PROMOTING SMOOTHER ROAD TRAFFIC BY EFFECTIVE MAINTENANCE AND OPERATION OF VEHICLE DETECTORS

Takami Aoyagi
Traffic Control Division, Traffic Bureau, Metropolitan Police Department
6-18-8 Shinbashii, Minato-ku, Tokyo 105-0004
+81-3-3581-4321(Ex. 7850-5213),s5000014@section.metro.tokyo.jp

Masayuki Jinno
System & Electronics Division, Sumitomo Electric Industries, Ltd.
1-43-5 Sekiguchi, Bunkyo-ku, Tokyo, 112-0014, Japan Tel.: +81-3-5273-7723

ABSTRACT
The road traffic control system deployed by the Metropolitan Police Department (MPD) that started operation in 1995 has been contributing to smoother and safer road traffic in the metropolitan Tokyo through the advancement of its signal control and information provision functions. Although goals are set to improve specific functions every year since 2005, 10 years after its inauguration, the operation to make the most of such functions is equally important.
This paper explains the outline of functional improvements added to the road traffic control system over the last 5 years, as well as the MPD activities to maintain more than 20,000 vehicle detectors installed on the roads for various purposes.

FUNCTIONAL IMPROVEMENTS OF ROAD TRAFFIC CONTROL

In 2005, the MPD developed a method of improving the accuracy of travel time delivered to the road users for informational purposes by utilizing the actual travel time calculated from uplink information transferred by in-vehicle units. The method has been deployed since March 2006, beginning with arterial roads where more uplink information is collected.
In the following year, road congestion was improved by upgrading the traffic signal control. Additional reduction in the cycle time to calculate signal control parameters from 150 seconds to 50 seconds in March 2007 helped shorten the delay time in the traffic signal control from 6-8 minutes to approximately 4 minutes, resulting in a 8.4 percent reduction in the total congestion at 500 important intersections. This percentage is equivalent to a 6.6 percent improvement in the total congestion across the Tokyo metropolitan area. The formula to calculate the signal timing split is also revised to be deployed in a phased...
manner. A study into traffic congestion at 12 intersections switched to the new method in September 2007 showed a 15.6 percent improvement after the introduction of the new formula.

In 2007, the MPD further reduced the delay time in information provision. An equipment upgrade in March 2008 led to shortening of the information delivery update cycle from 300 seconds to 150 seconds, resulting in at least 30 percent reduction in the information delivery delay.

In the same year, a new method to estimate congestion lengths based on the travel time calculated from the uplink information was introduced to make it possible to estimate congestion lengths in such segments as tunnels and bridges where the installation of vehicle detectors is not easy.

In 2008, the MPD developed a demand prediction signal control method which estimates traffic demand on road segments and reflect the result in signal control. The implementation of this demand prediction signal control eliminated delay in signal control as demonstrated by a 22.0 percent congestion improvement in 14 intersections that started operation in June 2009.

New functions such as improved travel time accuracy using the uplink information (March 2006), new signal split time calculation method (September 2007) and demand prediction signal control (June 2009) require fine-tuning by route and intersection and therefore a phased approach is taken for the changeover before starting operation.

**SIGNIFICANCE OF COLLECTING TRAFFIC INFORMATION**

While improving system functions is essential for increasing the performance of the traffic control system in signal control and traffic information provision, for instance, as previously stated, it is more important to get a correct view of traffic conditions.

The MPD has vehicle detectors installed at intervals of approximately 250 meters on main roads with the total length of 2,643km across the Tokyo metropolitan area and collects traffic data from them every 50 seconds. To pursue smoother traffic, highly accurate signal control and information provision should be achieved by controlling the quality of the data collected from vehicle detectors to make it more accurate. In order to collect accurate data, maintenance of vehicle detectors in service is important, and appropriate action (such as relocation) must be taken against any changes in the installed sites (such as road widening and intersection improvements).

In the Tokyo metropolitan area, many road widening and intersection improvement projects are executed every year and many vehicle detectors in service are aging. Aged detectors increase fault incidents and even negatively impact signal control and information provision operations by decreased reliability of collected traffic data.

Besides, vehicle detectors are installed at 250-meter intervals as stated above, improving the accuracy in estimation of where the congestion tail is in any of 250-meter segments on the road requires further sophistication of the congestion measuring algorithm.
Therefore, the maintenance of terminal equipment is as important as functional improvements in order to retain high performance of the Road Traffic Control System.

**DETECTOR INSTALLATION STATUS**

Different types of vehicle detectors such as ultrasonic, image processing and infrared (IR) beacon, are selected based on the purpose of use. Their performance and functionality are constantly improving along with the advancement of information and communication technology, and the IR beacon which enables bidirectional communication with vehicles has become a key infrastructure for driving ITS development.

In order to ensure smooth road traffic in the Tokyo metropolitan area, which has the largest traffic volume in Japan, broader scale and constant collection of traffic volumes, congestion lengths, travel time and other information is imperative. Figure 1 explains the trend in the number of vehicle detectors installed in the Tokyo metropolitan area.

