Trial Application of the Interactive CDRG in UTMS

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SUMMARY

Universal Traffic Management System (UTMS) and Tokyo Metropolitan Police Department are planning to realize the interactive Centrally Determined Route Guidance (CDRG) (1). The system selects the recommended route using link travel time data, which is gathered by the traffic control system. Therefore, even in the early stages of its adoption when it cannot obtain large quantities of travel time data measured by in-vehicle units, the system can still provide guidance relating to the shortest route in terms of time required.

We constructed the trial system for CDRG on major roads in central Tokyo, and successfully conducted the second-step field test in February of 1997, following the first-step test in autumn of 1996. In the second-step test, we evaluated the performance of the system with vehicles guided under different kinds of formulas running in the trial area, which resulted in proving the superiority of our route guidance. We also computer simulated our route guidance method to comprehensively verify its performance, which is difficult to investigate in the field test. This paper reports on the second-step field and simulation tests.

CDRG USED IN UTMS

Traffic congestion occurs daily in large cities in Japan. On the other hand, car navigation equipment was developed some years ago and drivers have begun demanding traffic information requiring the fastest route to the driver's destination. Therefore, recently, the National Police Agency has been adding a new infrastructure equipped with two-way communication between the ground and vehicles (that is, infrared beacons) to the existing traffic control system and started to provide in-vehicle units with dynamic traffic information in the spring of 1996, in accordance with Vehicle Information and Communication System (VICS) (2,3,4).

We decided to adopt interactive CDRG as a means of helping to reduce traffic congestion in the future. CDRG is one sub-system that has been made possible by the diffusion of two-way communication between the ground and vehicles. In this system an optimum route according to the destination of each vehicle is recommended from a center. In addition, when these beacons and in-vehicle units become more widely used and can identify individual vehicles, it will be possible to implement several new traffic management measures. Additionally, using collected origin-destination (OD) information of every individual vehicle will enable more accurate prediction of traffic movement, more appropriate signal control and the providing of traffic information.

SYSTEM STRUCTURE

This system consists of beacons, in-vehicle unites, CDRG central unit and traffic control system. A beacon returns the route information that includes the recommended route and predicted travel time to the destination designated by a vehicle passing through the communication zone. In order to respond to any destination within the vicinity of a beacon, it accumulates the route information on all destinations in the range that is sent by a CDRG central unit every 5 minutes. The CDRG central unit calculates the route information for all relevant beacons, and transmits this information to them. The traffic control system collects vehicle detector information and creates predicted travel times of all links from it. Predicted travel time will be obtained using travel time data measured and sent by in-vehicle units in the future when they become sufficiently widespread.

METHOD OF ROUTE SELECTION

The optimum routes to all destination links are expressed as a route tree from the location of the beacon. A route tree is crated by determining one optimum upstream link among all links that enter each of all destination links in terms of time cost and so on. A unique optimum route to the beacon is obtained by recurrently tracing a destination link to its optimum inflow link, which is also another destination link upward along the route tree. In CDRG, the center normally calculates a route tree along which travel times to the destinations are all the smallest by a means such as Dijkstra-method using link travel times, according to the information renewal cycle (five minutes), and sends it to the beacon as the recommended route tree. Which is called the “route direct calculation method”. According to this method, however, slight fluctuation in travel time data used for route calculation causes a significant difference in the recommended route, which is given as the result of calculation. Therefore, a different route may be recommended each time the driver passes a beacon and the driver may become confused. To combat this, we decided to adopt a method that prepares several route trees in advance each of which may possibly serve as the optimum route tree and selects the best route among them at the time. This is called the “route candidate method” and has the advantage that it can provide the driver with a stable recommended route even if there are unstable small fluctuations in the travel time data obtained on-line from the field. In addition, this method enables the selection of the route among candidate trees for each destination respectively, so the selection can be finely tuned according to the local traffic conditions. The number N of candidate route trees should be constant and those trees are created as follows: Route trees for an origin are obtained using estimated link travel times collected under diverse traffic conditions during a fixed past period. Then a particular combination of N route trees is chosen among the above trees so travel times of the shortest travel time routes picked out from these N trees according to all destinations are as close as possible on the whole to the true shortest times obtained without any route restriction during another fixed past period. It can be said that the number of candidate routes to a particular destination from a beacon’s location picked out from a set of N candidate route trees is greater, if the road network contains more alternative routes and traffic conditions on the road change more diversely. The number N of candidate route trees limits it, though.

