Development of the Nowcast Traffic Simulation System using Floating Car Data

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Abstract

The purpose of this study is to develop an on-line traffic simulation system called the “Nowcast Traffic Simulation System” for road traffic in urban areas. The system can reproduce the traffic situation based on floating car data provided in real time. The output data is used for several traffic information services, including CO_2 monitoring. In this paper, we explain the concept of the Nowcast Traffic Simulation System and its theoretical framework followed by an example of a demonstration experiment in Kashiwa City in Japan.

Keywords: Traffic Simulation, Floating Car Data, Data Assimilation

1 Introduction

In recent years, real time traffic data collected by floating car data (FCD) can be used for many traffic information services. There are many advantages of real time traffic data. For example, the accuracy of the travel time information for car navigation systems is improved by using FCD. However, it must be noted that FCD is observed temporally and spatially as only a part of the traffic situation. In this case, one of the solutions is to estimate the traffic conditions between FCDs using some traffic models or algorithms. An online traffic simulation system should be provided as an example of a framework to estimate all traffic conditions in an area. ‘Online traffic simulation systems’ is one of the important research topics in the traffic engineering field. Some systems are developed and applied to real road networks for new traffic information services. It is said that the reproducibility and the accuracy of the estimated traffic situation are one of the challenges for practical use. However, online traffic simulation can be a breakthrough for the upgrading of traffic information services and road administration. In past studies, Ishibashi et al. [Ish09] described the method of an online traffic simulation system and the validation results, such as travel times on the Hanshin Expressway in Japan. Munakata et al. [Mun09] described validation results on the Metropolitan Expressway using the online traffic simulation system developed by Shiraishi et al [Shi05]. DYNASMART-X[Dsx04], DynaMIT [Dym98] and Aimsun Online [Aim08] were also developed and applied as online traffic simulation systems to predict traffic situations using real time traffic data. These studies and examples are developed for application to road networks in which traffic volumes and speeds are obtained by traffic sensors. However, it is possible that there may be few sensors, or even no sensors, in regular road networks compared to arterial roads and highways. In addition, the locations of origin and destination of vehicles are difficult to determine. We can be fairly certain that the solution in the case of insufficient sensors has not been studied enough. Although applications of FCD, such as travel time prediction, have been the object of study in recent years, no studies have ever tried application according to the characteristics of FCD (e.g. traffic volume cannot be estimated from FCD). Therefore, we developed a framework of an online traffic simulation system which can estimate the traffic conditions of an entire road network using FCD in the case of insufficient traffic volume data.

2 Concept

The purpose of this study is to develop the Nowcast Traffic Simulation System (NTSS) to estimate the road traffic conditions in urban areas in real time. **Figure 1** shows the image of NTSS.

