High-fidelity Multi-agent Simulations for Social Systems

Shinobu Yoshimura
Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8589, Japan

Hideki Fujii
School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-8656, Japan
Email: syoshi@edu.k.u-tokyo.ac.jp, fujii@sys.t.u-tokyo.ac.jp

Abstract

For realizing the rational and quantitative design of social systems, we have been developing intelligent multi-agent based simulations together with high-fidelity models of social systems. The one is MATES (Multi-Agents based Traffic and Environmental Simulator), and the other is a virtual nursing care process simulator based on a multi-agent model. In this talk, I first describe the objectives of the research and some key technologies, and then introduce their practical applications with verification and validation, i.e. Tramway extension problem in an actual middle sized-city, Okayama, Japan, and an excretion care process in an actual day-care facility for elderly persons.

Keywords: Multi-agent simulation, High-fidelity model, Traffic simulation, Excretion care process

1. Introduction

Together with the rapid progress of computer technologies, computer simulations such as computational mechanics and computational science have been popular in various science and engineering fields. Simulation-based design of artifacts is now a central concept in CAE areas, because its superior capability of quantitative evaluation of artifacts' mechanics and physics behaviors. Such a capability of quantitative evaluation is also strongly demanded for the rational and efficient design of social systems, i.e. Simulation-based design of social systems.

Since 2000, we have been developing intelligent multi-agent based simulations together with high-fidelity models of social systems. The one is MATES (Multi-Agents based Traffic and Environmental Simulator) , and the other is a virtual nursing care process simulator based on a multi-agent model.

Road traffic is a key portion of the infrastructure supporting mobility through the transportation of humans and goods. At the same time, it is the cause of various types of urban and environmental issues including traffic jams, accidents, heavy energy consumption, as well as air pollution and global warming due to engine emissions. Since it is very difficult to restore a road environment to a previous condition once it has been changed, it is strongly desirable to accurately estimate the impact of transportation policies quantitatively. This is why simulations have been playing an important role in the field of traffic systems.

On the other hand, the Government of Japan has taken several measures to secure human resources for long-term care, including improving work efficiency by care workers, improving a working environment, and providing effective training for new employees. However, there are major barriers in resolving the issues, such as difficulties in public surveys due to a variety of situations involving personal data in long-term care facilities, and difficulties in quantifying information and features on care workers and care receivers in actual nursing care processes. Thus, as the first step, specifically focusing on ”excretion care, ”which is regarded to be a particularly high burden on care workers, we newly construct a virtual nursing care process simulator based on a multi-agent model.

In this lecture, we mainly describe our high-fidelity multi-agent traffic simulator for mixed traffic of cars, pedestrians, and trams. This simulator is then applied to a real-world case study on a tramway extension plan in an actual city. Based the results with other considerations, the Okayama-city has decided to extend the tramway into the station square, and it is under construction. Then, we briefly describe a virtual nursing care process simulator based on a multi-agent model. Applying it to simulate care processes in an actual day-service facility, we have confirmed that the simulated results agree with observed ones reasonably well.

2. Tramway Extension Simulation in Okayama-city

2.1. Target problem

In Okayama-city, which is the capital of Japan's Okayama Prefecture, many people have chosen cars as their primary mode of transportation, which causes various traffic problems. There are two tramlines operating in the city. The Okayama-city government had a plan to extend the tramway into the station square to improve access and convenience of movement for rail users around downtown areas. Because the tramway needs to cross the large and busy intersection in front of the rail station, and since there are plans to reduce the duration of green light time for car traffic, there are concerns that the project will have a negative impact on car traffic flow. The Okayama-city government asked us to perform the traffic simulation on this issue. We attempted to quantitatively clarify the impact of the proposed tramway extension.

2.2. Data preparation

The road network used in this research is shown in Fig. 1. Even if the extension plan were limited to around the rail station, we considered it probable that its impact would spread widely. The node positions and connections were set by importing data from OpenStreetMap2, and the precise lane configuration and signal control information were provided by the Okayama Prefectural Police (OPP).

