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論文題目	The behavioral impacts of uncertain access to free floating bicycle services (アクセスの不確実性がフリーフロート型のシェアサイクルの行動にもたらす影響に関する研究)		
(論文内容の要旨)			
<p>Free-floating bicycle sharing (FFBS) schemes have been praised as a great new addition to the urban mobility landscape and it is seen by some as a key solution to urban mobility problems. However, FFBS is still an emerging technology with insufficient research and regulations.</p> <p>This research focuses on the access to a randomly located bicycle from a person's origin and it has three main objectives. Firstly, it aims to develop a mode choice and bicycle flow model for a typical case such as morning commute scenarios, when the number of available bicycles is reducing over time. In that case, the access time depends on the competition for available bicycles as well as the distribution of demand and bicycles. Secondly, it aims to quantify the access distance to free-floating services considering the density and distribution of travellers and bicycles. A focus is on the effect of different information seeking and reservation strategies of travellers. Thirdly, a survey methodology is developed to obtain the required simulation parameters. The results can be fed back into the simulation for practical case studies.</p> <p>The thesis is organized as follows.</p> <p><b>Chapter 1 Introduction</b></p> <p>Chapter 1 describes the background of bicycle sharing development. The impact of bicycle sharing on urban management, on user behaviour, and theoretical as well as practical challenges are also introduced. These serve as the motivation for the thesis. Chapter 1 ends with the objective and outline of this thesis.</p> <p><b>Chapter 2 Literature review</b></p> <p>Chapter 2 reviews the development of various literature on bikesharing, assignment methodology, simulation structure, and survey. With the emergence of free-floating vehicle service startups around the world, researchers have applied a variety of methods for studying user preferences, usage pattern, and the resulting impacts of bikesharing. However, it is found that there is limited research aiming to analytically describe the evolving spatial fleet distribution of a sharing system. The lack of reflecting the microscopic dynamics of free-floating bicycles is identified and becomes the focus of this research. Simulation approaches of free-floating bicycles are also reviewed.</p> <p><b>Chapter 3 Assignment with free-floating</b></p> <p>Chapter 3 provides firstly a table of notations and basic assumptions for the subsequent sections. The general formation of the link-cost function is deducted first and followed by a step-by-step deduction of the access distance as the innovative link cost functions. The key concepts for FFBS are modelling the uncertain distances to reaching an available bicycle. To achieve this, random-random (RR) and centroid-random (CR) distances are deducted based on firstly a (1, 1) scenario to (1, <math>n</math>) and finally a (<math>h</math>, <math>n</math>) scenario, where <math>n</math> stands for the number of users and <math>h</math> for the number of available bicycles. The RR distance describes access costs from an individual's activity place to bicycles; the latter describes access costs from a central point, such</p>			

as a public transport station, to bicycles. The rationale and limitations of the derived formulations are discussed, together with the explanation of other assignment approaches used for comparison.

#### **Chapter 4 Basic simulation and comparison against assignment**

In Chapter 4, the basic simulation structure is explained. The results of both simulation and previous mentioned assignment are compared. Small scale case studies comparing the two approaches under different OD matrix and bicycle supply patterns are conducted as examples. Finally, contributions and limitations are discussed.

#### **Chapter 5 Discrete-event simulation**

In Chapter 5, the simulation structure is extended. This is followed by an introduction of our own simulation framework, including an explanation of the types of travellers distinguished in this study. Travellers with different levels of activeness in smartphone usage during the vehicle-seeking process are categorized. In “Event Separations” the decision-making process of different types of travellers is separated into events in order to reproduce these in the agent-based model (ABM) with discrete-event simulation (DES). Simulation settings and evaluation criteria are explained thereafter, and results are discussed in the following section before conclusions are derived in the final section of this chapter.