FIELD TRIAL

AIMS OF THE TRIAL

Trial system for CDRG was constructed in the field with vehicles equipped with in-vehicle units actually driving and it was verified that the system normally operates and guides in-vehicle units effectively compared with other kinds of route guidance formulas in the first-step field test in autumn of 1996. We conducted the second-step test on February 21, 26-28, 1997 in an extended area from the first-step. The goal of the second trial was to evaluate the performance of the system in more detail as follows:

-Comparing the route guidance methods along longer OD.

-Evaluating the accuracy of predicted travel time provided to in-vehicle units

-Estimating the stability of the recommended route.

Where the number of candidate route trees was set to be eight.

CONSTRUCTION OF THE TRIAL SYSTEM

OD in the trial area

OD	Origin	Destination	Length
1-A	Kouenji, southwards on the Kannana-dori	Nishishinbashi, eastwards on the Sotobori-dori	12-
B	Nishishinbashi, westwards on the Hibiya-dori	Hounancho, westwards on the Hounan-dori	14km
2-A	Ohashi, eastwards on the Tamagawa-dpri	Asakusabashi, eastwards on the keiyo-doro	12-
B	Asakusabashi, westwards on the Keiyo-doro	Ohashi, westwards on the Tamagawa-dori	13km
3-A	Seishokomae, northwards on the Sakurada-dori	Kasugacho, westwards on the Kasuga-dori	9-
B	Kasugacho, eastwards on the Kasuga-dori	Seishokomae, southwards on the Sakurada-dori	11km

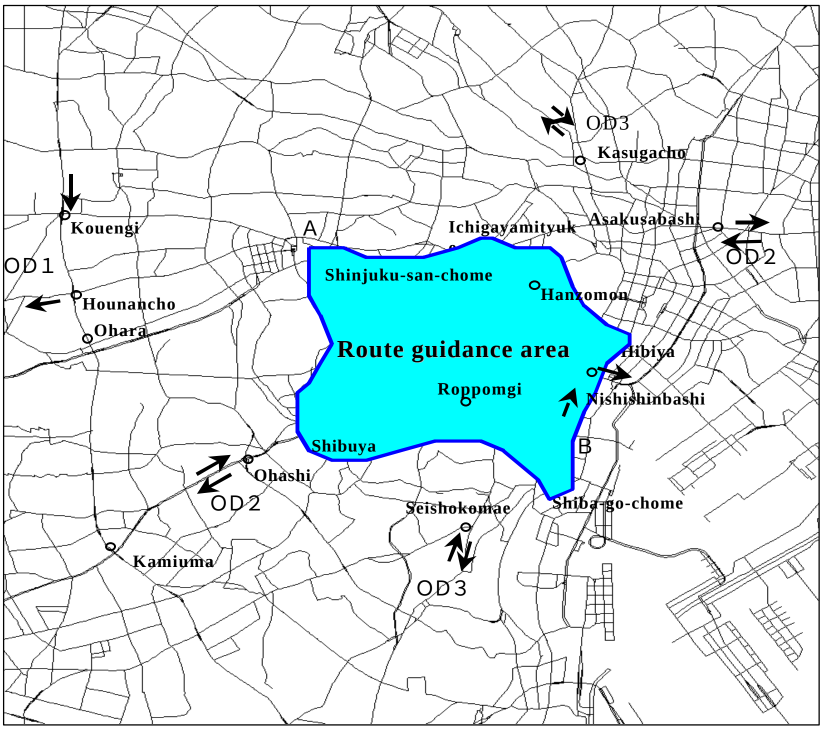

Figure 1 Trial area

Figure 1 shows the trial area, where nearly 100 infrared beacons were set up within an area having each side of about four kilometers in the center of Tokyo (the route guidance area within which the first-step test was conducted). A vehicle was supplied recommended route and predicted travel time to its destination at each beacon it went by in succession running within this area. Additionally six OD point pairs were set in the suburbs and across the route guidance area where beacons were installed so that a vehicle traveled with the route information guided at the starting point until they arrived at the edge of the route guidance area. The communication zone between a beacon and a vehicle is around 3.5 meters in length along the vehicle's direction. All these beacons hold detailed route information to any destination within about a 20-kilometer radius from them. And they are connected with one CRGS central unit through 9600 bps of communication lines. The CRGS central unit is connected with the traffic control system through a LAN. Only major general roads that can collect detector information are targeted for route guidance.

