Title	人の生活に浸透するモビリティサービスの設計支援手法
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Abstract

Transportation systems are no longer just a means of transportation but have become part of an urban system with significant social, economic, and environmental impacts, and have a major impact on people's lives, businesses, social relationships, and the living environment. A more holistic approach is required.

In this study, I leverage advances in computer science and computing power to propose new mobility service design and evaluation methods that go beyond the limits of cost-benefit analysis in transportation planning. The proposed method is a mobility service design support and evaluation method that allows multiple decision makers to derive optimal solutions from many service options, keeping in mind that new demands will arise, and new mobility will be operated in new environments. This is a method that uses an event-driven simulator interactively while accurately grasping evaluation indicators by utilizing formal specifications. This method evaluates three or more indicators simultaneously, taking into consideration not only economy and convenience, but also safety. After investigation of regional demand and traffic volume and extraction of possible operation patterns. Then, a simulator is used to reproduce these and extract the optimal solution from the balance of evaluation indicators.

Using the power of formal specification description and model checking, which are results of computer science, I examined the liveness properties of ride-sharing services. Ride-sharing services are an example of parallel systems that require liveness properties, such as dispatching rides during childbirth or accidents, or delivering medicines. It is socially unacceptable that a ride is not dispatched even after a reservation has been made. A ride-sharing system is described using linear temporal logic and Kripke structure. Using a specification description language called Maude, I showed an example of description of the ride-share system separating essential system specifications and parameters such as maps, locations of people, and vehicles. It is known that in parallel systems, the liveness property cannot be satisfied unless a fairness assumption is made. In this study, I pointed out that model checking of ride-sharing systems also requires strong fairness assumptions. If I make the assumption of fairness, the amount of calculation will explode, and even current computers may not be able to calculate it. For this problem, I adopted a divide-and-conquer approach and succeeded in speeding up model checking. It was demonstrated that model checking, which cannot be calculated on current computers due to the possibility of running out of memory, can be shortened to approximately 3 minutes and 43 seconds.

As a practical example of how to design and evaluate new mobility services by utilizing computational power using a simulator, I applied the proposed method to cases of transporting

people and goods. As an example of transporting people, I evaluated a self-driving ride-sharing system service in the Osaka area. In the Osaka area, there is data on the server where employees stamp the time on their employee cards when they enter and exit buildings, making it possible to accurately reproduce the movements of around 300,000 trip a day. I defined a safety indicator that calculates the severity of an accident based on the frequency of events in which an autonomous vehicle and a person are close to each other within a certain distance, and the weight and speed of the vehicle. Using StarBED, an HPC, I conducted a complete search for an optimal solution that took into account not only the economic efficiency and convenience indicators used in existing cost-benefit analyses, but also three indicators, including a safety indicator. I also searched for the optimal solution using the annealing method. As a result, contrary to the intuition that the optimal solution would be obtained by operating vehicles with a maximum capacity of 4 passengers per vehicle, I found that operating vehicles with 3 passengers per vehicle was optimal. In addition, since simulations can identify locations where people and vehicles are in proximity, when the location where the event occurred was visualized on a map, it has been confirmed that this location matches the location where an actual proximity event between a self-driving vehicle and a person occurred. In other words, it has been found that a more optimal solution can be obtained by redesigning a route that avoids places where dangerous events occur or by creating a new operation plan that limits the maximum speed when passing through such places. It can be said that the solution was obtained through comprehensive testing using the power of computers.

In addition, a simulator was used to utilize computing power to design and evaluate a delivery service using an automatic delivery robot at Fujisawa SST. At Fujisawa SST, many residents live by ordering, receiving, and consuming products. Assuming deliveries from multiple stores, I searched for an optimal solution using factors such as the number of robots and business hours as simulation parameters. Since there are over 1 billion parameter combinations, I proposed a method to find the optimal solution using an interactive method. I run multiple limited simulation batches and display Pareto solutions on the evaluation axes of safety, economy, and convenience to help decision makers select the best solution. As a result, even though there are over 1 billion options, many evaluators choose similar solutions as the best.

Through a questionnaire, I conducted subjective evaluations regarding execution time, explainability, UI, persuasiveness, and overall understanding. As a result, the evaluation of execution time and explainability was high. Although the UI, persuasiveness, and overall understanding were evaluated favorably, it was confirmed that there is still room for improvement.

Furthermore, I defined a fourth indicator, plotted it in three-dimensional space, and proposed a method to compare Pareto solutions. In addition to safety, economy, and convenience, I defined

new constraints such as ``stopping time on the road'' and ``waiting time at the store'' using descriptions of signal temporal logic (STL) and I searched for the optimal solution using an interactive method using a simulator. Mobility services include many indicators that change temporally and spatially, such as stop time while moving and waiting time at stores.
By introducing the STL formula into evaluation using a simulator, the number of items that can be designed and evaluated using the proposed method has increased, making it a more practical design and evaluation method.

The proposed method is suitable for the design and evaluation of mobility services where it is desirable to formulate a hypothesis and verify it using multiple evaluation indicators, especially mobility services that require the introduction of new mobility for which driving routes and operating methods have not yet been established.

Keywords: Transportation planning, Autonomous mobility, Decision simulation, Multi-objective optimization