行政院國家科學委員會專題研究計畫 成果報告

利用智慧型手機以詢問回覆機制收集即時交通路況之設計與評估
研究成果報告(精簡版)

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中 文 摘 要 ： 提供用路人即時交通資訊可避過塞車、節省行車時間及能源消耗。由於智慧型手機裝載 GPS 接收器與無線資料傳輸技術且逐漸普及，利用智慧型手機作為 GPS 探偵車回報車速取得即時交通資訊成為可行的方式。相對於傳統固定式車輛偵測器而言，GPS 探偵車大幅降低佈建與維護成本。然而目前 GPS 探偵車的回報方法可分為：固定週期回報或是固定地點回報，無論是哪種，皆會造成回報資訊超載的問題，若使用條件式回報可降低回報量，但傳統的條件式回報方式交通資訊中心不易計算出精確之平均旅行時間。本研究基於條件式回報支方式，提出交通資訊中心提供下個交通號誌週期之最大旅行時間與最小旅行時間給 GPS 探偵車，探偵車根據收到的資料與自身旅行資料相比做選擇性回報，能有效降低交通資訊回報次數和成本，並掌握精確的交通資料。為了分析系統效能，我們使用運輸模擬軟體 VISSIM 來進行實驗模擬。研究成果證實，我們所提供的資料的方法可大量減少探偵車資訊回報之數量，減輕交通資訊中心之負載，並能精確掌握交通狀況之波動。

中文關鍵詞： 即時交通路況，行動感測器，詢問回覆機制

英 文 摘 要 ： Providing real-time traffic information can help road users to avoid congestion, save traveling time and reduce fuel consumption. With the increasing popularity of smart phones equipped with GPS receiver and wireless data communication capability, smart phones on traveling vehicles can be used as probes to obtain the real-time traffic information, such as speed and travel time. The conventional report policy of GPS-equipped probes can be classified into two categories: periodical report and segment-based report. Both approaches may cause a large amount of redundant report messages if there are too many probes on the same road segment. Conditional reports can reduce the communication overhead, but it’s difficult for traffic information center (TIC) to compute the accurate average travel time from limited conditional reports. We propose a conditional report policy and our TIC predicts the maximum and minimum travel times for the next traffic light cycle, broadcasts the predicted travel times to the probes as well as general vehicles. The probes report to the TIC only when their travel times are close to the maximum or the minimum travel time. To evaluate the performance of the system, we have performed computer simulations using traffic model simulator VISSIM. The simulation results indicate that our approach significantly reduces the number of traffic reports and the loading of the TIC, and we can accurately catch the change of the travel time during traffic congestions.

英文關鍵詞： Traffic information, GPS, mobile sensor, query-response

行政院國家科學委員會專題研究計畫成果報告

利用智慧型手機以詢問回覆機制收集即時交通路況之設計與評估

The Design and Evaluation of Real-time Traffic Information Collection Using Query-Response Mechanism on Smart-phones

計畫編號：NSC 100-2221-E-009-108

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中文摘要

提供用路人即時交通資訊可避過塞車、節省行車時間及能源消耗。由於智慧型手機裝載GPS接收器與無線資料傳輸技術且逐漸普及，利用智慧型手機作為GPS探偵車回報車速取得即時交通資訊成為可行的方式。相對於傳統固定式車輛偵測器而言，GPS探偵車大幅降低佈建與維護成本。然而目前GPS探偵車的回報方法可分為：固定週期回報或是固定地點回報，無論是哪種，皆會造成回報資訊超載的問題，若使用條件式回報可降低回報量，但傳統的條件式回報方式交通資訊中心不易計算出精確之平均旅行時間。本研究基於條件式回報支方式，提出交通資訊中心提供下個交通號誌週期之最大旅行時間與最小旅行時間給GPS探偵車，探偵車根據收到的資料與自身旅行資料相比做選擇性回報，能有效降低交通資訊回報次數和成本，並掌握精確的交通資料。為了分析系統效能，我們使用運輸模擬軟體VISSIM來進行實驗模擬。研究成果證實，我們所提供的資料的方法可大量減少探偵車資訊回報之數量，減輕交通資訊中心之負載，並能精確掌握交通狀況之波動。

Abstract

Providing real-time traffic information can help road users to avoid congestion, save traveling time and reduce fuel consumption. With the increasing popularity of smart phones equipped with GPS receiver and wireless data communication capability, smart phones on traveling vehicles can be used as probes to obtain the real-time traffic information, such as speed and travel time. The conventional report policy of GPS-equipped probes can be classified into two categories: periodical report and segment-based report. Both approaches may cause a large amount of redundant report messages if there are too many probes on the same road segment. Conditional reports can reduce the communication overhead, but it's difficult for traffic information center (TIC) to compute the accurate average travel time from limited conditional reports. We propose a conditional report policy and our TIC predicts the maximum and minimum travel times for the next traffic light cycle, broadcasts the predicted travel times to the probes as well as general vehicles. The probes report to the TIC only when their travel times are close to the maximum or the minimum travel time. To evaluate the performance of the system, we have performed computer simulations using traffic model simulator VISSIM. The simulation results indicate that our approach significantly reduces the number of traffic reports and the loading of the TIC, and we can accurately catch the change of the travel time during traffic congestions.

I. Introduction

As the number of vehicles constantly increases and traffic congestions become daily phenomenon in urban areas, it is more and more important to provide real-time traffic information to drivers traveling on urban roads. With real-time traffic information, drivers can avoid congested roads to save travel time and reduce fuel consumption. Many countries around the world have been committed to build Traffic Information System (TIS) for the benefits mentioned above. For example, in 1991, the European Road Transport Telematics Implementation Coordination Organization (ERTICO) committed to providing real-time traffic information [1]. Service providers, such as TomTom [2], IntelliOne [3], ITIS Holdings PLC [4] and Mediamobile [5] have developed applications to provide real-time traffic information recently.

There are two primary methods in collecting real-time traffic information. One uses stationary vehicles detectors (VD) [6-7], such as inductive loops, radar devices, and video image processors installed on the road segments under surveillance to obtain real-time traffic data. Inductive loops are embedded in the road surface to measure the number of vehicles passing by and the speed of the vehicles. Video image processors installed beside or above road segments also measure the flow and speed of the passing-by vehicles. The average speed of the passing-by vehicles in a time interval measured by a stationary VD is referred to as Time Mean Speed (TMS). Some intelligent video image processors are capable of reading vehicle plate numbers. When a vehicle passes by two such processors, the vehicle's traveling speed between can be obtained. This speed is referred to as Space Mean Speed (SMS). Although vehicle detectors are very accurate in calculating the number of passing vehicles, Each VD requires a communications link back to the Traffic Information Center (TIC). Moreover, due to extreme weather exposure, the failure rates of VDs are usually high. Therefore, stationary VDs are very expensive to install, operate and maintain, and their installations are typically limited to freeway or highway surveillance.

The other method uses floating car data (FCD) to measure traffic speed. In FCD systems, probe vehicles collect their own traveling data, and share the information with others [11-16]. As long as probe vehicles travel on a road, the traffic information of the road can be collected. The coverage of the FCD can be very wide if a sufficient number of probe vehicles are deployed. Compared with the stationary VD technique, since there is no need to build and maintain the extra traffic sensors on the roads, FCD systems can be more cost–effective, and cover a wider road network. It's suitable to use FCD system to maintain the traffic information in urban roads. Traditionally, fleet vehicles, such as taxi and public transportation buses, are equipped with GPS receivers and used as probes. Due to the widely use of smart phones with GPS capabilities, Mohan et al. [8] has proposed a method using mobile smart phones as probes to monitor the traffic conditions. As a result, the number of probes can be potentially huge.

A new approach of FCD systems uses cellular network control messages, such as location update and handover, to detect traffic speed and congestion [9]. One of the advantages of using cellular-network control message to estimate traffic information is that it requires little extra cost, since cellular networks have already been deployed and mobile phones on moving vehicles are used as probes. Compared with the conventional GPS-equipped probe vehicles, this approach does not require any additional on-vehicle devices, and there are sufficient probes since MSs are so pervasively used. However, the accuracy of the traffic speeds estimated by this technique is lower than that obtained from GPS-equipped probes. To estimate traffic speed using cellular network control messages, we need to locate a mobile phone at two different locations and divide the distance of the two locations by the time elapsed. The errors in locating a mobile phone would result in errors in estimating the traffic speed. However, a cellular network can't pinpoint the exact location of a mobile phone from the control messages exchanged between the mobile phone and the network. On the other hand, the position errors in locating GPS-equipped probe vehicles are typically within tens of meters. Therefore, traffic speed obtained GPS-equipped probe vehicles are much more accurate than that from cellular control messages.

