Realization of Smooth Traffic Flow using Digital Twin

Takahiro Suzuki

Reducing accidents and alleviating traffic congestions are social issues in the traffic field, and achieving smooth traffic flow through effective measures is important to solving these issues. Against this background, OKI has made a number of developments, such as road management system, congestion prediction technology, and traffic anomaly detection technology that utilize traffic probe data in its effort to contribute to solving these social issues[1]. As a next step, OKI is researching and developing construction technology for a traffic digital twin that enables virtual verification of various traffic measures. This article will first explain the use of a digital twin, the issues, and an overview of traffic probe data. Then the article will introduce traffic flow simulation modeling, which is the key to digital twin, and data assimilation technology that will improve the reproducibility of traffic flow simulations.

Use and Issues of Digital Twin

Digital twin is a technology that reproduces real-world conditions in virtual space based on real observation data collected through sensing and other methods. The reproduced virtual space is called a digital twin because it is seen as a "virtual twin" of reality. Constructing a digital twin that accurately reproduces reality will enable a more realistic simulation of the future. The ability to predict and analyze the real future and prototype new products in a highly accurate virtual space will lead to cost reductions and quality improvements. In the traffic field, digital twin can be used to verify the effects of various traffic measures from multiple perspectives allowing road administrators to make optimal decisions to reduce accidents and alleviate congestions (**Figure 1**).

Although various positive effects can be expected from the use of a digital twin, there are also issues in its construction. Simulation modeling is the key to constructing a digital twin, and in order to accurately reproduce reality, it is necessary to set up an appropriate simulation model. For example, traffic flow models include multiple parameters that represent road characteristics, vehicle characteristics, etc., but unless these parameters have appropriate values, the simulation will not be able to reproduce reality. That is, in order to construct a realistic simulation, it is important to set appropriate model parameters. However, in many cases, the appropriate model parameters are not known and are determined by rule of thumb or trial and error, resulting in time-consuming settings and concerns about accuracy. Therefore, it is hoped that it will become possible to "easily construct simulations that match reality based on collected data."

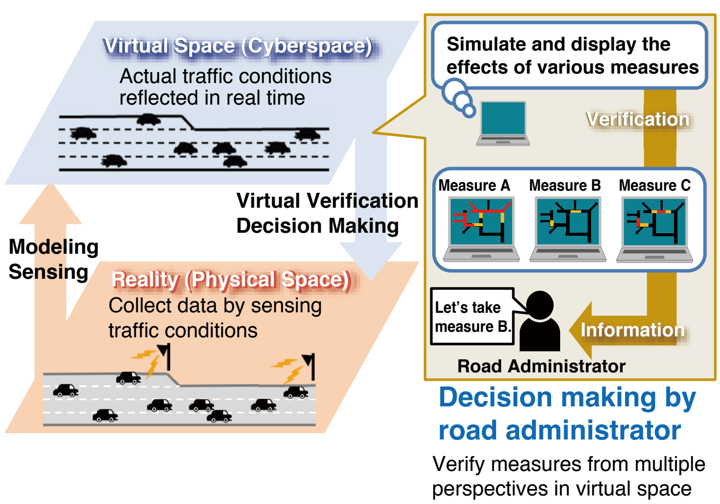

Figure 1. Traffic Digital Twin

Understanding Traffic Flow using Traffic Probe Data

This section will provide an overview of the traffic probe data used to construct a traffic digital twin. Traffic probe data refers to traffic information collected from vehicles equipped with onboard equipment via antennas installed on the road. In addition to basic information about the vehicle and onboard equipment, collected information includes driving history, such as time, location, speed and acceleration, and behavior history.

Based on traffic probe data, road information can be visualized by colorizing the average speed at the time of recording in each space and time, with time on the vertical axis and position on the horizontal axis (**Figure 2**). The black dotted line in **Figure 2** presents the traveling trajectory of a certain vehicle. The vehicle travels from left to right, and while it can move smoothly in the light-colored areas where the average speed is high, it takes time to move in the dark-colored areas where the average speed is low. In this way, traffic flow can be understood in real time using information obtained from traffic probe data.

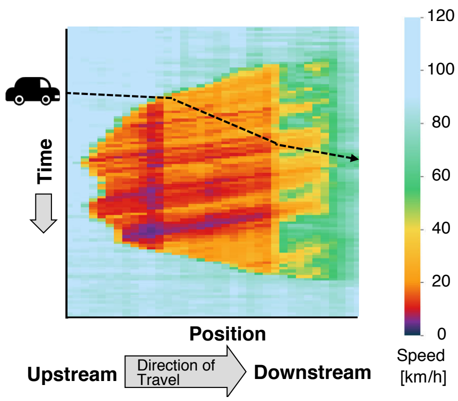

Figure 2. Visualization of Traffic Probe Data

Traffic Flow Simulation

Traffic flow simulation reproduces traffic conditions by performing calculations based on a traffic flow model, but there are many models and various studies are being conducted. OKI is conducting joint research on traffic flow simulation with Hideki Fujii, an Associate Professor (Yoshimura-Fujii Laboratory) at The University of Tokyo[2]. This article provides an overview of CTM (Cell Transmission Model), one of the traffic flow simulation models used in the joint research.