TRIAL APPROACH

We composed five groups of four types of vehicles as follows:

-CDRG: driving under guidance with CDRG system

-VICS: driving under human judgement with congestion information from VICS

-TAXI: driving in accordance with an experienced taxi driver's judgement

-SRG: driving under the guidance of the autonomous in-vehicle unit with the shortest distance route selecting method

These classified vehicles drove the same OD simultaneously every group and collected data such as travel time between the OD points and so forth. Where CDRG drove only along the general road of CDRG links where link travel times are available through vehicle detectors, while the other three types of vehicles could drive along any general road other than fine streets besides CDRG links.

RESULTS OF THE TEST

Travel Time per Vehicle Type

The total number of trial runs through all groups was 15 for OD3-A, OD3-B and 12 for each of the other four OD respectively. But along OD3-A, the number of beacons was small and in most cases only the beacon at the starting point guided vehicles, so the data for this OD is considered inappropriate for evaluating system performance. Table 1 shows two kinds of index obtained from trial run data for all OD except for OD3-A. One is the average of travel time per vehicle type, and the other is the average of travel time increase rate per vehicle type to evaluate how much later each vehicle other than CDRG arrived at the destination than CDRG. Travel time increase rate is defined as follows:

Table 1 Average of travel time and increase rate of it per vehicle type

Vehicle type	Travel time	Increase rate
CDRG	2698.2 sec.	0 %
VICS	2765.0 sec.	2.5 %
TAXI	2842.0 sec.	5.3 %
SRG	2891.7 sec.	7.2 %

$$TIR = (TTO-TTC)/TTC$$

Where TIR is travel time increase rate, TTO travel time of a vehicle other than CDRG and TTC travel time of CDRG. It is said on average that CDRG arrived at the destination the earliest and VICS arrived later than CDRG by 2.5 %, TAXI 5.3% and SRG 7.2 %.

Winning Rate of CDRG

Another index was calculated; winning rate that is defined as the number of times the respective vehicle arrived at the destination with the shortest travel time divided by the total number of trial runs. The winning rate of CDRG was the highest for every OD exclusive of OD3-A, and was 45.6 % totally for those five OD. For OD3-A, the winning rate of TAXI was 75% that was much higher than that of CDRG, but their travel times averaged for this OD were not so much different. Which implies that even when this system cannot obtain the optimum route for some reason, it might mostly provide a route close to it.

Accuracy of Predicted Travel Time

Figure 2 shows the examples for comparison of predicted travel time provided by each beacon and actual travel time measured by vehicles from the beacon's position to the destination. The difference of both times was somewhat diverse depending on OD, but not so much on the whole and it proved that the system provides fairly reliable travel time information in terms of practical use.