Collecting traffic information from GPS-equipped probes can be carried out in a centralized or decentralized structure. In a centralized structure, a centralized server called Traffic Information Center (TIC) collects traffic data from a group of Probe Cars (PCs) [11-16]. The PCs measure the traffic data of the road segment where the PCs currently travel, and report the measured data to the TIC periodically or when the PCs pass predetermined locations. From the traffic data collected, the TIC generates traffic speed and/or travel time for each road segment. If a road segment has not been traveled by probes for a period of time, the TIC may use historic traffic information. The traffic information generated by the TIC can be delivered to PCs and general vehicle drivers in two ways: pull or push. In “pull” approach, PCs can send requests to the TIC and retrieve the traffic information by wireless communication. In “push” approach, the TIC broadcasts the generated traffic information periodically. In this report, we use the centralized structure to design our system.

Wischhof et al. [10] have proposed a decentralized traffic information system, PCs exchange traffic data based on inter-vehicle communications. Each PC broadcasts traffic data to other probe cars periodically; no central server exists in their system, i.e., it is a peer-to-peer (P2P) architecture. One of the advantages of the decentralized approach is no server is needed to collect the traffic information, and thus there is no system bottleneck or single-point-of-failure problem.

In this report, we present a traffic notification system using a centralized structure and a conditional report policy to reduce the number of report messages from GPS-equipped smart phones. Our traffic notification system has the following features:

(1) GPS-equipped smart phones are our probes.

(2) Use a conditional report policy to reduce the number of report messages

(3) Instead of providing the probes the reported traffic information, we provide the prediction value according to the trend of the traffic.

The remainder of this report is organized as follows. Section 2 describes the current work in Floating Car Data report policies related to our system. Section 3 describes our system design in details. Section 4 discusses the experiment results and analysis of our system. Finally, we give our conclusions in Section 5.

II. Background and Related Work

The TIC generates the real-time traffic information based on the traveling data of the GPS-equipped probes. One of the design issues is how often the probes should send traveling data to the TIC. In conventional systems, probes send reports to the TIC periodically, for example, Schaefer et al. [11] proposed an urban traffic information system using GPS-equipped probe taxis, and each taxi has to send the GPS position to taxi headquarters once per minute. One of the advantages of periodical reports is that it is easy to implement. Traffic information of a road segment can be obtained as long as a probe vehicle travels by. However, when GPS-equipped smart phones are used as probes, there may be a large number of probes on a road segment. As a result, many redundant traffic reports would be sent to the TIC. This wastes the valuable wireless transmission bandwidth and may over-load the TIC’s computation resources.

Hoh et al. [12] use virtual trip lines on the road to collect the traffic information. A virtual trip line (VTL) is a line in geographic space that, when vehicles cross, triggers a client’s location update to the traffic monitoring server. When a vehicle traverses the trip line, its location update comprises time, trip line ID, speed, and the direction of crossing. The trip lines are pre-generated and stored in probes. The advantage of the virtual trip line approach is that it reduces the number of reports to only once in a segment. However, as the number of probes increases, there will be redundant reports sent to the TIC for the same segment from different probes.

Van Buer et al. [13] proposed a notification system for reporting the traffic anomaly condition. In their system, each probe car has an on-board database to record its historical travel data, and it determines its speed anomaly during each trip. Each probe car needs to compare its historical database with its current speed, and determines whether the speed discrepancy is greater than a predefine threshold or not. If the discrepancy satisfies the predefine threshold, the probe car report its current speed to the TIC. When the TIC receives the probe car report, the TIC generates and broadcasts an alert to probe cars on the road segment. After receiving an alert from the TIC, each probe car has to compare its speed discrepancy with the alert, and report to the TIC if the speed discrepancy is greater than a predefine threshold.

Kerner et al. [14] developed a FCD-based traffic information system using a travel time threshold to reduce the number of messages sent to the TIC. In this method, TIC periodically broadcasts the average travel time and a threshold for each road segment. By comparing the difference between the received travel time and the travel time record itself with the threshold, the PC decides whether or not to send a report to the TIC. The decision is based on checking if the travel time difference between the probe cars measured value and the TIC broadcasted value is greater than the TIC broadcasted threshold. If the condition is satisfied, the probe car sends the traffic information report to the TIC. Using threshold values does reduce the communication cost, but the accuracy of the generated traffic information may also decrease.

Tanizaki and Wolfson [15] designed a randomized report policy to improve the threshold approach. They define server delay, which is a delay from a probe car sending reports to the TIC till the TIC broadcasts a new threshold. In this delay time interval, there may be a large amount of unanimous traffic information sent to the TIC if there are many probes traveling on the same road segment. To address this problem, when the threshold is satisfied, instead of always sending a report to the TIC, the probe sending the report with a probability p, which is determined by the TIC for each road segment to reduce the number of reports and achieve high accuracy. This reduces the volume of reports sent at a server delay interval, but may result in incomplete traffic data received by the TIC and less real-timeliness of the traffic information generated.

To deal with the issues above, Ayala et al. [16] proposed a flow-based report policy for FCD-based traffic information systems. They did not use threshold values to determine whether to send the traveling data to the TIC or not. Every probe car transmits the traveling data to the TIC with the same probability. The transmission probability $p = k / N$, where k is the number of messages that the TIC needs to receive from probe cars in order to guarantee a given confidence in the average speed computation, and N is the estimated of the flow of vehicles through the road segment during the collection period. When a vehicle reaches the end of a road segment, it estimates k and N. The sample size k is computed by probes based on the central limit theorem, and N is estimated by Greenshields speed-flow model. After computing the k and N, the probe vehicle transmits the traffic record to the TIC with probability $p = k / N$. Compared with the threshold method, this method generates more accurate traffic information and lowers the communication cost. However, Greenshields model is suitable for highway road segments, but unsuitable for urban roads.

III. The System Design

Our TIS design is based on the reporting threshold model, but instead of broadcasting the average travel time of each road segment, we broadcast both the maximum and the minimum travel times, i.e., we monitor the probes that travel faster or slower than the average probes. In addition, we consider the current trend of the changing traffic condition in generating the maximum and the minimum travel times that we broadcast. We will show that this monitoring approach can reduce the number of reports sent by the probes, and this implies that the broadcasted traffic information is more accurate.

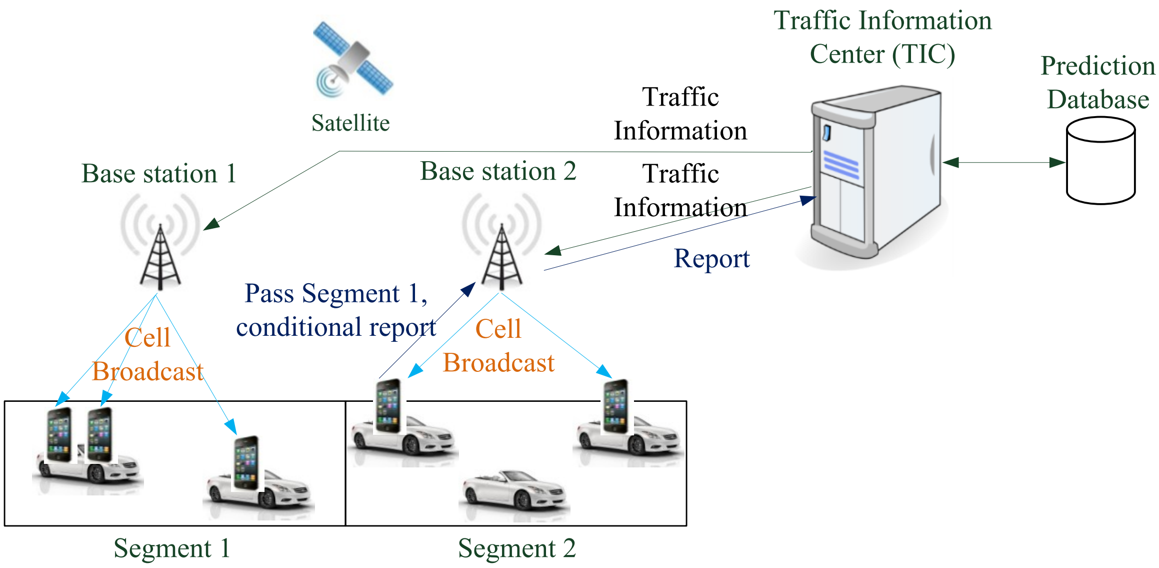

Fig. 1. The System Architecture

Fig. 1 depicts our system architecture. Our system consists of two types of components: a Traffic Information Center (TIC) and Probe Cars (PCs). The TIC is a centralized server, which receives the traffic reports from probe cars and generates the traffic information for each road segment. In our system, a road segment is defined as the roads between two major intersections in the road network. PCs are general vehicles with people on-board carrying smart phones equipped with Global Position System (GPS) receiver and wireless communication ability, and installed with our traffic information reporting application. The smart phones receive the maximum and the minimum travel times of the traveling road segment from the TIC, and measure the traffic condition. After the smart phones passed the road segment, they send reports to the TIC if reporting conditions are met. So, there is a close-loop feedback in our system. Probe cars report their traveling data to the TIC, and based on the reports the TIC predicts the traffic information broadcasting to the probe cars.