![Figure 1: Trend in Number of Vehicle Detectors](image)

**TRAFFIC INFORMATION COLLECTED BY VEHICLE DETECTORS**

Table 1 shows traffic information measured by detector type. As shown in Figure 1, there are more ultrasonic vehicle detectors than any other detectors currently in service. The types of traffic information collected by ultrasonic detectors are traffic volume and occupancy, which are used for estimating congestion lengths and travel time to feed into signal control
and information delivery. Image processing vehicle detectors are capable of determining vehicle types in addition to collecting basic information such as traffic volumes and occupancy time, and IR beacon detectors are capable of receiving travel time information from in-vehicle units.

<table>
<thead>
<tr>
<th>Table 1: Traffic Information Measured by Vehicle Detectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
</tr>
<tr>
<td>Ultrasonic detector</td>
</tr>
<tr>
<td>Image processing detector</td>
</tr>
<tr>
<td>Infrared beacon</td>
</tr>
</tbody>
</table>

TRAFFIC INFORMATION PROCESSING FLOW

Figure 2 shows the flow of processing traffic information.

![Figure 2: Traffic Information Processing Flow](image)

SIGNAL-SYNCHRONIZED TRAFFIC VOLUME, OCCUPANCY TIME AND AVERAGE SPEED

Traffic volume can be obtained by measuring the number of detection pulse in a given period of time, and occupancy time of the vehicle in the detection zone can be derived by dividing the sum of detection pulse widths by the measuring time.
If traffic volumes and occupancy time are measured at regular time intervals such as every 2.5 minutes, the reading may vary significantly by cycle, affected by the traffic signal control operation. To avoid such influence of traffic signal control operation, these data are measured in synchronization with the traffic control timing. This is called cycle-synchronized data collection.

The average speed can be calculated from the traffic volume, occupancy time and effective vehicle length in the following equation:

$$\text{Average speed} = \frac{\text{Effective Vehicle Length}}{\left(\frac{\text{Occupancy Time}}{\text{Traffic Volume}}\right)}$$

Since the average vehicle length varies depending on the percentage of heavy vehicles, it is estimated from measured vehicle types.

**DEGREE OF CONGESTION**

The degree of congestion is an indicator of the degree by which the congestion is spread to the installation site of the detector, and is calculated from the average speed. Conventionally, any average speeds lower than the speed threshold $V$ were determined to indicate the presence of congestion. However, this resulted in variation of congestion decision depending on minor fluctuation in the average speed. In order to solve this problem, the MPD set three speed thresholds. If the average speed equals to the conventional speed threshold $V_2$, the degree of congestion is determined as 0.5. If it is higher than $V_3$, then the degree of congestion shall be 0. If it is lower than $V_1$ the degree of congestion shall be 1. For any other speeds in between, the degree of congestion shall be calculated as the continuous quantity of 0 to 1. Figure 4 shows the calculation of the degree of congestion.

These thresholds are set by the system maintenance administrator individually for each vehicle detector used for measuring congestion based on the traffic conditions surrounding the detector and are considered to be significant in influencing the accuracy of congestion.
lengths and travel time.

**CONGESTION LENGTH ESTIMATION**
Congestion lengths are estimated from the degree of congestion calculated by individual detectors. As shown in Figure 5, segments with the congestion degree of 0.5 or above are considered to be congested while those with the degree lower than 0.5 are considered to be not congested. The congestion tail is estimated to be located between the detector indicating the congestion degree of 0.5 or above and the one lower than 0.5, where the congestion degree becomes 0.5.

**TRAVEL TIME ESTIMATION**
The travel time is calculated separately for congested and non-congested segments.
The travel time in the congested segment as shown in Figure 6 is the sum of travel time in sub-segments which constitute the segment and the travel time in each sub-segment is estimated from the number of vehicles located and the traffic flow rate in each individual sub-segment with a consistent flow rate. The following shows the calculation formula.

\[ T = \sum L_i \cdot K_i/Q_i \]

- **\( T \)**: Travel time in the congested segment
- **\( L_i \)**: Length of sub-section \( i \)
- **\( K_i \)**: Average traffic density in sub-section \( i \), \( K_i = \text{km}\cdot\text{a}Q_i \)
- **\( km \)**: Jam density (traffic density of standing traffic)
- **\( a \)**: Correlation coefficient between traffic flow rate and density
- **\( Q_i \)**: Traffic flow rate in sub-segment \( i \)

**Figure 6: Sub-segments for Travel Time Calculation**

The travel time in non-congestion segments will be calculated by dividing the length of non-congestion segment by travel speed for non-congestion time that takes the waiting time for the signal to change into account. The fixed number for travel speed for non-congestion time period is set to 25-30km/h.

**TRAVEL TIME CORRECTION BY UPLINK INFORMATION**

In March 2006, the MPD started collecting measured travel time utilizing uplink information (uplink measured travel time). In the traffic control system, traffic information that includes congestion and the travel time is updated every 2.5 minutes. In order to calculate reliable travel time in a given segment, at least three or more pieces of valid uplink data over a 10 minute period or ideally three or more over a five minute period are required.

