論文の要旨
Summary of the Dissertation

論文題目
Dissertation Title
A Framework Towards Data-Driven Transport Management During Disaster: Application to July 2018 Heavy Rain Disaster in Japan
(災害時におけるデータ駆動型交通マネジメントに向けた枠組み：平成 30 年 7 月豪雨災害への適用)

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Disasters can have significant impacts on transport networks disruptions, leading to detours, trip cancelations, and economic losses. Understanding the performance of these networks during disruptions is crucial for effective planning and response. One way to assess the performance of transport systems is through the concept of vulnerability analysis, with resilience being a key matrix that considers temporal changes in network performance. Numerous studies have explored the resilience of transport systems under disrupted situations, often using frameworks like the resilience triangle. This concept allows for the analysis of how network performance changes over time during disasters. To comprehensively assess network performance, it is essential to consider both the physical network performance (connectivity and accessibility) and the efficient use of the network (delays and congestion). With advancements in technology, passive data analysis also offers a promising approach for studying transport network disruptions. This method eliminates the need for time-consuming surveys or interviews with disaster victims. However, its application in disaster studies remains limited, particularly emphasizing the dynamic nature of both travel demand and supply in the context of disaster.

The study aims to develop a data-driven framework for better transport disaster management. Specifically, the objectives focus on 1) developing a framework of the impact of transport network disruption on travel demand, 2) developing a framework to identify the phase transition and monitor the transport network after disruption, and 3) developing a method to quantify the drivers' perceived level of the information under the disrupted situation. To achieve these objectives, the study utilizes logit-based model falling within the stochastic category. This choice is motivated by the fact that deterministic models do not guarantee improvements in road network performance during the road recovery process. However, stochastic models offer such assurance due to two key properties associated with the expected minimum generalized cost, as outlined in Ben-Akiva and Lerman (1985): (1) monotonicity concerning the choice set size, and (2) monotonicity concerning systematic utility. The property of monotonicity concerning choice set size implies that the evaluation of road network performance relies heavily on the route enumeration process. This can be problematic, as the enumerated routes may exhibit inconsistency during the recovery process. Therefore, in our study, we employ a recursive logit model introduced by Fosgerau et al. (2013), which equivalent in terms of model structure to Markovian traffic assignment, as proposed by Akamatsu (1996). This model allows us to calculate the expected minimum generalized travel cost without the need for enumeration process, ensuring that all possible paths, including cyclic routes, are taken into account. This approach enhances the reliability of our analysis and its applicability to road network recovery scenarios. Moreover, passive data is used to monitor network performance, assess monetary losses, and understand travel demand elasticity. Some passive data that we utilize include: (1) Mobile Spatial Statistics data and GPS trajectory data as the travel demand data, and (2) network data obtained from DRM (Digital Road Map) data. The July 2018 heavy rain disaster in Japan serves as the case study, including the condition of the transport network during the disruption. Considering the temporal dynamics of the network, we take into account data spanning June to October 2018, encompassing the period before, during, and after the disaster.

We begin by quantifying the logsum-based network performance measured and monetary loss to assess the impacts of transport network disruption caused by the heavy rain disaster. The results of the accessibility vary across different origin-destination pairs over time. The recovery process shows evidence that some areas that initially experienced poor accessibility have gradually regained it over time. The analysis also reveals that an increase in the accessibility index corresponds to higher travel demand. For the monetary loss, we found that the total is nearly 6 billion Japanese Yen. The results also highlight that while the impacts may be modest in certain areas, a delayed recovery process can lead to an overall increase in losses.

We then identify the phase transition and monitor the transport network after disruption by utilizing the multilevel log-log linear model and change point detection model. The results of the multilevel log-log linear model show that the average elasticity value is -1.253, which indicated that a 1% increase in the expected minimum generalized cost would lead to a 1.253% change in travel demand. The results also reveal that there are two distinct peaks in travel demand, one in the morning around 07:00 AM and another in the afternoon at approximately 05:00 PM. Additionally, the analysis of variables related to the day of the week and holidays unveiled interesting insights. Notably, an increase in the expected minimum generalized cost is found to negatively affect travel demand during Saturdays, Sundays, and the Obon holiday, though the effects were relatively small. We then confirm the hypotheses that we have: (1) the first hypothesis indicated that immediately after the disaster, travel demand becomes more elastic particularly for the 'affected' area, while (2) the second hypothesis suggested that once the urgent situation is over, travel demand becomes less elastic. The change point detection of the elasticity value reveals that the transition between adaptation and recovery phase is approximately one month after the disaster.

To quantify the drivers' perceived level of the information under the disrupted situation, we utilize the concept of recursive logit model and redefine the scale parameter. We consider factors such as severity of damages, travel time values, and the presence of a U-turn dummy. Four datasets are also used to estimate the parameters for affected and non-affected areas with both network travel time and observed travel time. The results show negative estimated parameter values for travel time and U-turn dummy, indicating that an increase in travel time and presence of U-turn are associated with a decrease in the likelihood of choosing the link. Comparing the different datasets, those using network travel time data show better results compared to observed travel time data. Additionally, we investigate the variance decomposition to understand the variation in factors influencing route choice across different time periods. The observed travel time is found to have a larger variance, likely due to disrupted roads after the disaster. The variance of unobserved variables also decreases over time, suggesting that conditions become more predictable as the situation stabilizes.

There are some important implications of this study: (1) prioritizing the recovery of major transport corridors in the short term is essential due to their potential for higher monetary losses. However, as the network recovers, the total benefits of restoring main corridors diminish. Hence, shifting the recovery efforts towards minor links, in the long term, can minimize the extent of the resilience triangle. (2) In the disaster situation, people tend to consider travel as luxury good soon after disaster. This could enhance the efficiency of emergency response activities but also could have negative effects on local economies, e.g., economic loss due to longer travel time. Hence, Policymakers should consider supporting the travel needs of non-affected people as long as it has minimal impacts on disaster-related activities, i.e., start time of the recovery activities. (3) The variance decomposition results of the drivers' perceived level of information highlight the importance of providing real-time information on road conditions, traffic updates, and alternative routes. To optimize route decision-making during disasters, policymakers should establish dynamic information dissemination systems that continuously update and relay crucial data to the public and emergency responders.

The study acknowledges several limitations. First, the analysis used the total number of trips as the dependent variable, which included both recovery and emergency activities. It would have been preferable to separate trips unrelated to the disaster for better clarity. Second, the study relied on data from Docomo phones, excluding users from other mobile phone networks, which could introduce biases. Third, the study focuses solely on the July 2018 heavy rain disaster in Japan and does not account for the magnitude of the disaster. Fourth, in examining the impact of access to traffic information on route choice behavior, the study does not consider other influential factors like social and psychological aspects. Future research should explore a broader range of factors to enhance understanding of route choice behavior during disasters. Nevertheless, the study introduces a novel methodology for quantifying the impact, identifying phase transitions, and quantify the drivers' perceived level of the information under the disrupted situation, which holds potential as an essential tool for transportation management in various disaster scenarios.

備考　論文の要旨はＡ４判用紙を使用し，4, 000字以内とする。ただし，英文の場合は1, 500語以内とする。

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