CTM is a model that treats traffic flow as a fluid, dividing a road into unit sections (cells) and calculating changes in the amount of traffic flowing into and out of each cell so that the number of vehicles is preserved for each cell. Specifically, the number of vehicles for the next time period is calculated by subtracting the number of vehicles flowing out from the number of vehicles in the cell and adding the number of vehicles flowing in (**Figure 3**). Concentrated traffic congestion occurs when the maximum amount of traffic that can flow in is exceeded, for example, on expressways it is likely to occur at points such as the start of an uphill slope, a sag section (a concave section where a downhill slope changes to an uphill slope), a tunnel entrance, or where the number of lanes is reduced. The traffic volume that is the threshold for congestion to occur is called traffic capacity, and it varies depending on the

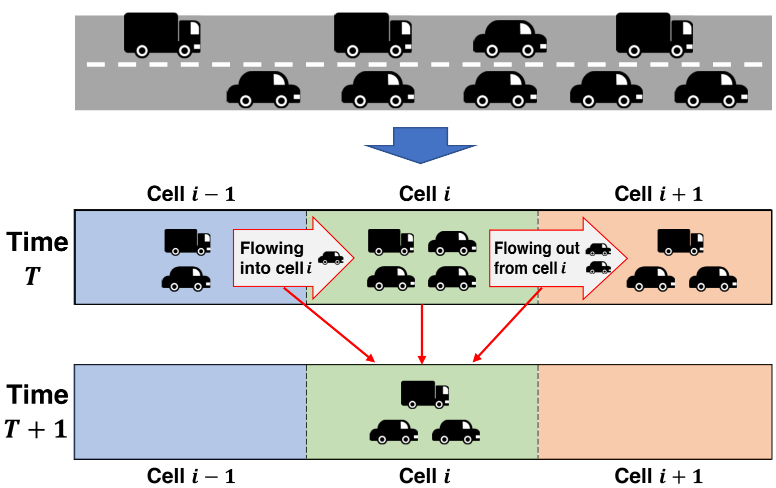

Figure 3. CTM Calculation

characteristics of the road. This traffic capacity is one of the model parameters, and in addition to this, CTM includes other parameters such as maximum traffic density that represents the number of vehicles that can be allowed in a cell, and traffic congestion propagation speed that represents the speed at which the generated congestion extends upstream.

Since these model parameters are not necessarily quantities that can be directly measured, conventionally they have been determined empirically or experimentally. However, model parameters can change depending on road structure, vehicle characteristics, etc. Therefore, in order to avoid deterioration of simulation accuracy, it is necessary to manually adjust parameters like an experienced craftsman each time the simulation target or situation changes, but it is not practical to manually fine tune parameters for every situation. For this reason, OKI is conducting research and development in applying data assimilation technology to traffic flow simulations to allow anyone to easily utilize highly accurate simulations.

Traffic Flow Simulation with Data Assimilation Technology

Data assimilation is a statistical method that modifies simulation results and model parameters based on observed data so that the simulation results are closer to reality. Until now, there have been active researches to increase the precision and speed of predictions through numerical calculations in the marine and meteorological fields[3]. Focusing on the fact that model parameters can be modified mechanically if observation data is available, OKI is conducting research on “traffic flow simulation with data assimilation technology” in order to solve the previously mentioned issues regarding the use of traffic flow simulation. In the research, OKI is aiming for automatic construction of a traffic flow simulation that accurately reproduces actual traffic flow by modifying model parameters using data assimilation technology based on traffic probe data. **Figure 4** shows the procedure for automatically constructing a traffic flow simulation.

First, observation data is entered. Observation data is used to create initial conditions for the simulation and assimilate data. In the research, traffic probe data was used as observation data. Traffic probe data is different than the data from traffic counters (fixed-point observation devices) installed on roads because it provides information from moving vehicles at each point, therefore data assimilation can be performed more effectively. Next, simulation and data assimilation are performed. The research utilized a data assimilation method called Ensemble Kalman Filter, which is a method that successively performs data assimilation on simulation results. It repeatedly performs simulation and correction of model parameters through data assimilation at each predetermined time step. That is, the model parameters are gradually modified at each time step. Through this process, even if simulation settings initially output results that do not match reality, the model parameters will eventually be corrected to make the simulation resemble reality.