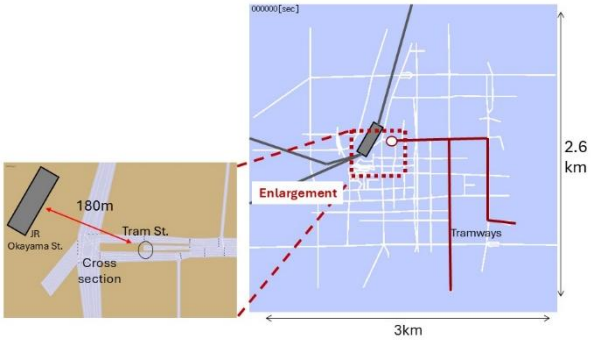

Fig.1 Road network in Okayama city

The time period to be simulated was set as one hour from 13:00 to 14:00 on a holiday, which is one of the time periods with the highest traffic volumes. The OD (Origin-Destination) matrix for this time period was estimated iteratively via the gravity model by referring to the observed link traffic volume, which was provided by OPP. A comparison of link traffic volume in the simulation and that in the real world is shown in Fig. 2. The correlation coefficient was 0.939 and the slope of the regression line was 0.923. Based on these simulated results, we judged that the estimated OD matrix was reliable enough to be used as the baseline in the subsequent simulation scenarios.

The observed traffic volume of pedestrians at the intersection was also provided by OPP. The actual routes and timetables were provided by the bus and tram agents.

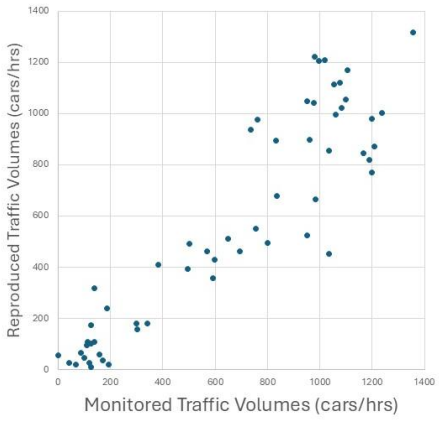

Fig. 2 OD matrix estimation result

2.3. Simulated scenarios

The road environments around the intersection with and without the tramway extension, are shown in Figs 3(a) and 3(b), respectively. The main difference is that the tram stop is relocated from the east side of the intersection to the station square. As a result, the signal pattern at the intersection needs to be changed, and it is also expected that the volume of pedestrians on the east side crosswalk that are getting on and off of the tram will be reduced. In this research we conducted simulations according to the following four scenarios, before and after tramway extension, and measured the distance from the intersection to the rearmost car agent, which is stopped by a red signal in each scenario.

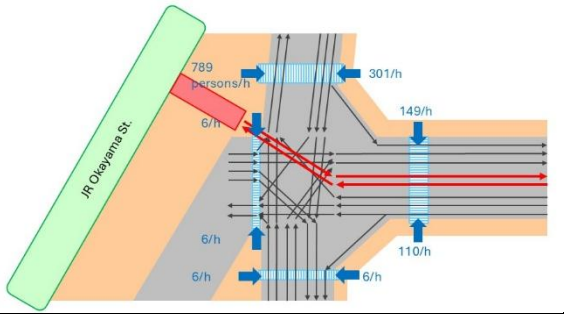

Fig. 3(a) Intersection with tramway extension

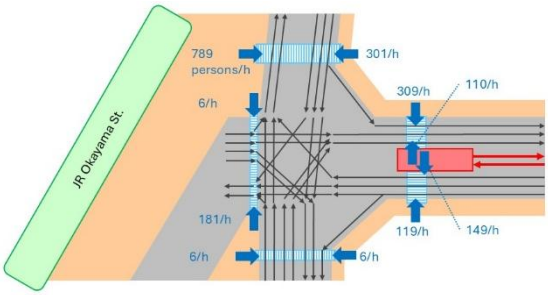

Fig.3(b) Intersection without tramway extension

Baseline scenario 1 (baseline_1): without tramway extension, without pedestrians

Baseline scenario 2 (baseline_2): without tramway extension, with pedestrians (current status)

Extension scenario 1 (ext32): with tramway extension (green light for tram: 32 seconds, 1 time per cycle), with pedestrians

Extension scenario 2 (ext64): with tramway extension (green light for tram: 32 seconds, 2 times per cycle), with pedestrians

The signal cycle at the intersection is fixed at 150 seconds for all scenarios to maintain coordination with neighboring signals. The minimum time required for a tram to cross the intersection is 32 seconds.

2.4. Simulation results

Figure 4 shows a simulation screenshot around the intersection for ext32. The red rectangles represent passenger cars, black rectangles represent trams (which are not seen in the screenshot), and green circles represent pedestrians. Small squares on the lanes indicate traffic light colors or passage permissions.