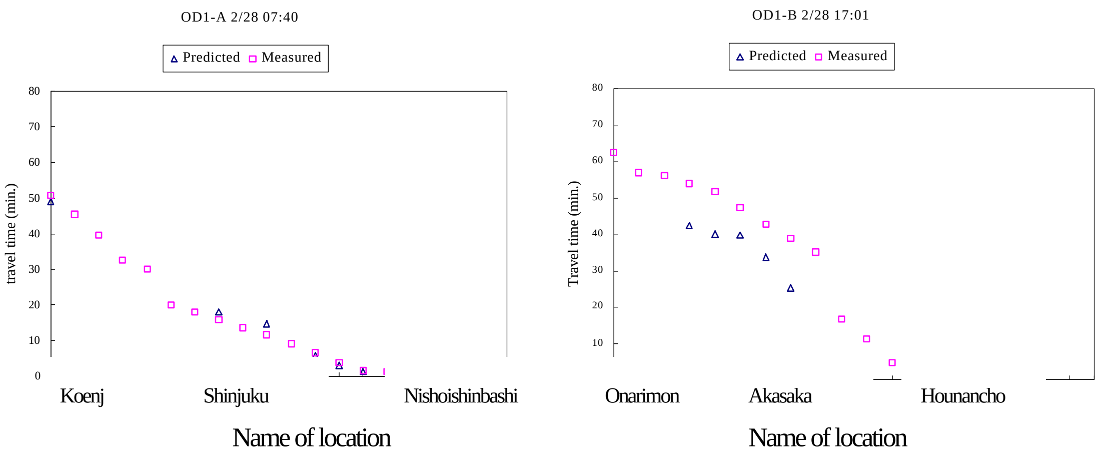

Figure 2 Comparison of predicted and measured travel time

Stability of Recommended Route

In the test, routes guided by each beacon appeared to appropriately alternate responding to the change of traffic conditions, but not as sensitively as to confuse drivers. So the route selection method of this system turned out to be effective from a stability point of view, as was expected.

OFF LINE SIMULATION

METHOD OF VERIFICATION

We verified the route selection algorithm using travel time data collected by the traffic control system. The method of verification is described below:

We collected the predicted and estimated travel times from the traffic control system and provided them to the simulator. The predicted link travel time is the time that will be required to drive through the link within the specified future interval, and the estimated link travel time is the time that was required to drive through the link. In the candidate route method, the predicted link travel times are used to calculate the predicted travel time for each candidate route between the OD. The route, which had the shortest predicted travel time is adopted from N candidate routes as the recommended route for that OD.

An optimum route (the shortest travel time route), which is used as the standard for evaluating the recommended route should be calculated from the actual travel time. However, it is difficult to obtain the actual travel times for all links. We therefore used smoothed estimated link travel time and calculated the optimum route by the route direct calculation method.

We analyzed the routes for which the direct-line distance between the origin and destination was 10 to 20 kilometers. The analysis involved comparing the differences in travel times for the recommended and the optimum route. The simulation was conducted between 3:00 a.m. and 6:55 p.m. (with the routes calculated at intervals of five minutes). The number of destinations depended on the location of the beacon but was generally 300 to 600.

RESULTS OF ANALYSIS

Characteristics of the candidate route method

The candidate route method selects a route from several candidate route trees. It makes this selection independently for each possible destination. Figure 3 shows the characteristics of this method; the predicted travel time for each route to the main destinations. The routes marked in black are the routes, which have the shortest predicted travel time (the selected routes). The selected route number differs depending on the destination.

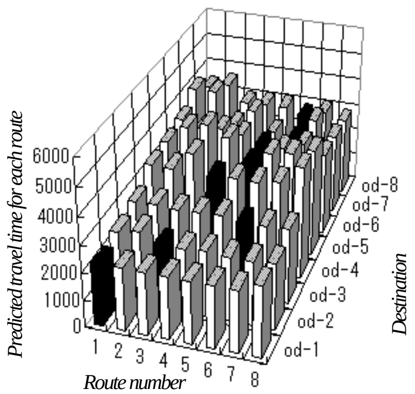

Figure 3 characteristics of this method

Suitability of the number of candidate route trees

In the field trial system, the number of candidate route trees was set to be eight. We changed the number of candidate route trees (8, 12, 16, 24) here and compared the number of effective candidate routes to the destination picked out from those trees and the difference in travel times for the recommended and the optimum route. (The evaluation value is the average of the values for all destinations in all time periods.) Table 2 lists the results.

-When the number of candidate trees increases, so does the number of effective candidate routes on average. (Here, a route was determined to be different from another route when less than 50% of its links were included in another route and the number of effective candidate routes is the average number of different routes in the set of candidate routes.)

- The reduction of travel time difference was not so much as expected from the increase of the effective candidate route number.

- The result of the analysis indicates that the suitable number of candidate trees is 8 to 12.

Provided that the system can calculate a predicted travel time with considerable accuracy, increasing the number of candidate route trees should bring the travel time for the recommended route close to the travel time for the optimum route. However, since the predicted travel time for a link includes random error, the recommended route is affected by this error and fluctuates rapidly. The greater the number of candidate routes, the greater the effect of the error on the recommended route. This is the reason why the difference in travel times cannot be reduced beyond a certain point as shown in the figure.