3.1 The Maximum and Minimum Travel Times

Before we design our TIS, we have used traffic simulation software to simulate traffic congestion on urban roads. Fig. 2 shows the change of travel time in one of our computer simulations. In this experiment, the simulation time is 3 hours, and the simulated road segment is 1.6 km long. The initial input traffic flow is 1800 vehicle/hr. The input traffic flow starts to increase at simulation time 1 hour, and keep increasing at a rate of 200 vehicle/hr. every 5 minutes until simulation time 1.5 hours when the largest flow is 3000 vehicle/hr. The input traffic flow starts to decrease at simulation time 1.5 hours at a rate of 200 vehicle/hr. every 5 minutes until the simulation time 2 hours, and back into the initial flow of 1800 vehicle/hr. in the last hour. The traffic light cycle is 120 seconds. We record the maximum, minimum and the average travel times of the vehicles passing the road segment in each traffic light cycle. Each vertical stick represents the range between the maximum and the minimum travel times, and the short horizontal bar on the stick represents the average travel time. In the congestion period, we can find that the average travel time of the segment is roughly equal to the mean of the maximum and the minimum travel times. From this simulation, we can observe that it is possible to estimate the average travel time from the maximum and the minimum travel times. We also found that the difference between the maximum and the minimum travel times is within a stable range for plurality data; we call this range Δ. Based on the statistics, the value falls in 40s to 125s, i.e.

the maximum difference between the maximum travel time and the minimum travel time in a traffic light cycle would not be larger than 125s, and the minimum difference would not be smaller than 40s. We can use this feature to adjust the predicted maximum and minimum travel times.

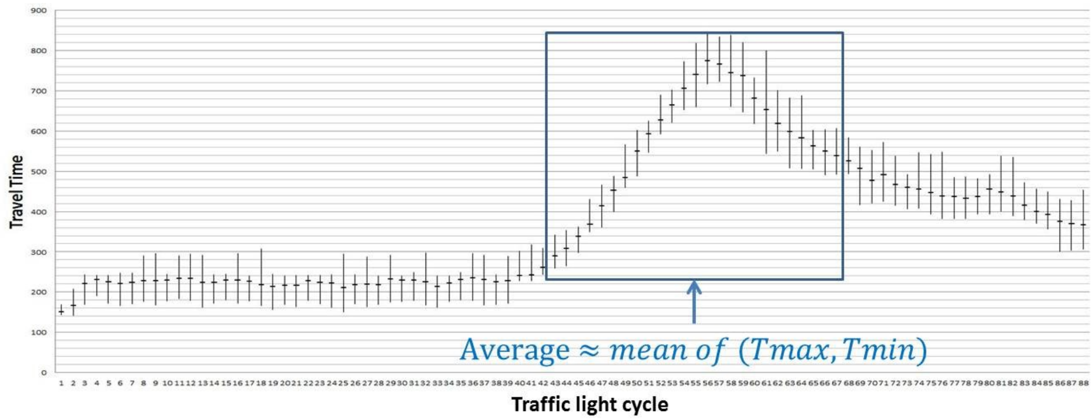

Fig. 2. The maximum, minimum and average travel time during traffic congestion.

3.2 The System Operations

The goal of our system design is to reduce the number of traffic reports that PCs send to the TIC, while maintaining the accuracy of the traffic information broadcasted by the TIC. To achieve the goal, PCs adopt a conditional report policy, i.e., PCs send reports only when certain conditions are met. In our system, the TIC would broadcast the predicted maximum travel time (denoted T_{max-p}) and the predicted minimum travel time (denoted T_{min-p}) of each road segment. When a PC travels through a road segment, the PC compares its travel time (denoted T_{PC}) with the maximum travel time and the minimum travel time broadcasted by the TIC. The PC sends a report containing the traveled segment and the travel time to the TIC when $T_{PC} > (1-\alpha)*T_{max-p}$ or $T_{PC} < (1+\beta)*T_{min-p}$, where α and β are small percentages, i.e., only the PCs that travel faster or slower than the average are required to report. In this way, we can monitor the changes of the maximum and the minimum travel times that PCs take on a road segment. Compared with the conventional TISs where PCs report periodically or when passing a road segment, this conditional report policy would reduce the number of reports sent to the TIC when there are a large number of PCs on the road network.

Second, to further reduce the number of reports sent by the PCs while maintaining the accuracy of the traffic information broadcasted by the TIC, the TIC generates T_{max-p} and T_{max-p} based on the trend of the changing traffic condition. For example, when the TIC detects that the traffic speed is slowing down; the TIC would predict larger T_{max-p} and T_{min-p}, so that it would keep receiving the reports of travel times from PCs that travel faster or slower than the average. Otherwise, the TIC may not receive the reports from PCs whose travel time is shorter than T_{min-p} because the traffic is slowing down.

Last, since the travel time prediction based on the trend of the changing traffic condition could be wrong, so that there is no report from PCs travel faster than $(1+\beta)*T_{min-p}$ or slower than $(1-\alpha)*T_{max-p}$. The TIC would detect this problem and modify the T_{max-p} or T_{max-p} accordingly. The modification process may repeat a couple of cycles before the respective reports of travel time are received by the TIC.

3.3 The Algorithm of the Probe Car

Our probe car is designed to be an event-triggered system. Table 1 lists the notations used in the probe car system. The events that a PC system needs to handle can be classified into three cases: (1) when a PC entering a pre-defined road segment, (2) when a PC receives Traffic Information (TI, i.e., T_{max-p} and T_{min-p}) broadcasted by the TIC, and (3) when a PC passes through a pre-defined road segment. Figs. 3-5 describe the flow charts of the three events in our PCs system.

Table 1. Notations used in the probe car system.

Notation	Definition
T_{PC}	The travel time of the probe car passing a segment.
T_{max_p}	The predicted maximum travel time of a segment provided by the TIC.
T_{min_p}	The predicted minimum travel time of a segment provided by the TIC.
α	The margin threshold to report T_{max}.
β	The margin threshold to report T_{min}.

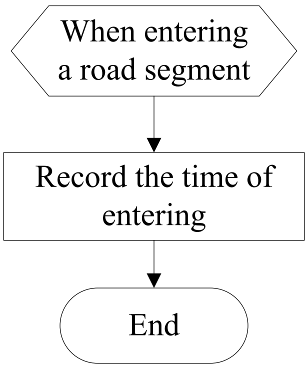

Fig. 3. The flow chart when a PC enters a road segment.

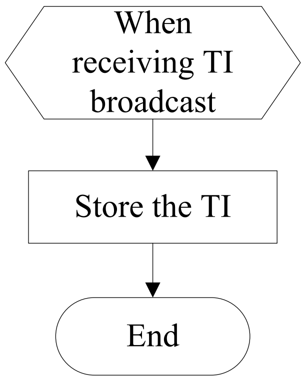

Fig. 4. The Flow chart of when a probe car receives broadcasted TI.

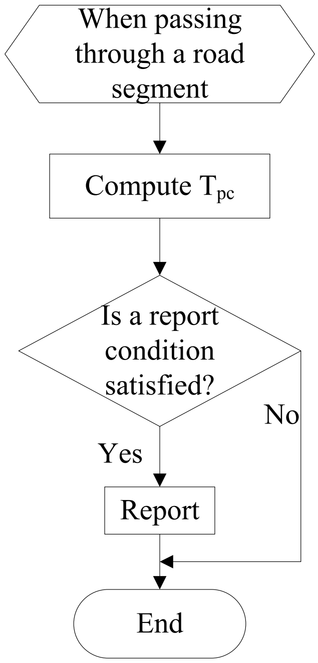

Fig. 5. The Flow chart when a probe car passed through a road segment.

