A STUDY OF ENVIRONMENT CONSCIOUS TRAVEL GUIDANCE WITH PARETO IMPROVEMENT

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ABSTRACT

This paper examines the effects of traffic flow and environmental improvements through the provision of Pareto-improved route guidance in situations where an adequate amount of traffic information is provided by means of floating car data. Pareto-improved route guidance is defined as guidance information that modifies routes or departure times in such a manner that it is capable of improving route costs for a given driver without worsening the route costs for other drivers.

INTRODUCTION

Current traffic information services, of which VICS is an example, are designed to provide optimal route information for motorists. In other words, such information services are intended to create a dynamic user optimum (DUO) state that is achieved when drivers select the shortest possible route to their destinations at a given current time and when this process is repeated on a real time basis. However, the desired condition is not achieved because such information is provided only on some roads at present. Information services based on flow information are expected to achieve better conditions, given the fact that they provide high-precision information covering a larger number of roads than has been possible in the past. In terms of social cost, however, the condition that is optimal for users is generally different from the dynamic system optimum (DSO) state. It is known that in order to achieve DSO, some motorists must be required to pay a penalty in terms of a disadvantage. Implementation of car navigation services solely intended to optimize social costs might not be acceptable to users.

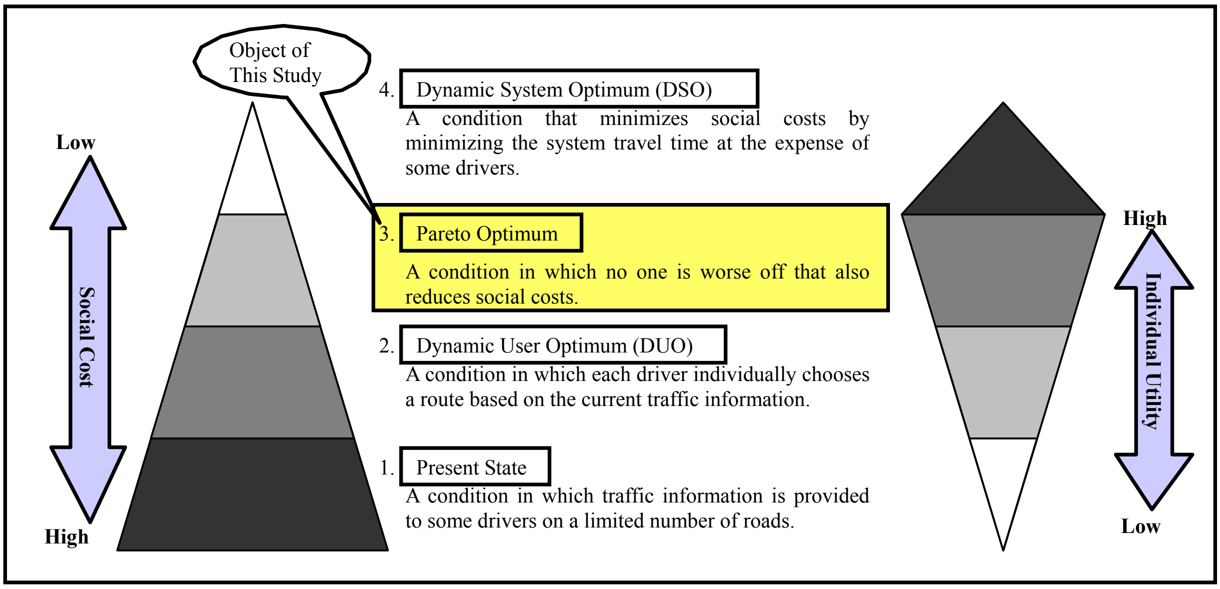

Fig. 1 Location of Pareto Optimum

In this study, we first compare the condition (the present state) that is achieved through the provision of incomplete information with the condition (DUO) wherein complete information can be provided by floating car data whose effectiveness is validated. In the next step, we discuss whether the state wherein no one personally suffers a disadvantage when compared with the DUO state and wherein social costs can also be reduced can be achieved though the provision of traffic information and route guidance information. Such a state is referred to as the Pareto optimum state, and it is assumed that the state lies between the DSO and DUO, as illustrated in Fig. 1. The Pareto optimum state is defined as a condition wherein no one can improve on the route costs unless someone else's route cost is worsened. The text that follows verifies the existence of such a Pareto optimum state and its effects on improving traffic flow and the environment.