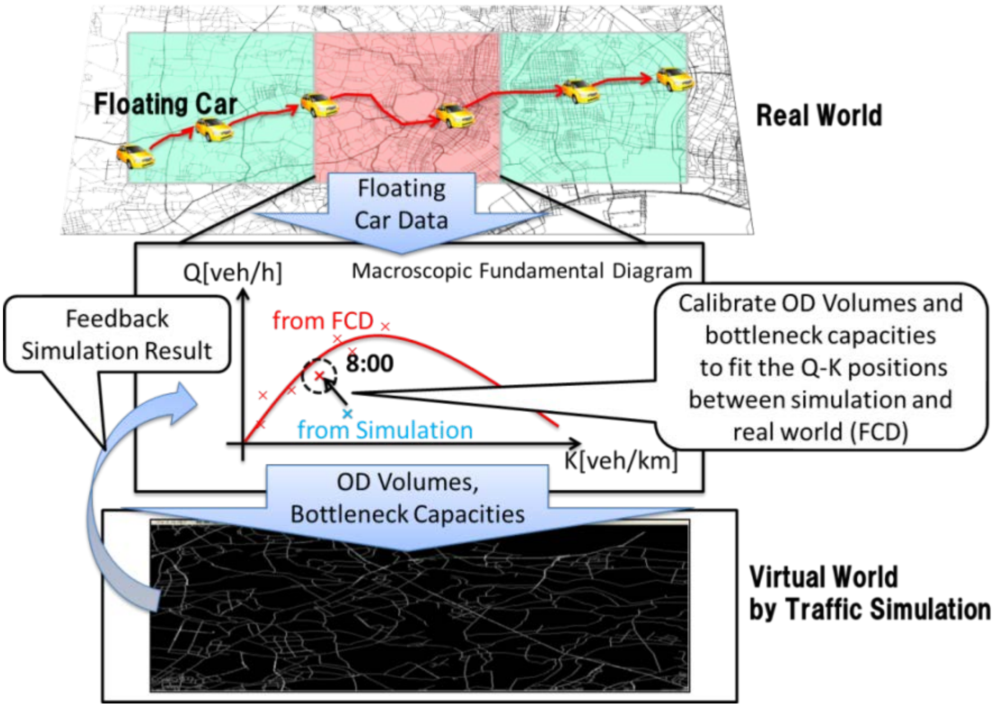

Figure 1: Concept of NTSS.

"Nowcasting" is the meaning to predict some sort of present situation such as weather. Thus NTSS forecasts the present traffic situation using real time traffic data. NTSS can be applied to several kinds of traffic monitoring systems for city-wide road networks. The purpose of the monitoring is to measure not only traffic flow and travel time but also environmental impacts such as CO_2 emission and traffic noise. NTSS complements the entire present traffic situation by a traffic simulation model using FCD. In this case, NTSS calibrates the parameters of traffic simulation to fit the traffic situation given by the traffic simulation model to the traffic situation from the observed data in real time. In this study, the traffic simulation model SOUND is used and the parameters for the calibration are below.

- OD traffic volume
- Bottleneck capacity (saturation flow rate)

Figure 2 shows the image of the parameter calibration of NTSS. NTSS calibrates these two types of parameters estimating the variation in the average traffic situation (the base case).

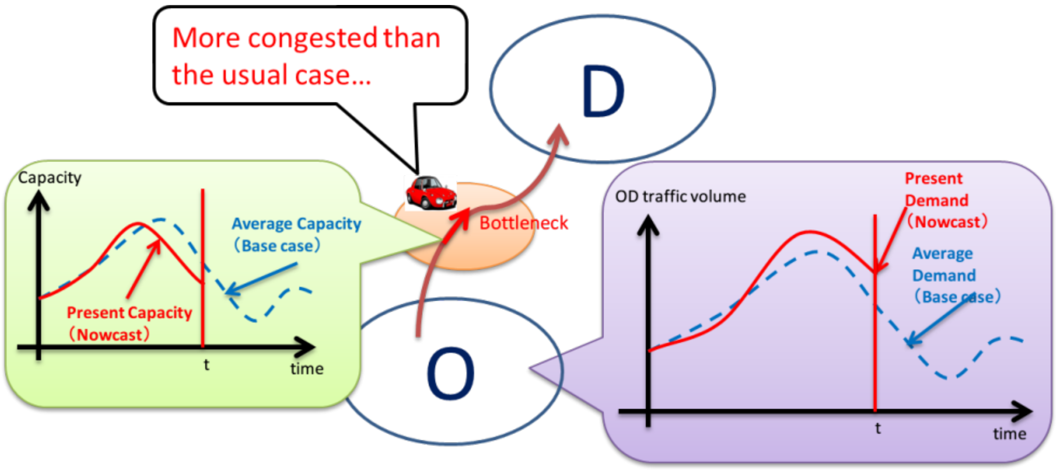

Figure 2: Image of Parameter calibration of NTSS.

3 Methodology

In the parameter calibration process in NTSS, the methodology of Macroscopic Fundamental Diagram (MFD) [Dag07] [Ger07] is applied. **Figure 3** shows the concept of the evaluation using MFD. For NTSS, we assume that the aggregated traffic flow and the aggregated density on MFD are calculated by FCD. We divide the target road network area into some zones for MFD. Here, we assume that the relationship between the MFD aggregated by FCD and the MFD aggregated by the simulation result is similar. The extended MFD of FCD can be compared to the MFD of the simulation result. If the two positions of the aggregated traffic flow and the aggregated density (the QK plot) between FCD and the simulation result are same, we can consider the traffic situation between the real traffic and the traffic simulation. Thus NTSS searches the target parameters to match both QK plots on MFD.