In traveling, a probe car constantly checks whether it has passed a road segment's entry point or not by using the probe car's on-board segment database. If the probe car detects that has passed a segment's entry point (see. Fig 3), it will record the current times as the segment entering time. As depicted in Fig. 4, when a PC receives the broadcasted TI, the PC would store and update the TI in its database; the TI is composed of T_{max_p}, T_{min_p}, α, and β. When a PC passes through a road segment (see Fig. 5), the PC would first compute the segment travel time (T_{PC}) by using the current time minus the entering time. Then, the PC compares T_{PC} with the T_{max_p} and T_{min_p} to check if $T_{PC} > (1\text{-}\alpha)*T_{max\text{-}p}$, or $T_{PC} < (1+\beta)\ T_{min\text{-}p}$. If one of the conditions is satisfied, then the PC report T_{PC} as T_{max} or T_{min} to the TIC. Otherwise, the PC does nothing.

3.4 The Algorithm of the Traffic Information Center

Based on the reports received in each traffic light cycle, the TIC would generates the predicted T_{max_p} and T_{min_p}.,The TIC is also designed to be an event-triggered system. Table 2 lists the notations used in our TIC system. The events that the TIC system needs to handle are: (1) when receiving T_{max} (T_{min}) report, and (2) when a traffic light cycle ends. The Figs. 7-8 describe the flow chart of the two events in our TIC system.

Table 2. Notations used in the TIC system.

Notation	Definition
T_{max}	The report value of the maximum travel time
T_{min}	The report value of the minimum travel time
adoption_flag	A flag indicating whether the report is adopted by the TIC or not
significant_change	A flag indicating that the report has a significant difference with the prediction value
steadyArg	A threshold for determining the trend is steady or not (= 0.05)
γ	A parameter for calculating the prediction value, (= 1/3)
AdjustArg	A parameter for modifying the prediction value, (= 0.04)
Δ	The suitable range for the difference of T_{max_p} and T_{min_p}, (= 40 - 125s)

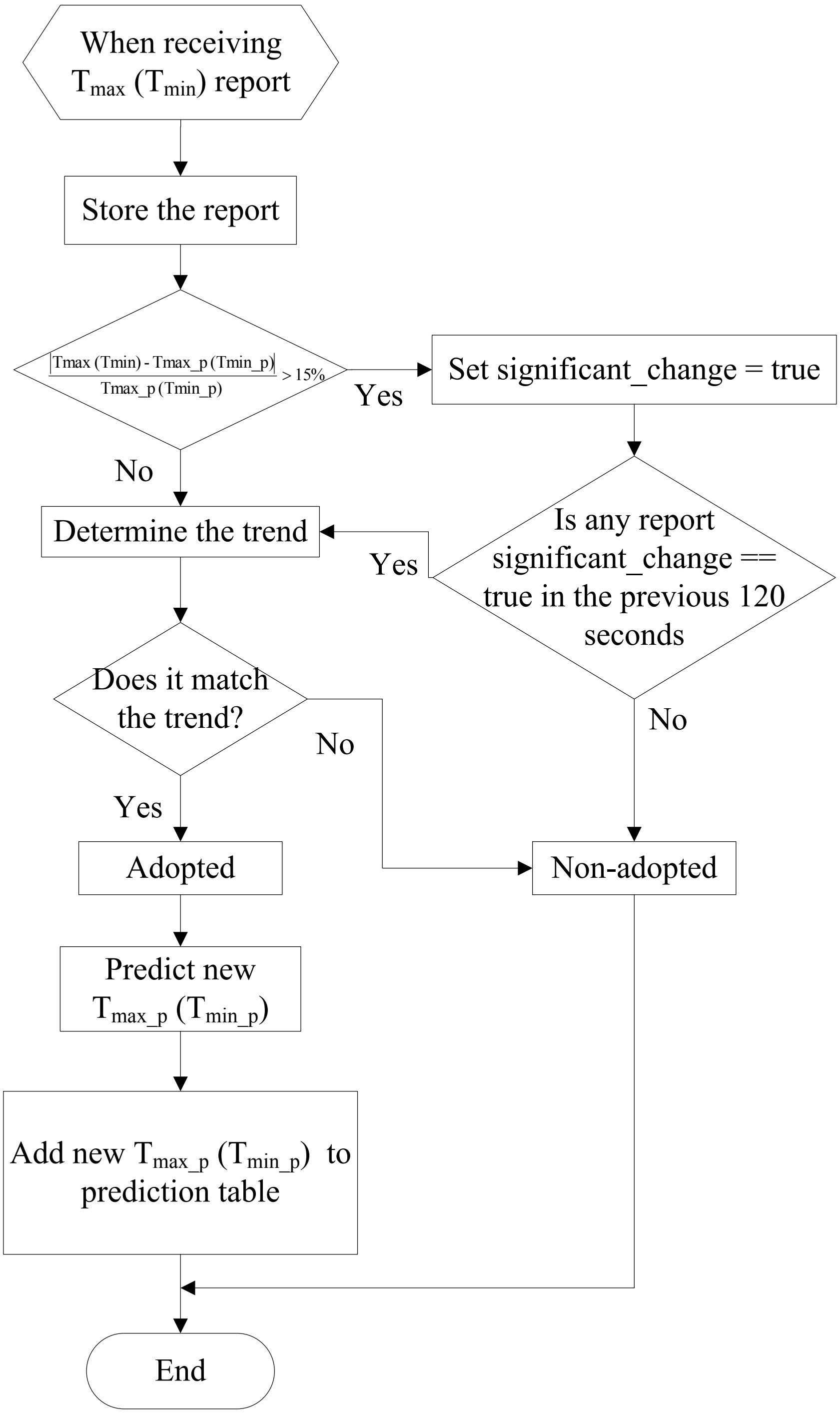

Fig. 7. The flow chart of the TIC when receiving T_{max} (T_{min}) report.

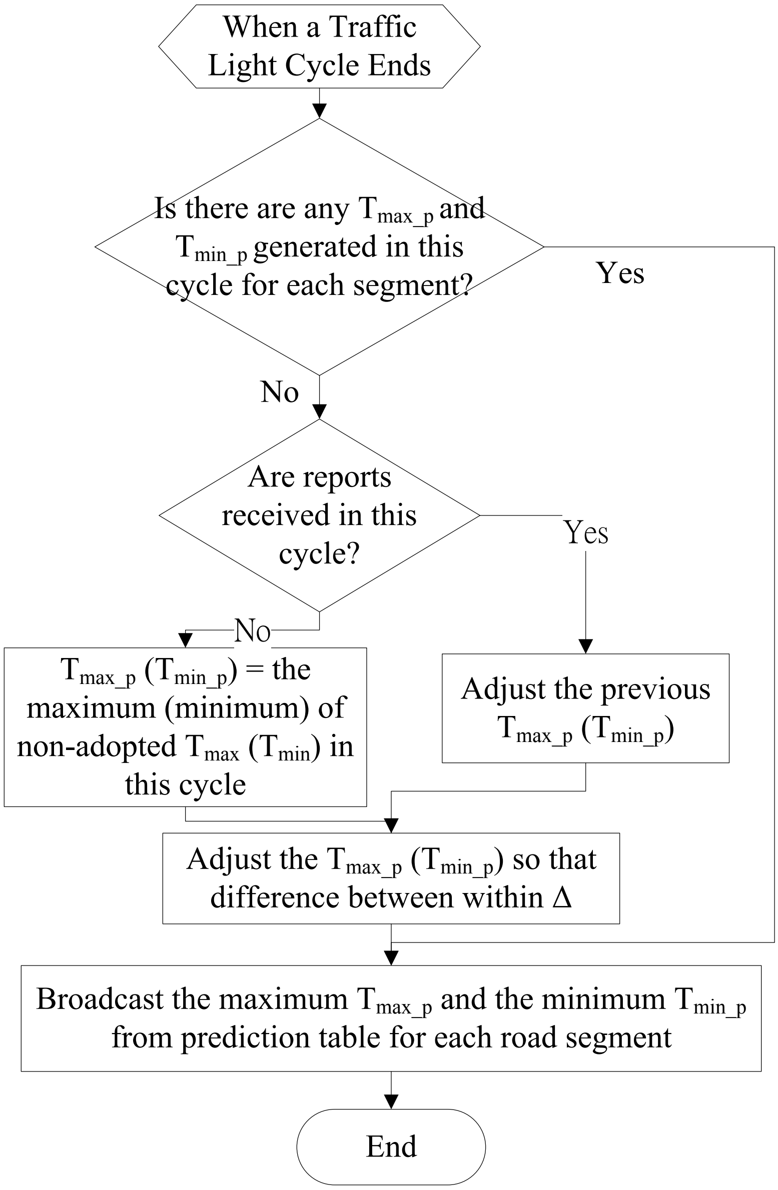

Fig. 8. The flow chart of the TIC when a Traffic Light Cycle ends.