In segments of multiple lanes and a relatively high traffic volume, it is now possible to collect uplink measured travel time under these conditions and this made the correction of the travel time by uplink information helped improve the accuracy of the travel time delivered to the user.
CURRENT STATE OF DETECTOR INSPECTION

The traffic information collected from various types of detectors is important for maintaining the performance of traffic signal control and the accuracy of information delivered to the user. Therefore, the MPD is monitoring the state of the detectors to detect any equipment that may need tuning or repair at an early stage. This section shows an example of detector inspection.

DETECTOR DEFECT INSPECTION USING LONG-TIME-CONGESTION EXTRACTING TOOL

When the speed threshold values set to determine the degree of congestion ($V_3$, $V_2$ and $V_1$) do not reflect the actual traffic, a non-congested segment is likely to be determined as congested or vice versa.

The Long-Time-Congestion Extracting Tool is a system to extract non-congested segments which have become likely to be determined as congested. The MPD has been reexamining these threshold values since 2001 by using this verification tool to narrow down the installation sites that require tuning.

Figure 8 shows an example of the segment that had been determined as congested almost all day long due to the setting of threshold value ($V_3$, $V_2$ and $V_1$) higher than actuality. Since it is rare to find roads in the Tokyo metropolitan area remaining congested at nighttime, the MPD examined the traffic status on site and adjusted the speed threshold to lower values in this segment.
IMPROVING ACCURACY IN INFORMATION MEASUREMENT BY UTILIZING UPLINK INFORMATION

In Japan, the Vehicle Information and Communication System (hereinafter referred to as ‘VICS’) which displays traffic information including congestion on car navigation systems has been in service since 1996 and the number of users is growing year after year. In major cities including Tokyo, traffic information systems including VICS are very useful for selecting routes to avoid traffic congestion.

The rate of installing in-vehicle unit which is capable of bidirectional communication with infrared beacons installed on the roads has reached to 9% in 2010.

A vehicle that passes over IR beacons send actual travel time collected from the previous
beacon it passed as uplink information. On the other hand, IR beacons send the latest congestion information and travel time information as downlink information to in-vehicle unit.

This actual travel time information has been used for calculating the travel time to be provided to road users, estimating congestion length and verifying the effect of travel control improvements since 2005 when the uplink rate reached six percent.

The travel time measured by IR beacons and congestion lengths estimated by vehicle detectors are correlated to each other: as shown in Figure 10, the longer the estimated congestion length becomes, the actual travel time increases. The segments with a low level of correlation may indicate improper measurement of congestion. The MPD plans to develop an assistant tool to verify the correlation between the two on the control console in 2010.

![Figure 10: Correlation between Congestion Length and Actual travel time](image)

**MANAGEMENT SYSTEM**

An appropriate system must be in place to detect and take necessary steps against changes in road conditions and defects of detectors at an early stage.

In order to efficiently maintain the system, the MPD has been developing various tools, examining inspection methods and reviewing the management organization. As an initial step, the MPD decided to standardize the optimal deployment of detectors for different purposes of use and the design policy in on-site installation to efficiently operate the traffic control system.

Currently, the MPD is investing the types of detectors in service, purpose of use of
detectors (for congestion measurement etc), installed years, installed sites, installed lanes, distance between detectors on main roads (a total length of 2,643 km) and relocating, merging and removing detectors based on the findings. However, due to the long total length and a large number of detectors, it used to take 8 years to complete the investigation covering all main roads. From 2010, to achieve more effective maintenance by pursuing more efficient and appropriate deployment of detectors, the MPD decided to complete investigation of all roads in four years.

![Figure 11 Reviewing Detector Deployment on Main Roads (Main Segments)](image)

When replacing detectors due to aging and other reasons, installed location and usage of such detectors were reviewed on a detector by detector basis. From 2010, the MPD decided to get the entire main road (main segment), to which the subject detector belongs, in perspective and proceed with the review based on the detector deployment standards taking installed locations of surrounding detectors into consideration as shown in Figure 11. In addition, by presenting the surrounding detector deployment status (on the main segment in the other direction), the MPD made it possible to design replacement construction of subject detectors en bloc.

In parallel with investigation into the detector deployment status, the MPD has been verifying the accuracy in congestion length detection at segments reporting chronic congestions inconsistent with the traffic actuality, by adopting the chronic congestion verification tool described above. The time required for verification of all main roads which used to take five years is reduced to one year, and speed thresholds and location of detectors whose detection of congestion is inappropriate are reviewed as needed to improve detection accuracy.

**SUMMARY**

The smoother road traffic does not benefit vehicles alone. Besides, delivery of safer services to vehicles will also result in providing pedestrian and cyclists on the road with safer and more comfortable environment.

Installation and maintenance of high performing vehicle detectors including IR beacons are not only effective for smoother road traffic but also imperative for the development of ITS.
The MPD will continue to promote appropriate maintenance and operation of the detectors in service by developing new assistant tools for checking operational status of road traffic control as well as further deploying and maintaining the cutting-edge detectors.

REFERENCE