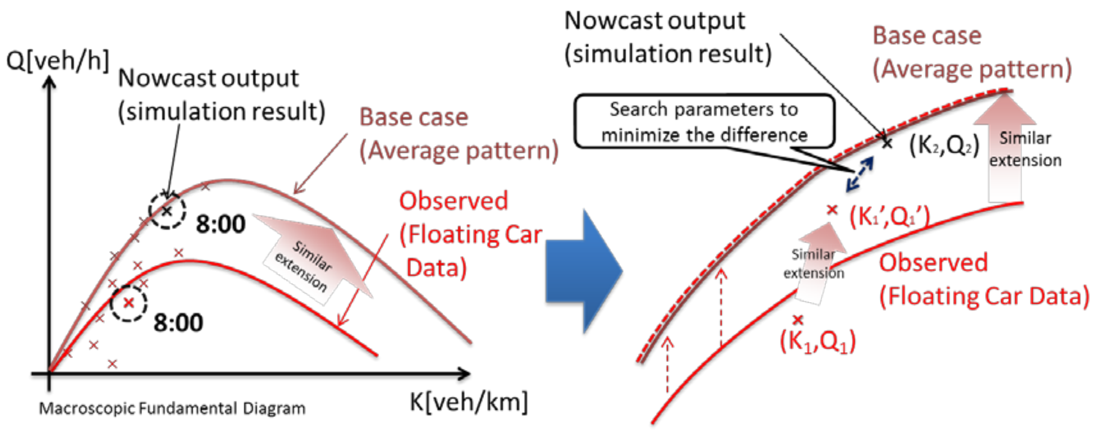

Figure 3: Image of the evaluation using MFD.

3.1 Strategy for the Parameter Calibration

To search for the most suitable parameters, we introduce a mathematical model. **Figure 4** shows the comparison of the calibration process between a conventional method and NTSS. Normally, we repeat steps to find the parameters considering the simulation results and the objectives such as traffic volume and travel time. Conventional calibration is needed to run traffic simulation to find the next parameters every time. On the other hand, NTSS adds the mathematical model to the conventional calibration. The calculation time of traffic simulation is decreased substantially because the traffic situations, including congestion, are modelled to the mathematical model. Therefore the real-time estimation can be processed.

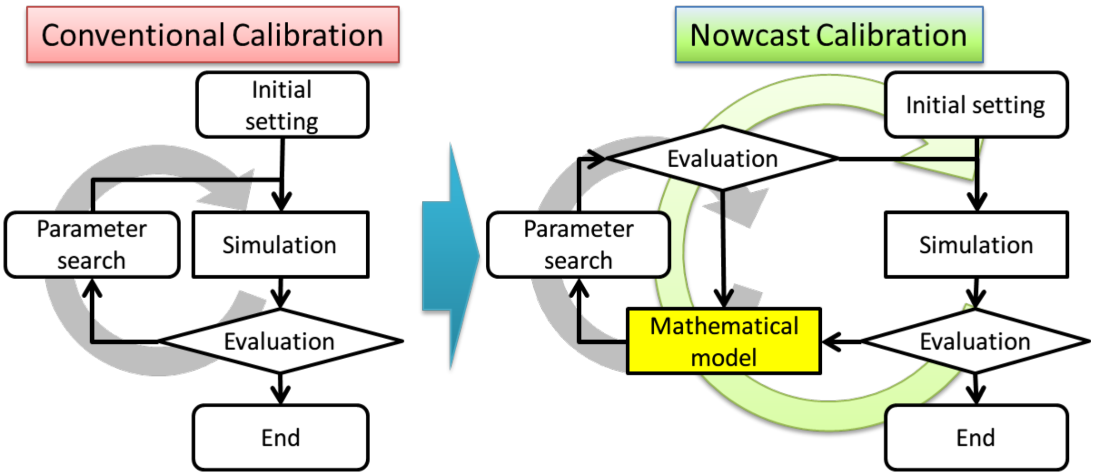

Figure 4: Calibration process of NTSS.

