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主　論　文　の　要　旨

論文題目　**Route search problem considering travel time reliability and CO_2 emission in road network**
(道路ネットワークにおける旅行時間信頼性とCO_2排出量を考慮した経路探索に関する研究)

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論　文　内　容　の　要　旨

In an effort to provide better route guidance to travelers, this study investigates the route search problem considering travel time reliability and CO_2 emission. This study adds to the emerging route guidance technology regarding reliable path finding and eco-routing in the following aspects. First, the α-reliable path problem in a stochastic network with correlated and truncated lognormal link travel times is addressed. The Lagrangian relaxation approach is applied to solve the nonlinear and non-additive problem. The Lagrangian relaxation based framework enables to handle the mean-variance α-reliable path problem, by which an intractable problem with a nonlinear and non-additive structure can be decomposed into several easy-to-solve problems. A subgradient algorithm is used to iteratively update the Lagrangian multipliers and find the approximate optimal solution. The availability of such reliable paths in a navigation system application would help travelers plan their travel time budgets with a specified on-time arrival probability efficiently. Then, travelers' risk preferences to travel time reliability are explored. The degree of risk-averse preference is formulated by comparing the on-time arrival probabilities of the pre-defined α-reliable path and the observed path under the theory of stochastic dominance. As a parallel study, the experientially reliable routing considering travel time uncertainty

and driving experience of local probe vehicle drivers is proposed. Second, considering the environmental benefit, this study investigates the eco-friendly path that results in minimum CO_2 emissions while satisfying a specified budget of travel time. This eco-routing problem with travel time constraint is transformed into a bi-objective like optimization problem. Specifically, the benefit tradeoff between CO_2 emissions reduction and the travel time buffer is discussed by carrying out sensitivity analysis on a network-wide scale.

Chapter 2 offers a comprehensive literature review related to reliable routing problem and eco-routing problem.

Chapter 3 introduces the data collection method. The travel time distribution and variability at the link and path levels are analyzed based on GPS probe vehicle data. Travel time distributions at link level and path level are characterized. Several classical distributions (normal, lognormal, truncated normal, and truncated lognormal) are subjected to the K-S test, A-D test and $\chi 2$ test. It is found that the truncated lognormal distribution enables to represents the link travel time distribution for about 90% of links. Because there is no closed-form expression for solving the joint probability distribution (sum of link distribution) function for each path, a normal distribution is selected as a surrogate for path distribution. This is computationally tractable and shown to be acceptable in accuracy.

Chapter 4 introduces the α-reliable path problem in a stochastic network with correlated travel time. The difficulties faced in finding a solution are twofold. First, the problem is non link separable due to the cross correlation of link pairs. The explicit unknown includes two variables, which makes the problem intractable. Second, sub-path optimality does not hold due to the nonlinear term. Such a problem cannot be computed by a standard shortest-path algorithm because additivity is violated. To overcome these problems, a Cholesky decomposition method for link separation in the variance-covariance matrix and a Lagrangian relaxation approach for problem decomposition are introduced. The Lagrangian relaxation approach is applied to approximate the α-reliable path solution by closing the duality gap. Specifically, the spatial correlation of link travel times is explicitly considered by introducing a correlation coefficient matrix. The Cholesky decomposition is proposed to separate the correlation coefficient matrix and make it tractable to the α-reliable path problem. The nonlinear and non-additive problem structure is decomposed into sub-problems that can

be regarded as standard shortest-path problems and series of tractable convex or concave problems. In solving the problem, the relative gap between the upper bound and lower bound of the solution is shown to decrease at each iteration and 30 iterations of the algorithm yield a small relative gap of within 2%-7%.

Chapter 5 investigated the traveler's risk-averse preference for α-reliable path problem in a transportation network. A novel data collection method for travelers' risk-averse preferences is introduced. The observed risk-averse preference is defined by using the theory of stochastic dominance. Ordered Probit model is applied to estimate the parameters of the travelers' risk preferences by considering variously individual properties (gender, age) and pre-trip information (OD distance, departure time, day of week).

Chapter 6 investigated an experientially reliable path considering travel time uncertainty and driving experience of local probe vehicle drivers. Accordingly, a two-stage route-finding procedure is proposed. First, a candidate path set is built by using the hyperpath algorithm, where the choice probability is assigned to each link with uncertain travel time. Second, the shortest path algorithm is applied to search the experientially reliable path on the graph of hyperpath where the modified link cost is penalized based on the link choice probability derived from hyperpath algorithm and the driving experience of local drivers. Four kinds of optimal path in a real-world network are compared with the observed one. It is found that the proposed path has the most similarity with the observed path and it has a higher degree of familiarity and reasonable time and distance.

Chapter 7 introduces how to determine an eco-friendly path that results in minimum CO_2 emissions while satisfying a specified budget for travel time. This eco-routing problem with travel time constraint is formulated to a bi-objective like optimization problem. The theory of Pareto-optimal optimization is then applied to solve this NP-complete routing problem. Specifically, a heuristic approach combining the weighting method and k-shortest path algorithm is developed to search the optimal path along the Pareto frontier. The performance of the proposed eco-routing strategy is verified by comparing it against other routing strategies in a real world network using real travel time and CO_2 emissions data collected by GPS-equipped probe vehicles. Specifically, the benefit tradeoff between CO_2 emissions reduction and the travel time buffer is discussed by carrying out sensitivity analysis on a network-wide scale. We

compare its computation efficiency against the classic Lagrangian relaxation approach over a set of real-world networks and demonstrate its advantage in solution quality and computation time.

Finally, Chapter 8 summarizes this study and gives direction for future research. The route search problem considering travel time reliability and CO_2 emission is promising to be applied to the current navigation system easily. This work might be a particular help in the design of a more effective navigation system for individuals with various preferences to travel time and environmental benefit. Potential directions for future study in this area include improvement of the path finding algorithm and consideration of the stochastic characteristics of travel time and CO_2 emissions: (1) an efficient path-finding algorithm suitable for a real-time eco-routing navigation system needs to be developed; (2) considering that travel time and emissions are non-deterministic, the reliability of the eco-algorithm routing should be considered further; (3) in addition to spatial link travel time correlation, temporal correlation should be considered in the finding algorithm and (4) a faster path finding algorithm suitable for real-time navigation systems needs to be developed.