EXAMINATION OF PARETO OPTIMAL

To evaluate the states assumed in Fig. 1, the following procedures are employed to recreate the conditions.

First, recreate by simulation the traffic conditions that can be achieved in the situation where the provision of traffic information is limited to some roads as the present state. Then, determine a DUO state using complete traffic information

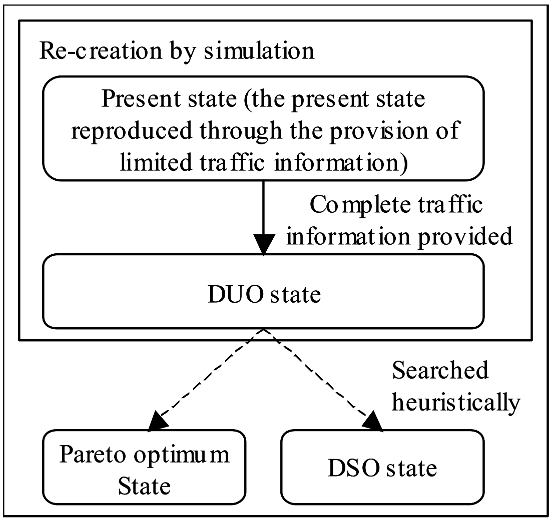

Fig. 2 Re-Creation Procedure

by running simulations on the assumption that traffic information can be employed on all roads (that is, for the situation where sufficient traffic information is provided by means of floating car data) in comparison with the aforementioned present state. Evaluate the merits of generating/providing traffic information by utilizing floating car data and by comparing the two states that are also determined through the simulations.

In the next step, based on the DUO state exploiting complete traffic information, heuristically search for the Pareto optimum and DSO states. By evaluating the results of the search, examine the possibility of implementing the Pareto optimum state and its environmental improvement effects.

OUTLINE OF SIMULATION

The present state and the DUO state are determined by simulation. The area subject to simulation is an approximately 16 km x 10 km area lying on the west side of Tokyo, as shown in Fig. 2.

Since the use of traffic information requires equipment that includes on-board units, not all vehicles are candidates. It is also assumed that not all drivers receiving traffic information use it and select routes based on it. Based upon this assumption, in the simulation, the proportion of traffic information used as route guidance is set as a parameter in this study.