3.2 Macroscopic Fundamental Diagram

The Macroscopic Fundamental Diagram (MFD) can explain the macroscopic conditions of road traffic by FCD, traffic sensors, and so on. Let l_j denote the length of a link j, $n_{j\tau}$ denote the traffic volume of link j at the time slot τ and $\bar{T}_{j\tau}$ denote the average travel time of a link j at a time slot τ. An aggregated traffic flow Q_τ and an aggregated density K_τ are defined in the following equation:

$$Q_\tau = \sum_j l_j n_{j\tau} \tag{1}$$

$$K_\tau = \sum_j \bar{T}_{j\tau} n_{j\tau} \tag{2}$$

Here L is the total link length in a zone z. Using this function, we can put the flow and the density by observed data and the simulation result on the MFD.

3.3 Evaluation Formula for Parameter Calibration

First, let us explain about the assessment function for parameter calibration. To fit the parameters, we use the distance between the aggregated QK position of the observed data and the aggregated QK position of the simulation result on MFD. We assume that the simulation parameters (OD traffic volume and link capacity) fit when the distance of the aggregated QK positions between the observed data and the simulation result is minimized. Then the assessment function for the parameter search can be formulated using the aggregated QK plot $\hat{\vec{u}}^{z\tau}$ by the observed data and the aggregated QK plot $\vec{u}^{z\tau}$ by the simulation result at a time τ in a zone z as follows:

$$\textit{To minimize} \quad E = \sum_z \sum_\tau \sqrt{\left(\hat{\vec{u}}^{z\tau} - \vec{u}^{z\tau}\right)^T \Omega^{-1} \left(\hat{\vec{u}}^{z\tau} - \vec{u}^{z\tau}\right)} \tag{7}$$

Where E is the total distance of the QK plots between the observed data and the simulation result on the MFD. The distance is calculated by the Mahalanobis' generalized distance. Secondly, the traffic volume and the travel time for Q_τ and K_τ are explained by the traffic flow $n_{j\tau}$ and the average travel time $\bar{T}_{j\tau}$ of a link j at a time slot τ. Let α denote the mitigation rate of the saturation flow. The traffic volume $n_{j\tau}$ is calculated in the case of a congested link at a bottleneck and otherwise as:

$$n_{j\tau} = \begin{cases} \alpha \hat{q}_{j\tau} & \textit{Congested link at bottleneck} \\ q_{j\tau} & \textit{Otherwise} \end{cases} \tag{8}$$

Where $\hat{q}_{j\tau}$ is the traffic flow of the simulation result. On the other hand, $q_{j\tau}$ is the traffic flow formulated as follows:

$$q_{j\tau} = \sum_{rs} \sum_{j\tau} \hat{p}_{j\tau}^{rsh} Q^{rsh}$$
$$Q^{rsh} \geq 0, \left| 1 - \frac{Q^{rsh}}{Q_0^{rsh}} \right| \leq \beta \tag{9}$$

Q^{rsh} is the OD traffic volume of of a link j at τ for the od pair rs in a origin hour h. $\hat{p}_{j\tau}^{rsh}$ is the link selection probability of of a link j at a time τ. β is the constrained condition for the adjustment of OD traffic volume. Finally, the average travel time $\bar{T}_{j\tau}$ for the aggregated density is calculated by the link travel times using the cumulative vehicle count curves. **Figure 5** shows the definition of the link travel time and the average travel time. Let $T_{j\tau-1}$ denote the travel time of the first departure vehicle and $T_{j\tau}$ denote the travel time of the last departure vehicle.

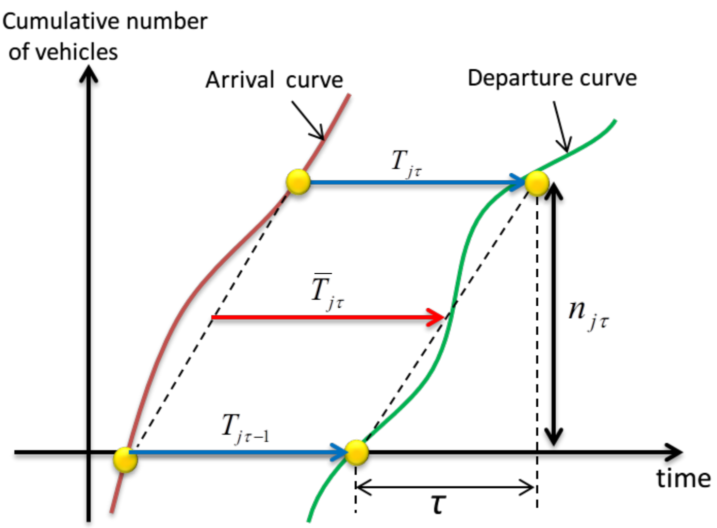

Figure 5: Cumulative curve to calculate an average link travel time.

