A Markovian route choice analysis for trajectory-based urban planning

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1 Introduction

This thesis aims at proposing an integrated framework of route choice analysis focusing on the possibility of the high operability and dynamic interpretation of Markovian route choice models on future transport and urban planning. It consists of a series of methodological developments to exhibit how Markovian models extend the existing methods for route choice analysis, what is required to solve the challenges of Markovian route choice models and how it can be applied to evaluate urban pedestrian network planning.

A Markovian route choice model was first proposed as a traffic assignment model[12]. The high operability of avoiding to explicitly enumerate paths has had a big impact on subsequent studies. Bell (1995)[4] and Akamatsu (1996)[1] introduced the expected maximum utility into the transition probability and proved that the product of the link transition probabilities is equivalent to the route choice probability of the logit model considering all feasible paths. This contribution has established the position of the Markovian traffic assignment along with the Dial's assignment [8]. At around same time, it was shown that the equivalent optimization problem for Markovian traffic assignment can be formulated, i.e. it can be extended to the equilibrium assignment [2, 3]. In recent years, the Markovian route choice models were interpreted in the context of disaggregate discrete choice analysis [9] and are collecting much attention again.

The contributions of the thesis are summarized in Figure 1. The thesis defines route choice analysis as an integrated framework of measurement, modeling, parameter estimation, network assignment and optimization of route choices. The thesis mainly consists of four parts (Chapter 3-6). Chapter 3 proposes a *link-based route measurement model* and a *structural estimation method* based on a Markovian route choice model with a Bayesian approach to remove the estimation biases of route choice models that are included in the process of route measurement. Chapter 4 develops a *β-scaled recursive logit model* that is able to describe both global and myopic decision in the route choice context in the same framework. Chapter 5 proposes a path restriction method, *prism-constrained set*, and a *choice-stage-structured assignment algorithm* based on the concept of time-space prism to solve three computational challenges of Markovian route choice models caused by cyclic structures in networks. Chapter 6 applies the developed methodologies to a time-space network and investigates a *pedestrian activity-based network design problem*.

2 Methodologies & Main results

Chapter 3: Data and Estimation

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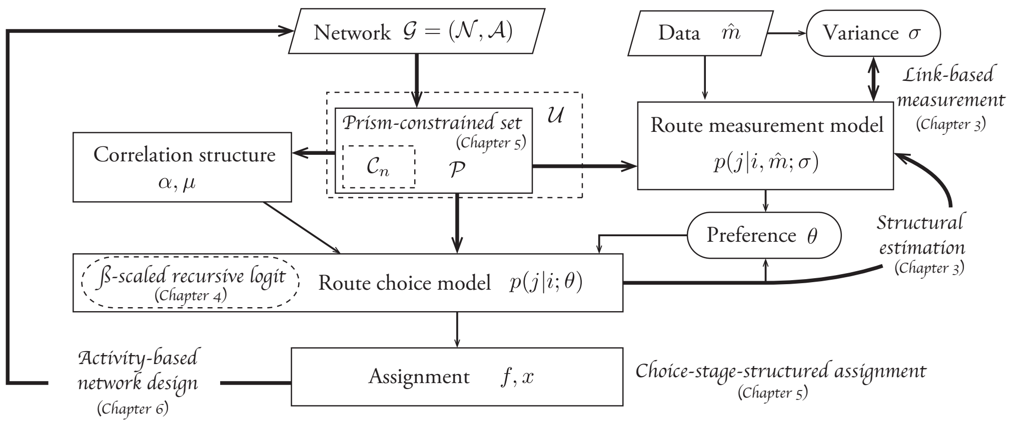

Figure 1: The framework of Markovian route choice analysis

In Chapter 3, we deal with the problem of measurement and parameter estimation of route choices, focusing on the measurement uncertainties of GPS data. Probabilistic route measurement models that identify routes from a sequence of location data based on the measurement probability are often used to deal with the measurement uncertainties. Although the measurement probability is calculated based on the probability distribution of the measurement error, the previous works [6, 5] assume that the variance of the measurement error is a given and constant value to define the route candidate set in advance. This causes the biased evaluation of measurement probabilities as well as a trade-off problem between computational efficiency and the risk of not considering the actual path as a candidate. Also, a Bayesian approach that incorporate a route choice model as the prior information to correct the measurement probability has been proposed [7], however, the approach remain a challenge that the estimated parameter using the detected routes is not consistent with the parameter used for the prior. This means that both of two main approaches of route measurement include the biases caused by initial parameter settings.