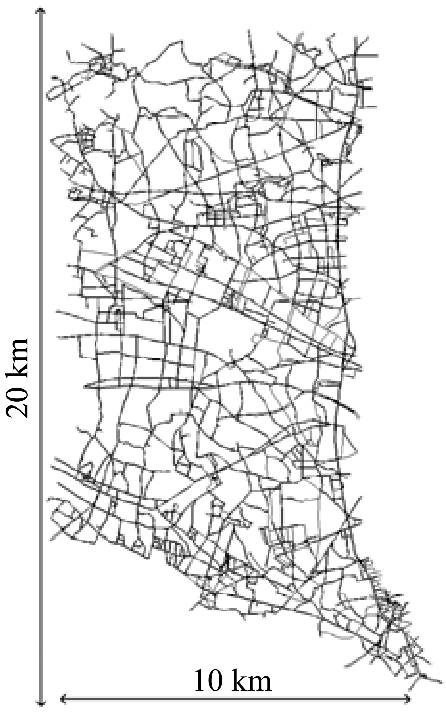

Fig. 3 Target Simulation Area

Re-creation of the present state by simulation: In the present state, traffic information is not provided on all roads covered by the simulation area. Taking the state of provision of traffic information into consideration, this case study assumes that traffic information is provided at 19.4% of road links. Based on the percentage of vehicles on the road that are equipped with car navigation systems, we assume that the percentage of drivers who use traffic information as route guidance is 50%. The present state is re-created as a DUO based on an incomplete information state. In the simulations, motorists who use traffic information and those who do not use it are assumed to select different travel routes. The extent to which the present state is recreated by the results of simulations is verified by comparing the link speeds and the volume of traffic determined by field surveys. This condition is referred to as the recreated present state. In addition, the condition in which the proportion of drivers using traffic information as route guidance has increased from the recreated present state to 75% is denoted as present state 75, and the new condition is reproduced in the simulations.

DUO simulation: This state assumes that traffic information is provided on all roads and to all vehicles. Therefore, this state is reproduced as the DUO based on complete information, as compared with the present state. In reality, however, since it is inconceivable that traffic information can be provided immediately to all vehicles, the three conditions of 50%, 75%, and 100%, representing the percentages of drivers using traffic information as route guidance, are reproduced by simulation. These conditions are referred to as DUO50, DUO75, and DUO100, respectively.

Pareto optimum and DSO: The two states, Pareto optimum and DSO, are calculated heuristically from the DUO75 determined by simulation (1). The Pareto optimum is determined according to the rules by which routes are changed if individual costs and the cost to the system as a whole do not degrade.

EVALUATION METHOD

Environmental improvement effects are relatively evaluated based on the simulation result of each state by comparing the total travel distance, the total travel time, and the total CO_2 emissions. The total CO_2 emissions are calculated from simulation results, using the method described in Reference (2).

SIMULATION RESULT

The results summarized in Table 1 were obtained by running simulations based on the conditions described above.

Table 1 Comparison of Simulation Results

	Present state	Present state 75	DUO 50	DUO 75	DUO 100
Total travel distance (1000 vehicles x kilometers)	6858.3	6843.9	6815.3	6829.5	7037.5
Total travel time (1000 vehicles x hours)	339.7	322.4	297.0	292.8	340.5
Distance traveled per vehicle (km) (total distance traveled /total number of vehicles)	3.9	3.9	3.9	3.9	4.0
Average travel speed (km/h) (total travel distance /total travel time)	20.2	21.2	22.9	23.3	20.7
Amount of CO2 emitted (ton/day)	1,562	1,519	1,456	1,448	1,586
Total travel time reduction effect Percentage reduction from present state (%)		5.1%	12.6%	13.8%	-0.2%
Amount of CO2 reduction Percentage reduction from present state (%)		2.8%	6.8%	7.3%	-1.6%

It was verified that in all cases with the exception of DUO100, both total travel time and total CO_2 emissions can be reduced from the present state. In DUO100, the total travel distance and the total travel time increased from the present state, thus representing an inefficient state. It appears that this result is attributable to the occurrence of a hunting condition, which is well-known in traffic engineering, as the users of traffic information increase and approach

100%, thus causing the traffic flow, contrary to the intended effect. A comparison of present state 75 and DUO50 indicates that in both total travel time and CO_2 emissions, DUO50 delivers a greater reduction effect, suggesting that an increase in the number of roads on which floating car data-based traffic information is provided produced a notable effect in reducing both of these quantities.

CONCEPT UNDERLYING PARETO OPTIMUM/DSO STATE SEARCH

The Pareto optimum state refers to a condition that is determined through Pareto improvements that involve minimizing the total cost under the condition that no one driver's individual cost is made worse than the present state; under the Pareto optimum state, it is expected that a cost socially smaller than the dynamic user optimum (DUO) state is produced, which is achieved when users select the shortest possible path to their destination under the condition that complete traffic information is provided under certain conditions. In this paper, we examined whether the Pareto optimum state can be determined under realistic traffic conditions, and to what extent improvements in social costs can be expected under those conditions, by means of simulation technique. However, because it is difficult to analytically determine the Pareto optimum state on a complex, large-scale network using the dynamic simulations conducted in this study, we adopted the technique of determining the Pareto optimum state by approximation by means of a heuristic numerical search method (3).