Therefore, $\bar{T}_{j\tau}$ is calculated as the following equation. $T_{j\tau-1}$ is the link travel time of the last departure vehicle in the last time slot τ.

$$\bar{T}_{j\tau} = \frac{1}{2}(T_{j\tau-1} + T_{j\tau}) \tag{10}$$

In addition, $T_{j\tau}$ is formulated by $\hat{q}_{j\tau} q_{j\tau}$, $T_{j\tau-1}$ and τ.

$$T_{j\tau} = T_{j\tau-1} + \tau - \frac{\alpha \hat{q}_{j\tau}}{q_{j\tau}} \tag{11}$$

$T_{j\tau}$ can be changed according to the traffic situation. **Figure 6** shows the image of the variation of the cumulative vehicle count curves by the traffic flow $\alpha\hat{q}_{j\tau}$ and $q_{j\tau}$. If the last simulation result (judged by the link travel speed) is not congested, $T_{j\tau}$ is the same as $T_{j\tau-1}$. On the other hand, if the last simulation result is congested, $T_{j\tau}$ is changed by the bottleneck capacity defined by $\alpha\hat{q}_{j\tau}$ and the traffic demand of $q_{j\tau}$.

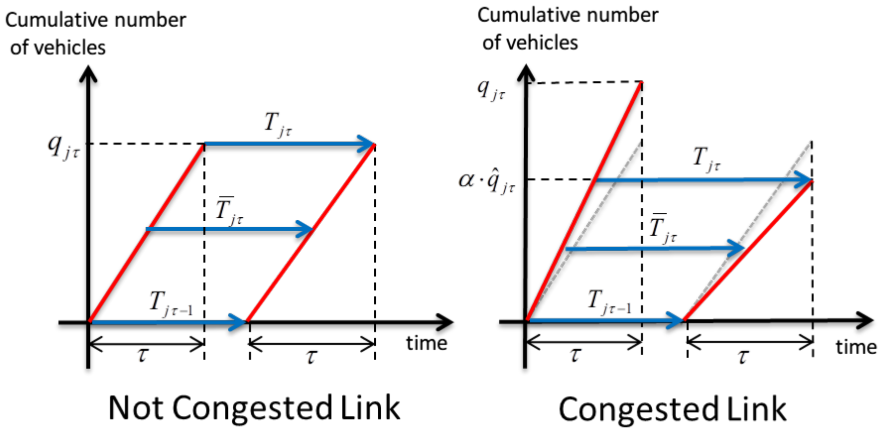

Figure 6: Variation of cumulative vehicle count curves.

4 Validation

For the validation of NTSS, we developed an on-line system of NTSS for a road network of Kashiwa City on the scale of 40 km square, consisting of 3566 nodes and 8171 links. The traffic data in the operation test in November 2012 is used as the input data of NTSS. **Figure 7** shows the validation area.