In order to remove the biases in the estimation process, the study first introduces a link-based route measurement model that sequentially identifies links using decomposed sequences of data and estimates the *link-specific* variance of GPS measurement error. The sequential identification does not require the definition of path candidate set in advance, i.e. we can assume the variance of GPS measurement error as a unknown parameter unlike the previous works. We also incorporate a link-based route choice model as the prior to correct the measurement probability by considering behavioral mechanism without path enumeration. Moreover, to solve the above-mentioned challenge of a Bayesian approach, this study proposes a structural estimation method in which the fixed point problem of behavioral parameter is identified by the iteration process. The proposed two methods solve the estimation biases caused by both measurement and behavioral parameter settings.

Numerical experiments validate the benefits of the proposed framework such as accuracies of route measurement and parameter estimation. A real case study using GPS data of pedestrians in a city center network shows that the structural estimation reveals the choice mechanism of arcade link that is typically difficult to identify due to the shielding effect. We also obtain the realistic distribution of the estimated variances of measurement error (Figure 2).

Chapter 4: Modeling

Chapter 4 focuses on developing an extended route choice model focusing on the dynamic interpretation of Markovian route choice models. Most of existing route choice models describe the global decision of travelers. This means that travelers evaluate the utilities of all links over a network with the equivalent weight and choose the route between an origin-destination pair before departing from the origin. The same

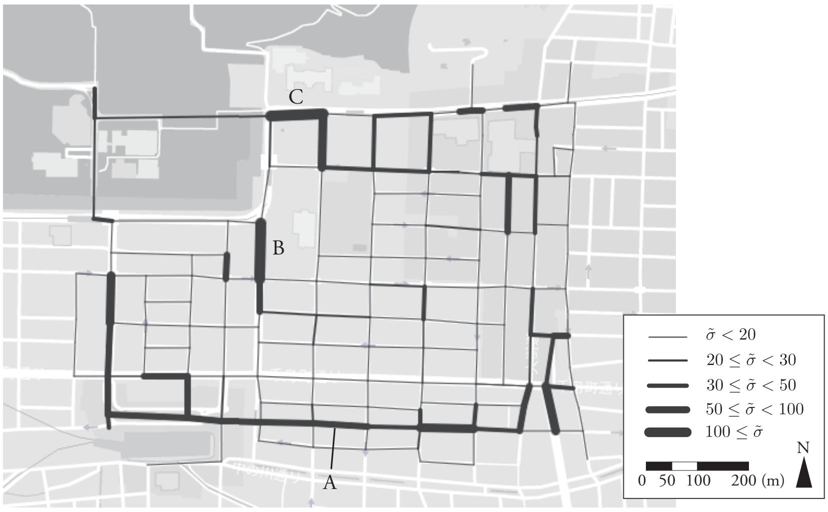

Figure 2: Plot of estimated link-specific variances (A: a shopping street with arcade, B: a link in front of the city hall, C: a link in front of the prefecture hall).

is true of even existing Markovian route choice models as their output are proved to be equivalent to that of the path-based MNL model. However, this assumption is too strong in some cases such as gridlock networks or pedestrian networks, and it is more realistic that travelers myopically evaluate utilities of links spatially close to them with larger weight than distant links and react the visible network conditions.