Based on the DUO state (in this simulation, DUO75, which produces the smallest total travel time and CO_2 emissions) that is achieved by simulation, if different alternative routes are assigned to a vehicle departing at a given time, we determine the Pareto optimum state by approximation by establishing a heuristic rule such that a change in route is allowed only when the vehicle's individual travel time is reduced (individual travel time check), when changing to that route leads to a reduction in social cost (total travel time check), and when the travel time required by all other vehicles is not degraded (Pareto improvement check).

VERIFICATION OF THE PARETO OPTIMUM SEARCH

Based on the above concepts, the plausibility of the results of a search for the Pareto optimum state was verified by limiting the scope of the search as follows.

Time window subject to analysis: 7:00 to 10:00
(Restricted to 3 hours including the morning peak rush hours)
O-D pair of vehicles subject to a route change: limited to one pair
The calculation of total travel time also takes the travel volume generated by other O-D pairs into consideration.
Number of candidate routes: 65 routes. Target O-D traffic volume: 211 vehicles (of which 111 vehicles use traffic information)

When a verification was made as to whether the search was performed correctly when a search for the Pareto optimum state was conducted using the above conditions, it was found that the total travel time diminished without any vehicles experiencing an increase in travel time, as intended, and the existence of a Pareto optimum state was confirmed.

STRATEGIES FOR REDUCING COMPUTATION TIME

Because it involves the verification of travel time on all vehicles in the simulation for each change of routes, the Pareto optimum search procedure requires a massive amount of computational processing. Since the required computational volume makes practical evaluations difficult, in the examinations that follow we decided to perform evaluations by treating the state searched for by removing the Pareto improvement check as the Pareto optimum state. Further, because in this search program the computational time required in the search process increases in proportion to the number of vehicles subject to route changes, if all vehicles are addressed when the Pareto improvement check is removed, a computational time on a scale of several days is required. For improved work efficiency, we removed the following vehicles that contribute relatively little to an improvement in traffic flow from being subjected to a route change: O-D pairs with a traffic volume less than a fixed number; and with respect to the routes and alternate routes determined by simulation, O-D pairs that have a total link extension/total path extension on paths less than a fixed number (pairs with extensive duplication). Further, in this search program, the time window to be processed is limited to 7:00 to 9:00 in the morning in which traffic congestion is likely to occur, and the vehicles subject to a route change are limited to those departing no earlier than 8:00 but no later than 9:00. In this manner, it was ensured that the computation is complete within a practical time frame.

EVALUATION OF ENVIRONMENTAL IMPROVEMENT EFFECTS IN PARETO OPTIMUM/DSO STATES

The two states, Pareto optimum and DSO states, determined according to the method described above were evaluated by comparing them with DUO75 used as a reference in terms of total travel time and CO_2 emissions. The results are summarized in Table 3.

Table 2 Evaluation of Environmental Improvement Effects in Pareto Optimum/DUO States

	DUO75	Pareto optimum state	DSO state
Total travel time	47,339	46,288	46,149
Amount of CO2 emitted (kg)	236,764	234,432	234,282
Total travel time reduction effect Percentage reduction from DUO75 (%)	—	2.22%	2.51%
Amount of CO2 reduction Percentage reduction from present state (%)	—	0.98%	1.05%

The above results provide verification that the Pareto optimum state achieves an environmental improvement when compared with DUO75, and produces results that compare favorably with DSO. Table 3 and Fig. 4 below show the impact of the Pareto optimum state on individual vehicles by comparing changes in their travel time.