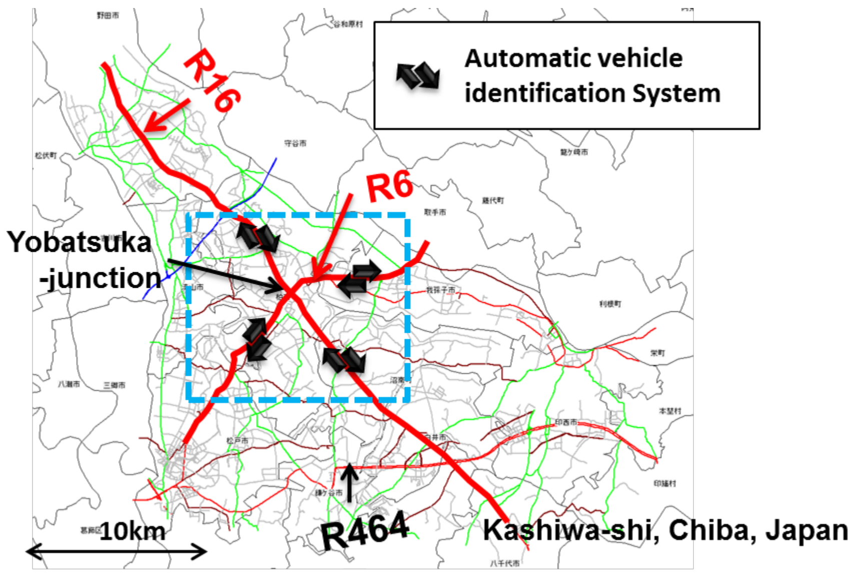

Figure 7: Validation area (Kashiwa City, Chiba, Japan).

The real-time data for NTSS is corrected by Automatic Vehicle Identification (AVI) systems on the national highways of R16 and R6 around the Yobasuka junction. The Yobatsuka junction is located in a suburban area of Tokyo. R16 and R6 are connected by the service roads of R6 at this junction (R6 is elevated with grade separation design). In addition, the Yobatsuka junction is one of the strategic junctions for road traffic in this area. Therefore, a high concentration of traffic to the Yobatsuka junction causes chronic congestion. There were 8 AVI systems around the junction. An AVI system can record vehicle plate numbers and the time vehicles passed. Therefore, the origin and the destination, route and the travel time of each vehicle between these AVI's can be identified by matching the vehicle plate numbers. This AVI data can be regarded as FCD in this study. **Figure 8** is the parameter calibration results by NTSS in the evening peak hour on a weekday. We can see the OD traffic volumes using Route 16 (R16) are increased. On the other hand, the OD traffic volumes using Route 6 (R6) are decreased. The capacity parameters are also calibrated based by NTSS to fit the present traffic situations. **Figure 9** shows the validation results of the travel time of R16. The base case is the average travel time as an initial value before the calibration by NTSS. The travel time of a section of R16 is estimated more precisely. The results need further consideration, and we will continue to improve the accuracy of the reproducibility.

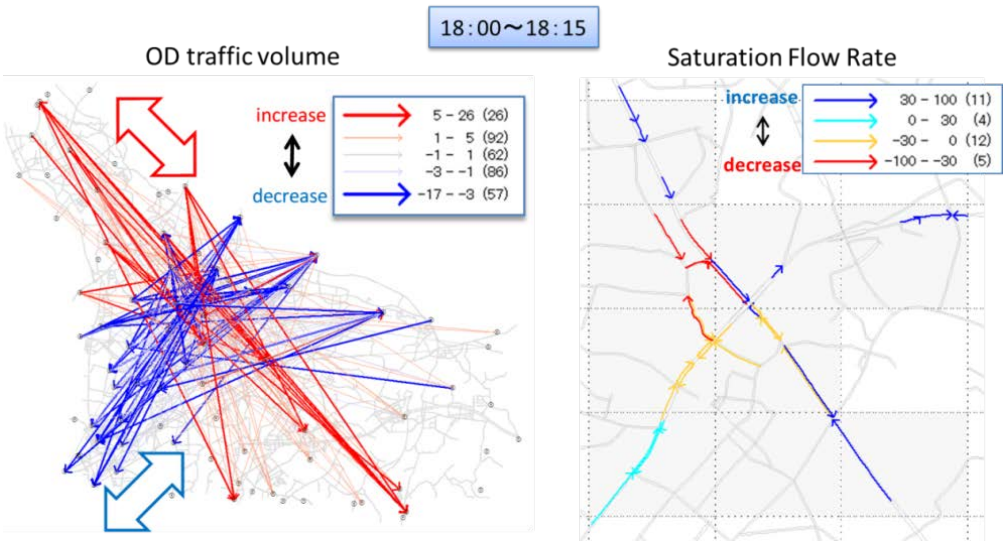

Figure 8: Variation of the traffic simulation parameters by NTSS.