#### **Chapter 6 Survey**

In Chapter 6, a survey is introduced with the objective to obtain some of the parameters that are found to be important from the theoretical simulations in the previous chapter. The detailed objectives of this survey and the art of designing corresponding questionnaire are explained. Eight random generated map figures are presented to the respondent that resemble the information respondents see on mobile phone applications when reserving a bicycle. In each figure, six alternatives are presented, and each alternative has, besides its location, attributes such as price and its level of “riskiness” which describes how quickly a bicycle might be taken by another user. Specific efforts are made to guarantee no obviously better alternative is generated in each figure. In the analysis, the correspondents are firstly categorized through a latent class analysis. The discrete choice analysis is conducted firstly through MNL (multinomial logit models) and advances to Nested Logit models to study the relationship and preferences of each attribute. This is followed by a study of the interaction of scenario attributes and socio-demographic attributes. Conclusions from the survey are derived in the final section of this chapter.

#### **Chapter 7 Conclusions and further work**

Chapter 7 summarizes main findings of this thesis and points out the limitations. Overall, it is highlighted that this thesis contributes to unveiling the fundamental changes of space perception of urban travellers. The importance of how the mobile phone is used to navigate uncertainties are discussed. Another main conclusion is the importance of matching the distribution of bicycles and demand. The effect of the mismatch in terms of travel time, mode choice and failure to obtain a bicycle could be quantified. This thesis provides the basis to improve software implementations of network flow models with free floating services. A complex pioneering study with methodology formulation, simulation verification, and a complementary survey are the main contribution of this research.

## (論文審査の結果の要旨)

対象地域内において自由に乗降場所を選択できる「フリーフロート型シェアサイクル (free-floating bicycle sharing: FFBS)」は、2015年に登場して以来、世界中で急速に普及し、重要な移動手段になりつつある。しかし、FFBSは新しい交通システムであることから、十分に研究が蓄積されておらず、時間的・空間的な車群分布の変化やその不確実性を解析的に記述することを目的とした研究は極めて限られている。本論文は、以上のような背景を踏まえ、FFBSのアクセスの不確実性が、利用者の行動に与える影響を明らかにするものである。

本研究で得られた主な成果は次の通りである。

## 1. SBBSとFFBSの相違の明示

ステーションベース型シェアサイクル (station-based bicycle sharing: SBBS) との明確な相違点である「空間的な不確実性」に着目し、時間的・空間的分布を考慮したうえでFFBSの動的な利用可能性を示した。

## 2. リンクコスト関数の推論と配分問題への適用

空間的な不確実性を考慮したうえで、シェアサイクルへのアクセス距離を調整したリンクコスト関数を導出した。リンクコストは、需要が増加するほど、また、シェアサイクルが少なくなるほど、増大するように表現した。このリンクコスト関数を包含した配分問題から得られる結果と、基礎的な交通シミュレーションから得られた結果を比較することにより、両者に良好な相関関係があることを確認した。

## 3. 利用者の予約戦略を考慮した離散事象シミュレーションの構築

利用者の予約戦略に着目して、出発前に利用可能なシェアサイクルを確認するだけの利用者と、出発後もスマートフォンで利用可能なシェアサイクルを探索する利用者の区別を行い、高度なエージェントベースの離散事象シミュレーションを構築した。構築したシミュレーション手法は、MATSimのようなオープンソースのシミュレーションプラットフォームにも対応可能であることから、大規模シミュレーションへの拡張、多様なエージェントへの対応、ならびに、シェアサイクルの再分配戦略の評価にも利用できる。

## 4. グラフィカルでゲーム的なアンケート調査の設計と実施

上述の離散事象シミュレーションのパラメータ値を精緻化するために、シェアサイクルの予約画面を模したRP (revealed preference) 調査とSP (stated preference) 調査を実施した。これらのアンケート調査結果の有効性から、他の複雑な空間選択の調査にも応用可能であることを示した。

以上の通り、本論文は、FFBSの空間的・時間的な不確実性がユーザーの行動に与える影響を明らかにしたものであり、提案された手法は、FFBSのネットワークモデリングの発展に貢献するだけでなく、都市交通計画の高度化、ならびに、商用ソフトウェアの基礎として活用されることが期待されることから、学術上、實際上寄与するところが少なくないと考えられる。よって、本論文は博士(工学)の学位論文として価値あるものと認める。また、令和4年7月29日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。