Table 3 Changes in Travel Time for Individual Vehicles Under Pareto Optimum/DUO States

	Pareto optimum state			DSO state		
	Routes changed	No route change	Total	Routes changed	No route change	Total
Number of vehicles (units)	3,492	250,433	253,935	4,810	249,125	253,935
Number of vehicles with no change in travel time (units)	281	204,474	204,775	680	200,039	200,719
Vehicles experiencing deterioration in travel time						
Number of vehicles (units)	218	4875	5093	1,358	6,348	7,706
Percentage (%) (vehicles with deteriorated travel time/total number of vehicles)	6.24%	1.95%	2.01%	28.23%	2.55%	3.03%
Travel time deterioration per vehicle (min)	0.92	0.51	0.52	2.06	0.52	0.63
Vehicles experiencing improved travel time						
Number of vehicles (units)	2,993	41,090	44,083	2,772	42,738	45,510
Percentage (%) (vehicles with deteriorated travel time/total number of vehicles)	85.71%	16.41%	17.36%	57.63%	17.16%	17.92%
Travel time deterioration per vehicle (min)	1.67	1.20	1.23	1.77	1.43	1.45

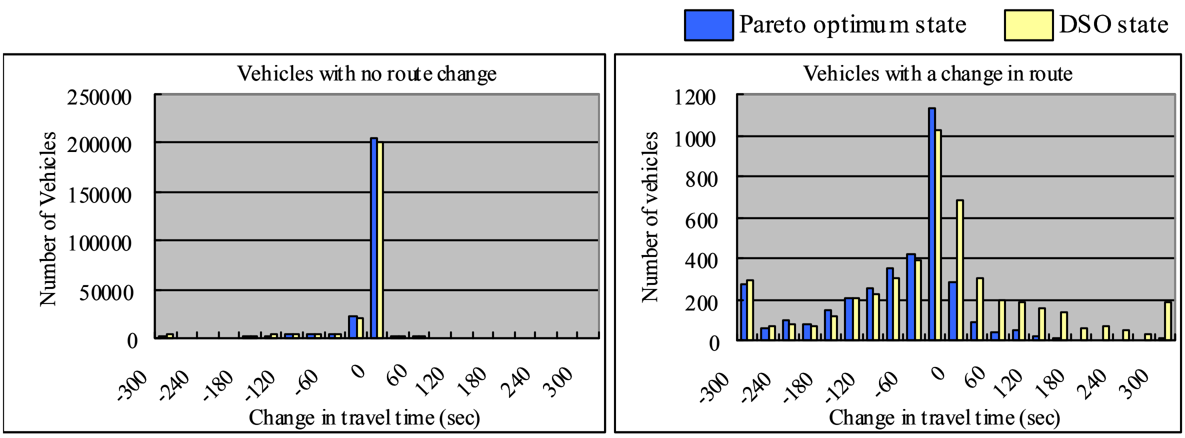

Fig. 4 Histograms of Changes in Travel Time by Individual Vehicles Under Pareto Optimum/DSO States

The histogram in Fig. 4 clearly shows that the Pareto optimum state determined in this study, when compared with the DSO state, contains an extremely small number of vehicles experiencing a deterioration in travel time. It should also be noted that the DSO state contains a large number of vehicles experiencing a deterioration in travel time, with a large proportion of route-changed vehicles experiencing a deterioration in travel time. This is due to the fact that DSO involves individual vehicles selecting routes that involve a deterioration in travel time in the interest of achieving overall improvements.

CONCLUSION

The following conclusions were obtained as a result of the present study. A Pareto optimum state exists for a given motorist wherein the total travel time is improved in a manner that does not degrade travel time, not only for the motorist himself but also for other motorists, through the reassignment of routes by simulation and by heuristic means. Through route changes that approximate a Pareto improvement that improves the total travel time without degrading one's own travel time, the total travel time can be improved over DUO without worsening individual vehicle travel times compared with DSO.

The evaluations conducted in this study provide verification of the possibility of achieving a Pareto optimum state that improves on total travel time without causing a deterioration in individual travel time, by means of a Pareto-improving route change. However, because a strict Pareto optimum state could not be determined in this study within reasonable computational amounts, we were unable to evaluate the extent of the environmental improvement effects. Also, the Pareto optimum state is determined by means of heuristic numerical searches based on simulation results. No attempt has been made to study the method for determining a Pareto-improving path in real time when drivers select routes in order to achieve the Pareto optimum state in real life.

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