Fig. 7 describes the flow chart when the TIC receives a T_{max} (T_{min}) report. When the TIC receives a T_{max} (T_{min}) report, it first checks the report information (i.e. segment ID, T_{max} or T_{min}) and then stores the report in the corresponding report table. In our TIC system, each road segment has its own report table for storing T_{max} and T_{min} reported by PCs. Then, the TIC checks if the T_{max} (T_{min}) is of significant change of 15 percent by comparing with the broadcast value. If so, The TIC sets a flag called *significant_change* true, and checks if there is another report of significant change in the previous 120 seconds. If not, the TIC would not adopt the report and sets the report's *adoption_flag* false. Otherwise, it goes on to determine trend procedure. In this step, the TIC rejects an isolated report of significant change.

To determine the changing trend of traffic condition, the TIC computes four factors based on the reports of each traffic light cycle as follows,

$$
\begin{aligned}
&M\_max = \text{The maximum of } T_{max} \\
&M\_avg = \text{The average of } T_{max} \qquad (1) \\
&m\_min = \text{The minimum of } T_{min} \\
&m\_avg = \text{The average of } T_{min}
\end{aligned}
$$

Then, the TIC divides the four factors of the current cycle divides by those of the previous two cycle (e.g.$\frac{M\_\max(T)}{M\_\max(T-2)}$, T denotes the current cycle), respectively, to obtain four trend factors. A threshold, *steadyArg*, is used to determine the trend of each trend factor; the trend may be rising, declining or stable. If a trend factor is larger than (1+ *steadyArg*), it indicates a rising trend. If it is smaller than (1- *steadyArg*), a declining trend. Otherwise, it is a stable trend. After that, the final trend is determined by the majority vote of the four trend factors.

After the TIC determines the trend, it checks whether the current report matches the trend or not. If the report matches the trend, the TIC adopts this report, and vice versa. The conditions of adopting a report are in Table 3. A T_{max} report is adopted during a rising or stable trend, if it's the maximum of all T_{max} in the previous 120 seconds (the length of a traffic light cycle), but it is adopted immediately during a declining trend. A T_{min} report is adopted during a declining or stable trend, if it's the minimum of all T_{min} in the previous 120 seconds, but it is adopted immediately during a rising trend. The TIC also sets the report's *adoption_flag* if the report is adopted. If the report is adopted, the TIC goes on to prediction procedure.

Table 3. The conditions of adopting a report.

Adoption table			
Condition	Rising Trend	Declining Trend	Stable Trend
T_{max}	The maximum value in 120 seconds	Adopt immediately	The maximum value in 120 seconds
T_{min}	Adopt immediately	The minimum value in 120 seconds	The minimum value in 120 seconds

In the prediction procedure, the TIC uses the average factor related to the report type (i.e. *M_avg* for a T_{max} report and *m_avg* for a T_{min} report to generate the predicted $T_{min\text{-}p}$ or $T_{min\text{-}p}$ as follows.

$$T_{max\ \_P} = T_{max} + (M\_avg(T) - M\_avg(T-2) * \gamma \qquad (2)$$

$$T_{min\ \_P} = T_{min} + (m\_avg(T) - m\_avg(T-2) * \gamma$$

If *M_avg*(T-2) or *m_avg*(T-2) factor is not available, then the predicted value will be the reported T_{max} (T_{min}). After that, the TIC adds the T_{max_p} (T_{min_p}) to the corresponding prediction table with the current timestamp.

Fig. 8 shows the operation flow chart of the TIC when a traffic light cycle ends. In this event, the TIC first checks if there are any T_{max_p} and T_{min_p} generated in this cycle for each segment. If so, the TIC broadcasts the maximum of T_{max_p} and the minimum of T_{min_p} generated in this cycle for each segment. If not, the TIC checks if there are any reports received in this cycle. If so, the TIC set the new T_{max_p} (T_{min_p}) to be the maximum (minimum) of the non-adopted T_{max} (T_{min}) in this cycle. If there is no report in this cycle, then the TIC adjusts the previous prediction with an *AdjustArg*. In adjusting T_{max_p}, the TIC multiplies the previous T_{max_p} with (1- *AdjustArg*), and in adjusting T_{min_p}, the TIC multiplies the previous T_{min_p} with (1+ *AdjustArg*). After generating the new T_{max_p} (T_{min_p}), the TIC uses Δ to adjust the generated value to ensure that the difference of T_{max_p} and T_{min_p} is in the suitable range. After that, the TIC broadcasts the new T_{max_p} and T_{min_p} generated above for each segment.

IV. Evaluation and Analysis

4.1 Simulation Environment

We use VISSIM [17], a traffic model simulator, to evaluate our TIC design. Fig. 9 depicts a simulated 6.8-km long urban main road, which is composed of 16 intersections with 16 branch roads. The 16 intersections evenly divide the main road into 17 small segments, each of which is 400 meters long. We collect traffic information for each 1.6-km long road segment, which is composed of 4 small segments, as the brown line (Segment 1) and the green line (Segment 2) depicted in Fig. 9. The vehicle flow will be input from the left side of the main road, and every branch also inputs vehicle flow into the main road. Starting from the entry of the main road, at every four branches, 60% of the vehicles on the outer lane of the main road make right turns to the branch. Other vehicles remain traveling on the main road.

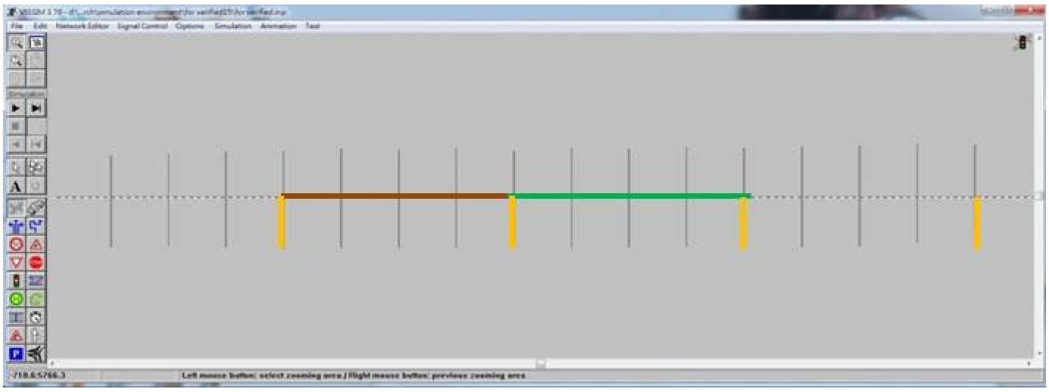

Fig. 9. A VISSIM simulator example.

We intended to simulate the traffic condition that reflects the entire period of traffic congestion. The simulated traffic flow changes from a smooth flow to a maximum flow and finally back to smooth. In the simulation, the input flow can be divided into 4 intervals: (1) a smooth flow for 1 hour, (2) increasing the flow for 30 minutes with a flow rise every 5 minutes, (3) decreasing the flow for 30 minutes with a flow decline every 5 minutes, (4) a smooth flow for 1 hour. We have simulated 3 flow settings: light, moderate and heavy traffic flows. Table 4 shows the simulation parameters used in our simulation, and Table 5 shows the traffic flow for each setting.

Table 4. Parameters used in the simulation.

Total road length	6.8 km		
Number of lanes	3		
Number of segments	2		
Vehicle composition	10% probe cars, 88% regular cars, 2% vans		
Desired speed	Car: 40 - 60 kph (uniformly distributed)		
	Van: 40 - 45 kph (uniformly distributed)		
Simulation time	3 hr		
Traffic light cycle (120 seconds)	Green	Yellow	Red
Main road	65 s	5 s	50 s
Branch	45 s	5 s	70 s

Table 5. Traffic flow setting for the 3 environments

Traffic flow	Smooth flow	Maximum flow
Light	1800 veh/hr	2000 veh/hr
Moderate	1800 veh/hr	2500 veh/hr
Heavy	1800 veh/hr	3000 veh/hr

At the end of the simulation, VISSIM generates a file containing the location records of the simulated cars. Each record consists of the simulation time, the ID of a car and the car's location. The location records of probe cars are used as inputs to the emulation program of the probe cars.