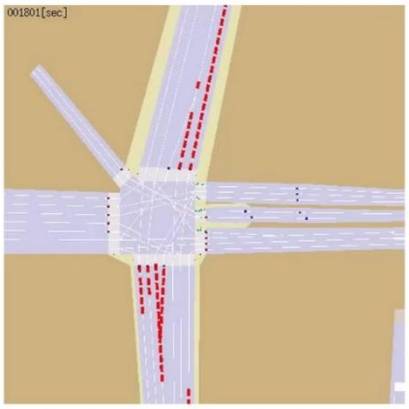

Fig. 4 Simulation screenshot around the intersection in front of Okayama station

As an example of the simulation results, Fig. 5 shows a comparison of the position of the rearmost stopped car agent in the first lane (where cars are permitted to turn left or go straight) on the north side road of the intersection. The mean, minimum, and maximum values of the positions that were measured once per signal cycle are indicated in the figure. A comparison between baseline_1 and baseline_2 shows that the existence of pedestrians significantly affects congestion levels, thereby also implying that the influence of pedestrians must be considered in those scenarios. In the comparison between baseline_2 and ext32, even though the average value is declining slightly, it can be seen that the change is sufficiently small as compared with the daily fluctuation level. In ext64, it is understood that car traffic is significantly affected by the tramway extension since the traffic jam length is becoming much longer.

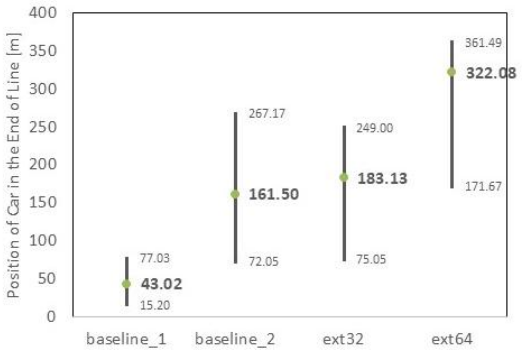

Fig. 5 Position of rearmost stopped car agent in the first lane of north-side road

2.5. Discussions

We developed a simulation framework for mixed traffic by implementing pedestrians and tram agents for the multi-agent-based traffic simulator. The results show that the layered road structure could be effectively reused in existing simulation models while maintaining their independence.

We simulated the tramway extension plan in front of Okayama Station with MATES, and quantitatively assessed its impact on road traffic. From the results, it could be determined that there was hardly any negative influence on car traffic patterns at the intersection in the case of ext32, in which the duration of the green light for the tram is 32 seconds × 1 time per cycle. In the case of ext64, in which the duration of green for the tram is 32 seconds × 2 times per cycle, car traffic on the north side road was noticeably degraded. We also checked to ensure that there are no remarkable changes on the west and south side roads of the intersection. Even though the simulation results in this research were obtained from a limited number of scenarios, they showed that this kind of simulation has the potential to provide objective data to stakeholders for use in discussions about transportation policies. Based the results with other considerations the Okayama-city has decided to extend the tramway into the station square, and it is now under construction.

3.Excretion Care Process Simulation

Specifically focusing on ”excretion care, which is regarded to be a particularly high burden on care workers, we newly construct a virtual nursing care process simulator based on a multi-agent model. As the first step, applying it to simulate care processes in an actual day-service facility, we have confirmed that the simulated results agree with observed ones reasonably well. Next, we evaluated the work efficiency of care workers quantitatively, parametrically varying the number of elderly people and that of care workers. As the results, it is confirmed that the total amount of assistance by care workers increases as the number of elderly people increases, and that the work time per care worker decreases as the number of care workers increases. We can conclude that although the developed multi-agent simulator is still limited to excretion care processes, such a simulation-based approach will be a powerful tool to discuss issues on nursing care processes quantitatively and to search for new solutions, by extending it to various situations in the nursing care processes.

Authors Introduction

Dr. Shinobu Yoshimura

He received Dr. Eng. in 1987 from the University of Tokyo (UTokyo). He is currently Emeritus Professor and Project Professor of Graduate School of Frontier Sciences in UTokyo. His research areas are high-performance and intelligent computational mechanics.

Dr. Hideki Fujii

He received Ph.D. in 2009 from UTokyo. He is currently Associate Professor of School of Engineering in UTokyo. His research areas high-performance social systems simulation based on a multi-agent approach.