Table 2 Comparison of the difference in travel times

Origin	Number of destinations	Evaluation value (average)	Number of candidate trees			
			8 trees	12 trees	16 trees	24 trees
Detector A	372	Difference in travel times Number of candidate routes	115.31sec 3.21	81.94sec 4.27	83.63sec 4.77	84.73sec 5.89
Detector B	519	Difference in travel times Number of candidate routes	90.65sec 3.32	78.32sec 4.14	76.84sec 4.45	75.80sec 5.36
Detector C	577	Difference in travel times Number of candidate routes	110.80sec 3.62	110.03sec 4.87	104.11sec 5.25	116.29sec 6.34

Effectiveness of the candidate route method

We confirmed the effectiveness of the recommended route calculated using the candidate route method (method A) by comparing the difference in travel times based on method A and the following two methods:

-Method B: Calculating the route using the route direct calculation method.

-Method C: Calculating the route, which has the shortest travel distance to the destination.

The results of a comparison of travel times for beacons at four locations are shown in Table 3.

The travel time along the recommended route was shortest when calculated by method A, followed by method B, and was longest when calculated by method C.

Table 3 Comparison of the route calculation methods

Method	Difference in travel time (average)
Method A	90.56sec to 146.62sec
Method B	121.42sec to 183.38sec
Method C	268.33sec to 552.77sec

Stabilization of the recommended route

The reason why we adopted the candidate route method is that it stabilizes the recommended route. However, the results of the analysis show that the route fluctuates to some extent at each interval even when the candidate route method is used. We tried to modify the method for stabilizing the recommended route by bringing in hysteresis in changing routes; If the difference in travel times for the previous recommended route and for the current route is T (constant) or less, the system recommends the previous route.

From the results of the simulation as shown in Figure 4 it is clear that the modification certainly stabilized the recommended route and brought the travel time closer to the travel time for the optimum route.

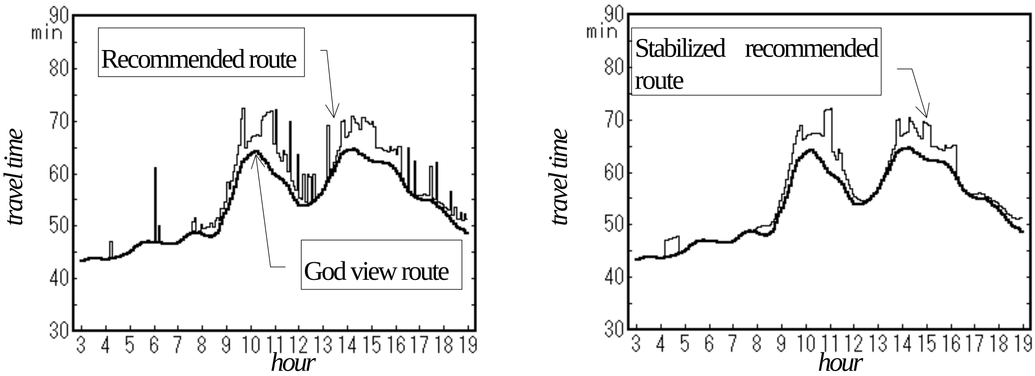

Figure 4 Stabilization of the recommended route

CONCLUSIONS

From the results of the field test, this system proved to be sufficiently practical and CDRG drove in the shortest time on average. An experienced taxi driver seems to have knowledge on what routes are advantageous during each time range from his experience, and then to select the best route to go forecasting form the traffic conditions he sees on the spot. Our system prepares several candidate routes in advance each of which is likely to be an optimum route on a statistical basis and selects the recommended route among them according to the predicted travel time. So this route selection method appears similar to the experienced taxi driver's in one way, but might provide an even shorter time route in higher provability because it operates automatically.

We also analyzed the performance of the route selection method of this system in detail thorough the off line simulation, and found out that the adequate number of candidate route trees is 8-12, and bringing in hysteresis in changing routes can even improve the performance of the system.

We are planning to conduct a further trial on an extended road network including express ways as well as to examine how to deal with unusual traffic such as an incident on large scale, and to exchange information among various facilities before the system is implemented in the near future.

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