4.2 Evaluations

We use Java programming language to develop an emulation program that implements the functions of our probe cars and the TIC; we called the emulation program TIS_Emu. We input the location records generated by VISSIM to TIS_Emu, and TIS_Emu generates reports to the TIC for each probe car, and T_{max_p} and T_{min_p} based on the probe cars' reports for the TIC.

To evaluate the performance of our system, we first check if the T_{max_p} and T_{min_p} predicted by the TIC match the change of the traffic. Figs. 10-12 plot the travel times of all vehicles and the predicted T_{max_p} and T_{min_p} against the simulation time. Each blue square dot represents a general vehicle's travel time, and each orange square dot represents a probe car's travel time. A red square represents a T_{max_p} and a green circle represents a T_{min_p} generated by the TIC. Fig. 10 plots the results of the light traffic flow setting (see Table 5), Fig. 11 plots the results of the moderate flow setting and Fig. 12 plots the results of the heavy flow setting. We can see that in every setting of flow, the predicted T_{max_p} and T_{min_p} generated by the TIC follow the traffic trends properly.

For the light traffic flow (see Fig. 10), the travel times are divided into three groups, with most of the vehicles in the middle group and very few vehicles on the upper group. The predicted T_{max_p} remains at the top of the middle group for both segments 1 and 2. Note that at simulation time about 4200, 6600, and 7500 seconds, there are three isolated T_{max} of significant change, which do not affect the predicted T_{max_p}. We can see in both segment 1 and segment 2, the T_{min_p} fluctuates around the lower group. The reason is that the volume of vehicles in the lower group is too small and the limited sampling of the 10% probe cars may not fall in the lower group for every cycle, which leads to no T_{min} report. In this case, the TIC modified the T_{min_p} by multiplying it by (1+*AdjustArg*) with the constraint that the difference between T_{min_p} and T_{max_p} must fall in the range of Δ. Therefore, T_{min_p} fluctuates but remains in the lower group.

Fig. 10. The travel times, T_{max_p} and T_{min_p} at the light traffic flow.

For the moderate traffic flow (see Fig. 11), T_{max_p} catches the change of the maximum travel time. We can observe that in the congestion worsening period (during simulation time 5000 to 7000 sec.), there is no T_{min} report, but T_{min_p} is properly adjusted by the T_{max} reports. In contrast, during the congestion relieving period, there is no T_{max} report, but T_{max_p} is properly adjusted by the T_{min} reports. For the heavy traffic flow (see Fig. 12), the results are similar to those of the moderate traffic flow setting.