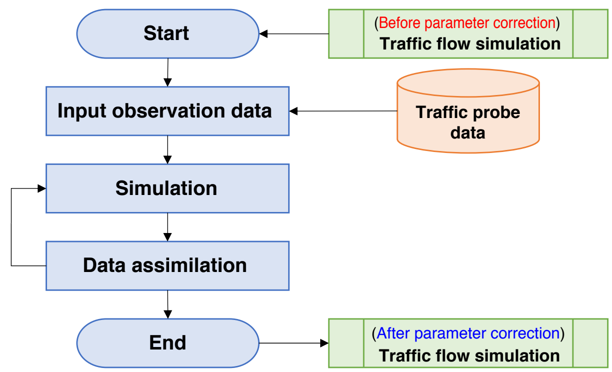

Figure 4. Automatic Construction of Traffic Flow Simulation

Result of Data Assimilation Technology

Figure 5 shows an example in which the accuracy of the traffic flow simulation is improved by applying data assimilation. **Figures 5(a)**, **(b)**, and **(c)** visualize speed information in space and time similar to **Figure 2**. **Figure 5(a)** shows the actual observation data, **Figure 5(b)** shows the simulation result using initial parameters estimated from past data, and **Figure 5(c)** shows the simulation result after applying data assimilation. In **Figure 5(b)**, congestion is simulated excessively compared to **Figure 5(a)**, and there are large differences in the spatiotemporal shape of the congestion and the average speed of each cell. On the other hand, **Figure 5(c)** shows that the application of data assimilation brings the simulation result closer to the actual traffic. This is due to the modification of the model parameters from their initial values. Parameters that cannot be directly measured can be estimated from past data, but it is difficult to make fine adjustments to suit the actual situation. Therefore, parameter estimation through data assimilation is extremely effective.

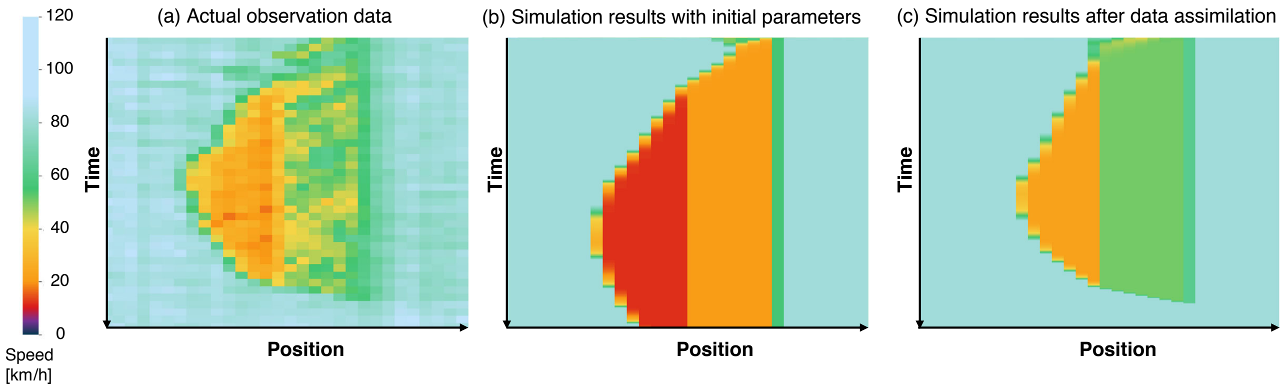

Figure 5. Result of Data Assimilation Technology

Figure 6 shows the process by which model parameters are corrected with the application of data assimilation using the traffic capacity at the point where congestion starts and the maximum traffic density of the cell as examples. The vertical axis represents the value of each parameter, and the horizontal axis is the time step (execution interval of simulation and data assimilation). It can be seen that the parameters change from their initial values due to data assimilation at each time step, and eventually converge on a constant value.

Through the use of data assimilation, it is possible to automatically correct model parameters and construct simulations that are close to reality without having to experimentally search for optimal values.

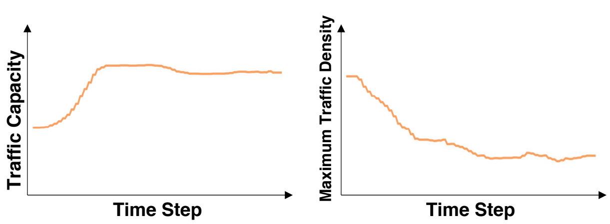

Figure 6. Parameter Correction Process

Conclusion

This article presented the data assimilation technology using traffic flow simulation and traffic probe data as a construction technology for a traffic digital twin. In particular, it explained that data assimilation is a technology that can solve such issues as concerns of simulation accuracy and burden of setting parameters, which are associated with constructing a digital twin. Through the construction of a digital twin, it becomes possible to easily verify the effectiveness of measures that are difficult to actually perform due to economic impact or time constraints. This will enable measures that may be more effective or measures that have never before been considered to be tried and verified. It is hoped that this will help resolve difficult social issues.

Additionally, as autonomous cars become more widespread in the future, it is expected that fine control of each vehicle will become possible. It is believed that such optimization of each vehicle's behavior can be achieved with the use of a traffic digital twin. Future plan considers applying data assimilation technology to a traffic flow simulation model that can also represent the behavior of each vehicle, thereby enabling fine control of traffic flow. ◆◆

References

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