論文の要旨
Summary of the Dissertation

論文題目
Dissertation Title
A Study on Measurement, Modeling, and Evaluation for Urban Street Space Design Considering Both Travel and Place Functions
Travel／Place機能を考慮した街路空間設計のための観測，モデリング，評価に関する研究

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Urban street space in Japan is used for human activities and the movement of people and goods. At the same time, urban street space is a space that generates people's social communication. However, the development of motorization eliminated people from the urban street space, and the urban street space was used to prioritize car use. In recent years, due to the increasing frequency of car accidents and growing environmental concerns, the use of urban street space is shifting from car use to people use. Moreover, the use of space for the introduction of new mobility devices is also becoming more important. To accommodate these needs, diverse uses of urban street space are important. Diverse uses of urban street space can create various benefits such as exercise, business and tourism, social inclusion, education, health promotion, culture and arts, and climate change mitigation.

In order to induce diverse uses of urban street space, the urban street space needs to fulfill two main functions: (1) *Travel function*, which supports the movement of people and goods, and (2) *Place function*, which provides space for people's activities. For urban street space design, it is necessary to evaluate the space based on user behavior and redistribute both functions according to this evaluation. However, each function has been targeted in different fields, leading to different evaluation approaches. It is therefore necessary to construct a framework that allows the evaluation of both functions in a consistent manner. This dissertation develop an evaluation framework for urban street space considering *Travel function* and *Place function* using consumer surplus.

In this dissertation, we propose to access the urban street space according to three scale based on the different effects of interaction on pedestrian walking. These are: (1) the effect of psychological interactions of objects and behavioral phenomena close to the pedestrian at the moment (current location), (2) the local effect of physical interactions of other pedestrians/vehicle behaviors or objects surrounding the pedestrian (i.e., a few seconds/meters ahead), and (3) the global effect of the physical interactions of objects or behavioral phenomena (e.g., crowding) going to the destination (i.e., several tens of seconds/meters ahead). Accordingly, the urban street space is divided into three parts as follows: (1) *personal space* (i.e., space less than about 1.5m), which focuses on the user perception of objects, vehicles, and pedestrians when the pedestrian approaches them at the present time (position), (2) *public space*, which is further divided into a *local domain* and a *global domain*, based on the differences in pedestrian prediction of the behavior of vehicles and pedestrians and the location of objects. The local domain is the domain where the local effect of the physical interactions surrounding the pedestrian is considered, and the global domain is the domain where the global effect of the physical interactions going to the destination is considered.

When evaluating the use of this urban street space, there are some challenges in measurement, modeling, and evaluation. This dissertation addresses the following three issues: (a) in the location-specific preference survey that observes the user preference at a location-specific point, the difference between when to complete a behavior and when to answer a question affects the choice result; (b) a framework describing interactions with new modes has not been established using real data; (c) there is no model that describes interactions between moving and staying using Random Utility Maximization (RUM) theory. Each research challenge is consistent with the definition of the urban street space. The first challenge focuses on the observation of user perception in personal space. The second challenge focuses on description of the micro interactions between AVs and pedestrians in local domain of public space. The third challenge focuses on developing a methodology for evaluating the use of urban street spaces that takes into account the

interaction between moving and staying in *global domain* of *public space*.

To address the first research challenge, we analyze the difference between when to complete a behavior and when to answer a question on choice result, called as *recall time*. The used data are from the location-specific preference survey, which observe the behavior change under congestion pricing scheme. The data is not related to pedestrian behavior in urban street space, but because it observes preferences at specific zones in an urban area, it represents a similar implication to the observation of user perception of urban street space. Using this data, we analyze whether the *recall time* causes systematic bias in the choice result and whether the recall time strengthens (or weakens) the effect of behavioral attributes and preference attributes on the choice result. From these results, we find that a longer recall time, leads to users placing more emphasis on the preference attribute rather than considering the behavioral context, and introduces systematic biases in the results of their responses. For example, when the recall time is long, users often choose not to change their behavior even if they pay a congestion fee. Therefore, a long recall time leads to a systematic bias in the choice result and strengthens (or weakens) the effect of behavioral attributes and preference attributes.

To address the second research challenge, we extend the discrete choice pedestrian model to consider pedestrian-vehicle interaction and conduct an analysis of the difference in pedestrian behavior around AVs and other vehicles (i.e., cars, bicycles, and motorcycles). We use data obtained by video camera measurement of pedestrian and vehicle behavior at crossings. For pedestrian-vehicle interaction, we create utility function considering four components: likelihood of collision, perception of vehicle behavior, risk at collision, and safety distance to collision. We set four behavioral hypotheses based on the components, but this Chapter only tests two hypotheses related to likelihood of collision and perception of vehicle behavior because of the instability of the model estimation. From the estimation result, we find that (1) when the car is not decelerating, the pedestrian avoids it, but when the car is decelerating, pedestrian does not avoid and (2) the pedestrian does not avoid it regardless of the AV's acceleration or deceleration. These results allow us to analyze the difference in pedestrian behavior toward vehicles using this utility function.

To address the third challenge, we develop a pedestrian model that describes the interaction between moving and staying with a dynamic discrete choice model, allowing the evaluation of the use of the urban street space using consumer surplus. In this chapter, using this proposed model, we conduct a numerical simulation in different number of sojourners/travelers entering the street and object location in order to analyze the change in the consumer surplus and behavioral outcomes for different use in urban street space. From the simulation result, the consumer surplus is stationary despite the existence of multiple equilibria (i.e., different location with concentrations of sojourners who stay). Moreover, we also find that the change in the number of travelers unexpectedly causes a paradox of the consumer surplus for travelers between center case and top and bottom case, i.e., the number of travelers is reduced, which should have made it easier to walk, but instead it made it harder to walk in the top and bottom case.

In conclusion, we discuss the contribution of each chapter in the evaluation of the urban street space design from the perspectives of Travel function and Place function. First, through the model in Chapter 5, we find results consistent with existing research, such as increased travel time when the number of sojourners decreases. However, contradictory results were found, such as the expected decrease in travelers making it easier for them to walk, but more difficult in the top and bottom cases. Thus, this evaluation framework is the basic framework to evaluate the use of urban street space considering the trade-off between Travel function and Place function (i.e., the interaction between moving and staying).

Second, the contribution of Chapter 4 is related to Travel function. Specifically, by developing a model framework for pedestrian-vehicle interaction using a discrete choice pedestrian model, we were able to analyze the differences in pedestrian behavior toward different vehicles, indicating that the importance of pedestrian-vehicle coexistence when designing space.

Third, the contribution of Chapter 3 is related to both functions. Specifically, we found that the larger the recall time, the lower the accuracy of the observation, and thus the more biased the selection results and the greater tendency of users to ignore the influence of behavioral factors. Similarly, in the context of observing pedestrian behavior, the influence of location-specific policy interventions on pedestrians may diminish with the time difference since their interaction at the specific location.

There are several research challenges remaining to be explored in the future. For example, in this research, we consider only trade-offs between both functions, i.e., when one function is prioritized, the other function will be reduced within the space. In the urban street network with multiple urban street spaces, however, there is a natural segregation of both functions, so that both functions are complementary. Therefore, it is necessary to evaluate the complementary and competitive (i.e., trade-offs) between the functions of moving and staying.

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