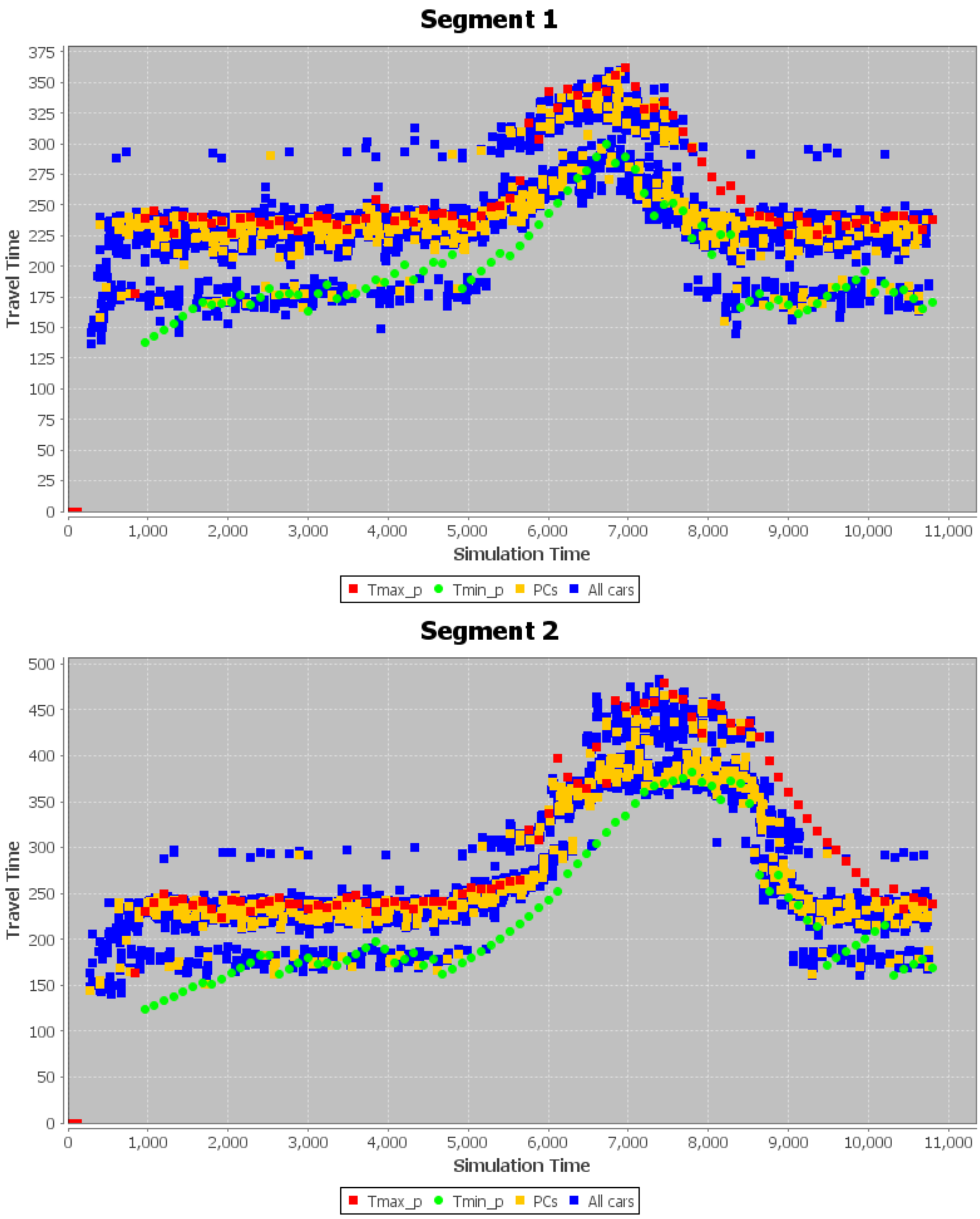

Fig. 11. The travel times, T_{max_p} and T_{min_p} at the moderate traffic flow

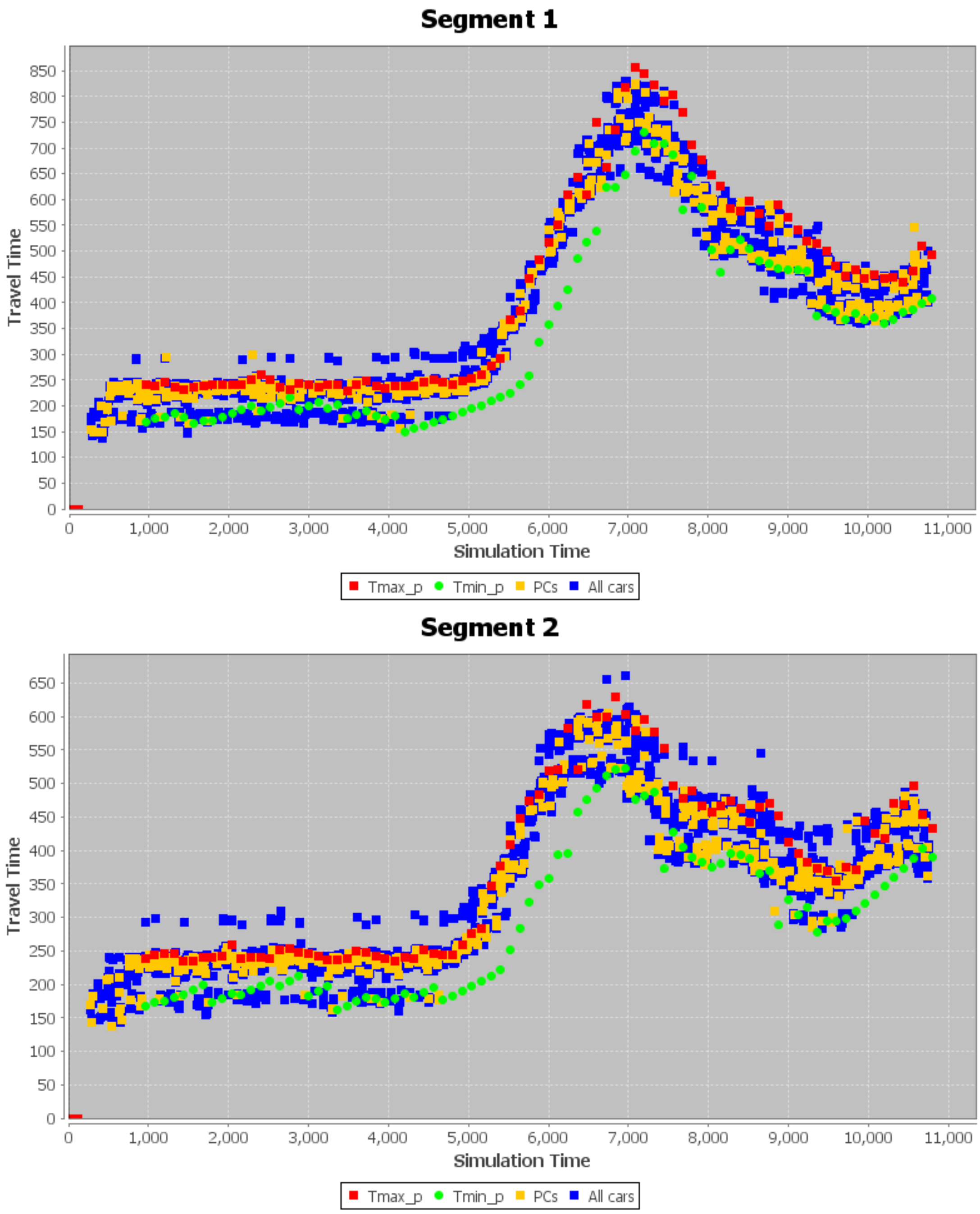

Fig. 12. The travel times, T_{max_p} and T_{min_p} at the heavy traffic flow.

Second, we evaluate the accuracy of the predicted T_{max_p} and T_{min_p} in our design. A predicted T_{max_p} (T_{min_p}) is compared with the maximum (minimum) travel time of all vehicles passing the segment after the predicted T_{max_p} (T_{min_p}) is broadcasted and before the next predicted T_{max_p} (T_{min_p}) is broadcasted. The prediction error of T_{max_p} (T_{min_p}) is defined to be the absolute error between the predicted T_{max_p} (T_{min_p}) and the maximum (minimum) travel time of all vehicles.

For all vehicles' experience, we count the number of vehicles that travel longer than the latest broadcasted T_{max_p} and the number of vehicles that travel sooner than the latest broadcasted T_{min_p}. In addition, we compute the Mean Absolute Error (MAE) between each vehicle's travel time and the mean of the latest broadcasted T_{max_p} and T_{min_p}. For each flow setting; we simulate with 10 different random seeds and average the 10 simulation results.

Tables 6-8 list the accuracy of the TIC's predictions for each traffic flow setting. The simulation results indicate that the prediction errors of T_{max_p} and T_{min_p} are about the same for both segments and for all three traffic flow settings. The MAE in percentage of T_{max_p} fall in the range from 8.5% to 11.2%, and that of T_{min_p} from 9.3% to 11.2%. For all vehicles' experience, 20-23% of the vehicles experience a travel time longer than T_{max_p}, and 5-12% experience a travel time shorter than T_{min_p}. Although the prediction errors of T_{max_p} and T_{min_p} are about the same, more vehicles experience a travel time larger than T_{max_p}. This does not imply poorer predictions for T_{max_p}. With 20% of the vehicles whose travel time is longer than T_{max_p} and only 10% of them are probe cars, we would expect 2% of all vehicles reporting T_{max} to the TIC. This enables the TIC to predict T_{max_p} from the reports. By contrast, we have fewer vehicles reporting T_{min}. In particular, during the traffic congestion worsening period, we have almost no T_{min} report, because T_{min_p} is under-estimated. The TIC can only adjust T_{min_p} from T_{max_p}. The MAE of using the mean of T_{max_p} and T_{min_p} to predict the average travel time is in a range of 27-39 sec. or 11-13% in percentage.

We also compute the communication overhead of our system. Tables 9-11 list the communication overhead for each traffic flow setting. We count the numbers of T_{max} reports, T_{min} reports and broadcast messages (BMs). The total number of PCs passing segment 1 or 2 is about 1000 for each flow setting. About 200 PCs send T_{max} reports and 100 PCs send T_{min} reports. This indicates that we reduce the number of reports by 67% to 72%, compared with the segment-based report approach. Since the TIC broadcasts the traffic information every traffic light cycle, in three hours, TIC only broadcast 180 times for 2 segments.

Table 6. Prediction accuracy for flow setting 1 (light).

Prediction Error (error percentage)			
	T_{max_p}		T_{min_p}
Segment 1	26.4 sec. (9.5%)		15.7 sec. (9.4%)
Segment 2	30.3 sec. (10.9%)		16.1 sec. (9.3%)
All Vehicles' Experience			
	The number of vehicles > T_{max_p}	The number of vehicles < T_{min_p}	Travel time error
Segment 1	1210 (22.0%)	387 (7.0%)	29.8 sec. (13.4%)
Segment 2	1300 (21.9%)	330 (5.3%)	27.2 sec. (12.3%)

Table 7. Prediction accuracy for flow setting 2 (moderate).

Prediction Error (error percentage)			
	T_{max_p}		T_{min_p}
Segment 1	29.0 sec. (9.9%)		20.3 sec. (10.9%)
Segment 2	32.1 sec. (10.1%)		24.9 sec. (11.2%)
All Vehicles' Experience			
	The number of vehicles > T_{max_p}	The number of vehicles < T_{min_p}	Travel time error
Segment 1	1162 (20.1%)	521 (9.1%)	30.97 (13.0%)
Segment 2	1232 (20.0%)	570 (9.2%)	31.77 (11.9%)

Table 8. Prediction accuracy for flow setting 3 (heavy).

Prediction Error (error percentage)		
	T_{max_p}	T_{min_p}
Segment 1	33.1 sec. (8.5%)	31.8 sec. (10.3%)
Segment 2	34.6 sec. (9.5%)	30.8 sec. (10.8%)

All Vehicles' Experience			
	The number of vehicles > T_{max_p}	The number of vehicles < T_{min_p}	Travel time error
Segment 1	1302 (23.0%)	678 (11.9%)	39.3 sec. (12.1%)
Segment 2	1295 (21.3%)	631 (10.6%)	34.4 sec. (11.1%)

Table 9. Communication overhead for flow setting 1 (light).

Communication Overhead				
The number of PCs	The number of T_{max} reports	The number of T_{min} reports	The percentage of reports reduced	The number of BMs
990.3	205.2	73.4	72%	180

Table 10. Communication overhead for flow setting 2 (moderate).

Communication Overhead				
The number of PCs	The number of T_{max} reports	The number of T_{min} reports	The percentage of reports reduced	The number of BMs
1041.6	195.7	110.3	71%	180

Table 11. Communication overhead for flow setting 3 (heavy).

Communication Overhead				
The number of PCs	The number of T_{max} reports	The number of T_{min} reports	The percentage of reports reduced	The number of BMs
1021.9	213.5	125.6	67%	180

Last, we investigate the effects of the penetration rate of the probes. We simulate the three flow settings with various penetration rates of probes equals, 2.5%, 5%, 10%, 20% and 40%. We compare the prediction error, the travel time error, the number of reports and the percentage of reports reduced. The results are depicted in Figs. 13-16.

Figs 13 and 14 indicate that when the penetration rate of probes increases, both the prediction error and the travel time error decrease slightly. We also simulate two settings of α and β, $\alpha = 0, \beta = 0$ and $\alpha = 0.04, \beta = 0.04$. The results in Fig. 13 and 14 indicate that for the two settings of α and β, the prediction error and the travel time error are about the same. Fig. 15 shows that as the penetration rate of probes increases, the number of reports increases significantly. In addition, the rising slop of the red line ($\alpha = 0.04, \beta = 0.04$) is much bigger than the blue line ($\alpha = 0, \beta = 0$). The results in Fig. 16 indicate that as the penetration rate of probes increases, the percentage of the reduced reports increases, and the reduced reports of blue line ($\alpha = 0, \beta = 0$) is much larger than that of the red line ($\alpha = 0.04, \beta = 0.04$).