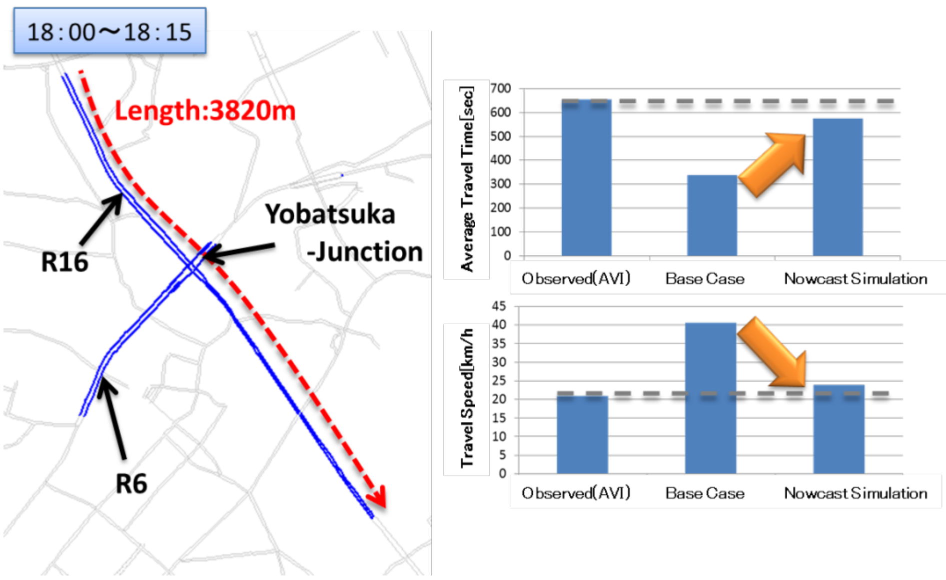

Figure 9: A validation example of travel time.

5 Application for CO_2 Monitoring

Figure 10 shows the experimental website for CO_2 monitoring in Kashiwa City. An operational test of NTSS has begun in the demonstration of the "Kashiwa Smart Project" [Kas13]. In the Kashiwa Smart Project, the present situation of CO_2 emission in Kashiwa City is monitored by NTSS in real time.

Figure 10: Experimental website of Kashiwa Smart Project.

The environmental information to reduce CO_2 emissions from cars is delivered to the citizens in Kashiwa City through the website and the mobile phone application. In the future, an increase of the amount of FCD is needed to improve the accuracy of the traffic situation.

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References

[Ish09] Teruhisa ISHIBASHI, Satoshi YOSHIMURA, Nobuhiro UNO, Fumitaka KURAUCHI , Takehiko DAITO: On-line Simulation Model for Traffic Control System of Hanshin Expressway and Enhancement of its Validity Using Dynamic Observations, 2nd International Symposium on Freeway and Tollway Operations, 2009.

[Mun09] K. Munakata, Y. Tamura, H. Warita, T. Shiraishi: A Case Study about the Traffic Prediction under Accidents Using Dynamic Traffic Simulation on Tokyo Metropolitan Expressway, Proceedings of 16th World Congress on Intelligent Transport Systems, Stockholm, 2009.09.

[Shi05] T. Shiraishi, R. Horiguchi, M. Kuwahara: A Development of Traffic Prediction System Based on Real-time Simulation, Proceedigs of 12th World Congress on Intelligent Transport Systems,CD-ROM, 2005.11.

[Aim08] http://www.aimsun.com/wp/?page_id=33

[Dsx04] http://www.its.uci.edu/~paramics/sim_models/dynasmart.html

[Dym98] Moshe Ben-Akiva ,Michel Bierlaire,Haris Koutsopoulos and Rabi Mishalani, “DynaMIT: a simulation-based system for traffic prediction”, DACCORD Short Term Forecasting Workshop February, 1998 Delft, The Netherlands

[Dag07] C. F. Daganzo, “Urban gridlock: macroscopic modeling and mitigation approaches,” Transportation Research B 41, 49-62; “corrigendum” Transportation Research B 41, 379, 2007.

[Ger07] N. Geroliminis and C. F. Daganzo, “Existence of urban-scale macroscopic fundamental diagrams: some experimental findings,” Working paper, Volvo Center of Excellence on Future Urban Transport, Univ. of California, Berkeley, 2007.

[Kas13] Experimental website for CO_2 monitoring in Kashiwa city:

http://www.kashiwa-smart.jp/index.php?go=traffic-kashiwa

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