks of cities around the county as the target network.

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