To describe the myopic decision in the route choice context, we focus on the parameter of the discount factor in dynamic discrete choice models [11]. In the context of dynamic discrete choice models, the expected future utility is described as a "discounted" utility, and the discount factor is used as the parameter of ambiguity. The incorporation of the discount factor into a Markovian route choice model [9] enables to describe both global and myopic decisions of travelers in the same framework. The discount factor (β) always takes a value between zero and one, and the travelers decide their routes based on the myopic decision when β is close to zero and on the global decision when β is close to one. The study investigates the impact of β on the evaluation of route choice probabilities, the existence of solution of the Bellman equation and traffic assignment results. We also estimate β using probe taxi data in a gridlock network at the time of the Great East Japan Earthquake and reveal the dynamic variation of traveler's decision-making mechanism in the disaster day (Figure 3).

Chapter 5: Assignment algorithm

This chapter deals with the main three computational challenges that Markovian traffic assignment remains: unreasonable cyclic flows, computational instability of the expected utilities and amplification of the IIA property. These challenges are caused by cyclic structures included in a network. Markovian route choice models use the expected maximum utility, also referred to as the value function, when calculating the transition probability and also consider all of feasible paths including infinite cyclic paths. In the case in that the cost of cyclic structures are not enough large, the expected maximum utility diverges, and the probabilities of cyclic paths are overestimated. This is the mechanism of the computational challenges of Markovian route choice models.

To solve the above-mentioned challenges, the study proposes an algorithm that is referred to as a choice-stage-structured assignment. We first decompose network states by the choice-stage, which is able to remove the cyclic structure from the calculation process. Based on the network description, we incorporate the choice-stage-constraint to systematically restrict path sets. The set of all feasible paths after the restriction forms so-called the time-space prism, i.e. the path restriction method reflects behavioral limitation of travelers,

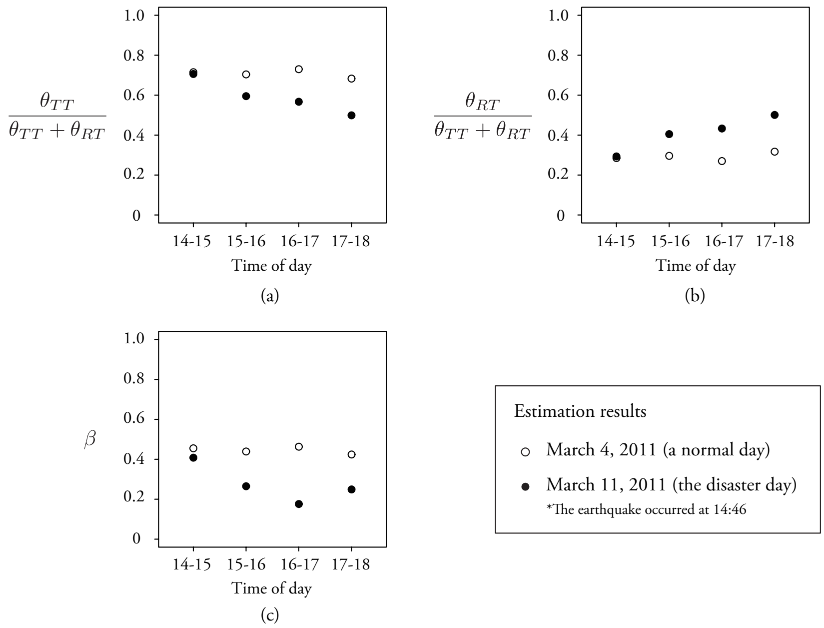

Figure 3: Dynamic changes of estimated parameters in the gridlock network. (a) The ratio of the travel time parameter, (b) the ratio of the right turn dummy parameter and (c) the estimated value of the discount factor.

while the previous models consider unreasonable paths from the behavioral point of view. The restriction method also reduces the number of states considered in the model, this allows the reduction of memory spaces and computational burden. Thus, we are able to remove unrealistic paths that are considered in the previous Markovian route choice models with the its high operability and efficiency kept. Also, we show that the equivalent optimization problem for the proposed assignment model can be formulated and then solve a stochastic user equilibrium (SUE) problem.

The numerical experiment shows that the proposed algorithm is always able to output the network flows in reasonable CPU time, while the previous algorithms are not able to do so when link costs or the perception parameter are small. The result of the SUE indicates the possibility that the application of the proposed algorithm could alleviate the unreasonable cyclic flows given by the existing Markovian traffic assignment. We also show that the proposed model can be extended to a network-GEV based model to describe the effect of overlapping among the paths including cyclic structures. The results show that the proposed algorithm is a solution to the remaining computational challenges of Markovian route choice models.

Chapter 6: Application

Chapter 6 applies the proposed methods to a time-space network to describe pedestrian activity-scheduling behavior in city center networks. Most of existing activity path choice models are focusing on daily household activities in large scale networks, and the stochastic models in high resolution networks are considerably thinner. This is because the activity path choice problem is very complex and difficult to solve. However, pedestrian activities in city centers are often more complicated due to the stochasticity, myopic decision and high resolution of the network.

To deal with the computational complexity, we propose an activity path choice model with the path restriction method proposed in the previous chapter. The method is extended here express several main activity constraints: prism, bundle and domain[10]. The model can consider decisions under the explicit time-constraint and integrally describe the choices of routes, activity locations and durations. Based on the model, we develop an activity assignment model that evaluates both spatial link flows and aggregate node duration time on a network.

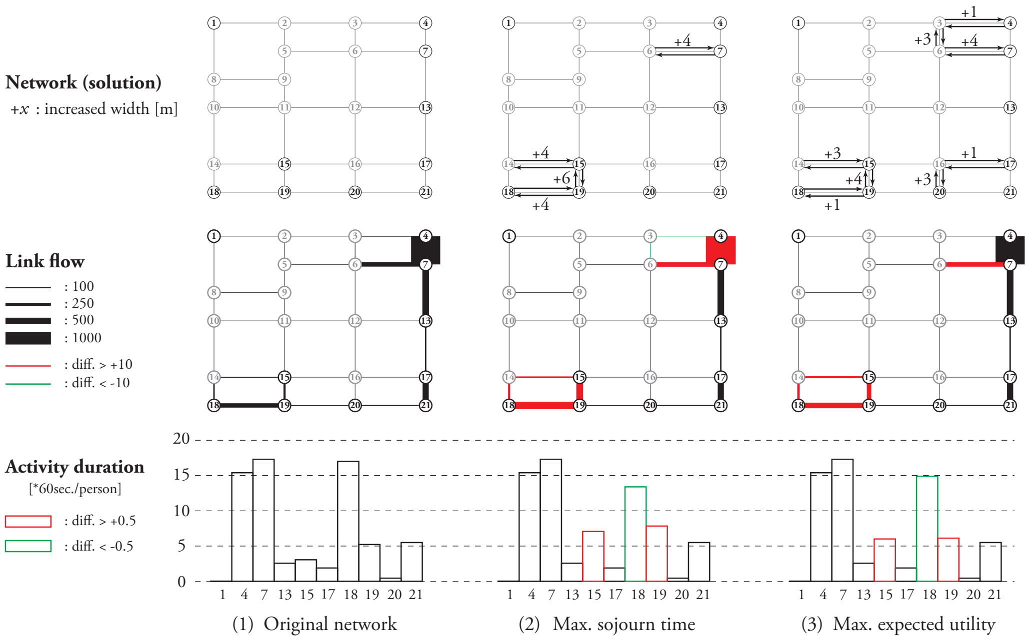

Figure 4: Results of pedestrian activity-based network design. (1) Current network, (2) a pareto solution on maximizing total sojourn time, (3) a pareto solution on maximizing total expected utility.

This can be used for a pedestrian activity-based network design problem in which the reaction of activity-scheduling behavior to network configurations are explicitly described. The problem is formulated as a bi-level and multi-objective programming, and its Pareto front solutions are investigated by a neighborhood search algorithm.

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