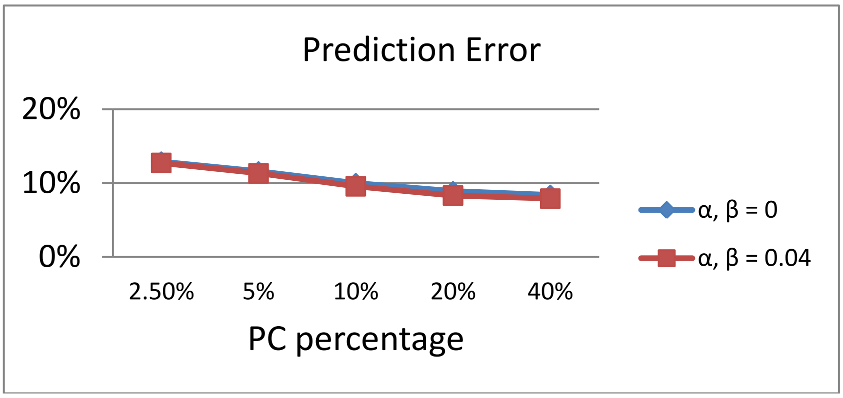

Fig. 13. The prediction errors for different penetration rates of probes.

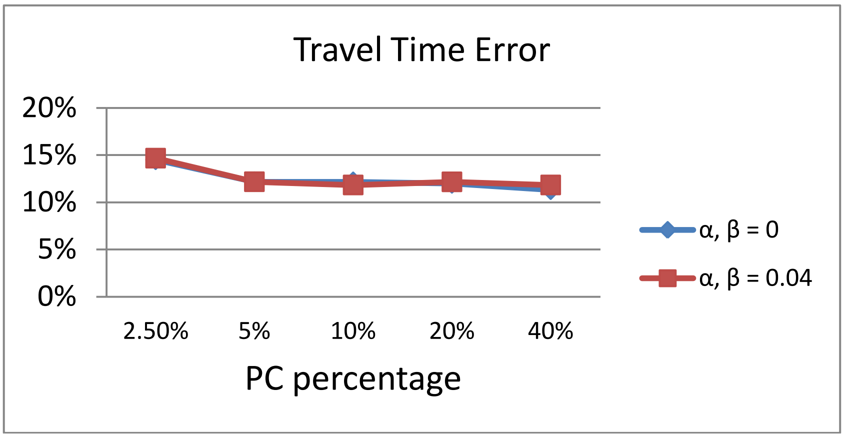

Fig. 14. The travel time errors of different penetration rates of probes.

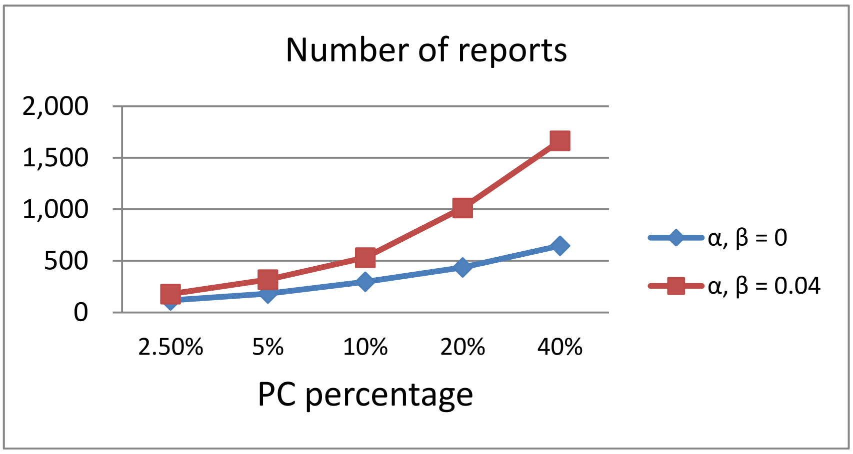

Fig. 15. The number of reports for different penetration rates of probes.

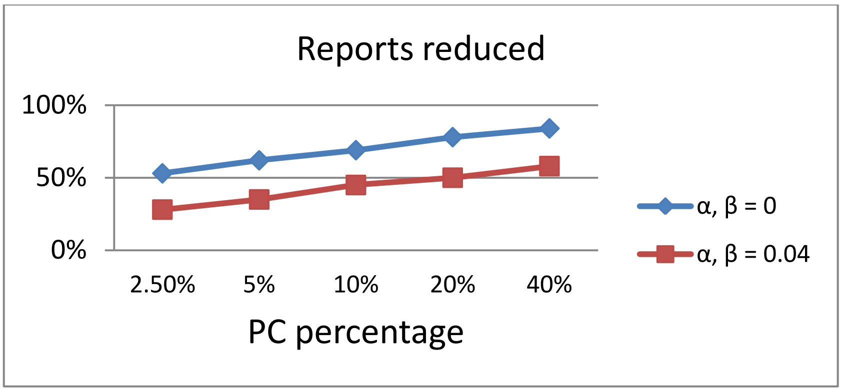

Fig. 16. The reports reduced for different penetration rates of probes.

V. Conclusions

In this report, we propose a FCD-based traffic notification system that addresses the issue of reducing communication requirements. The system consists of a centralized traffic information center (TIC) and a group of probe cars (PCs). The PCs can be general vehicles with people on-board carrying smart phones equipped with Global Position System (GPS) receiver and wireless communication ability, and installed with our traffic information reporting application. In our system, the TIC generates and broadcasts the predicted maximum and minimum travel time of a road segment to PCs periodically. In the conventional FCD-based TIS, the PCs send reports to the TIC periodically or when a road segment is traveled. In our system, only PCs that travel near the maximum or the minimum travel times are required to send reports. We have performed computer simulations to evaluate our design. The simulation results indicate that our approach reduced the number of reports by 70% in average, compared with the conventional segment-based report policy. The prediction error of the maximum and minimum travel time on a road segment of 1.6 km is 10% in average. In addition, when using the mean of the maximum and the minimum travel times as the average travel time, the estimation error of the average travel time compared with the all vehicles' average is 12.3%.

In our system, the TIC needs to broadcast the traffic information periodically to the PCs. However, the broadcast function is not yet well supported by the public wireless networks, such as the UMTS, or by the vehicular communication networks, such as WAVE. Without the broadcast function, real-time traffic information cannot be efficiently delivered to all the PCs on the road network, new approaches for real-time traffic dissipation to PCs need to be studied.

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附件四

國科會補助專題研究計畫項下出席國際學術會議心得報告

日期：101 年 10 月 25 日

<table>
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<tr><td>出國人員姓名</td><td>張明峰</td><td>服務機構及職稱</td><td>交通大學 資訊工程系 教授</td></tr>
<tr><td>會議時間</td><td>101 年 3 月 26 日
至
101 年 3 月 29 日</td><td>會議地點</td><td>Fukuoka Institute of Technology
Fukuoka, Japan</td></tr>
<tr><td>會議名稱</td><td colspan="3">(中文)
(英文)The 26th IEEE International Conference on Advanced Information Networking and Applications</td></tr>
<tr><td>發表論文題目</td><td colspan="3">(中文)
(英文)Temporary Call-back Telephone Number Service</td></tr>
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一、參加會議經過

AINA-2012 國際會議於 101 年 3 月 26-29 日在福岡理工大學舉辦。除了 AINA 主會議之外，有多個並行 Workshops。AINA 安排三個平行 sessions，加上其他並行 workshops，同時有 8 個 sessions 進行。會議安排三個 Keynote speech: Choichi Noguchi 教授探討日本福島震災後，通訊網路系統受到嚴重損害的狀況，及其後復原過程中學到的經驗，做為日後設計高可靠度資訊與通訊系統設計的規範。David Taniar 教授介紹在日益龐大的資料庫系統中，如何利用網格計算環境，提昇平行處

理效能。Fatos Xhafa 教授介紹在 P2P 集體合作的系統中，資料複製與同步的複雜度，及其解決方案。

我的論文發表第二天上午 AINA-S4B: Communication Systems。論文題目是”Temporary Call-back Telephone Number Service.”介紹一種新穎的臨時電話號碼服務，採用三個欄位之電話號碼轉換表，給予服務使用者一或多個臨時電話號碼，其每一臨時電話僅可供該使用者指定之一或多個電話網路用戶撥打此一臨時電話號碼，以和該使用者建立通話連線。非指定之電話用戶撥打此一臨時電話號碼，並不能和該使用者建立通話連線。同一臨時電話號碼可以同時由多個服務使用者使用；不同使用者，只要通訊的對象不同，即可同時使用同一臨時電話號碼。如此，可大幅降低系統所需臨時電話號碼的總數。此外，回收臨時電話號碼的老化問題也大幅降低，因為一服務使用者之臨時號碼只指定給單一或少數的通訊對象。論文發表後，有法國電信公司的研究員對此設計感興趣，雙方就此設計的優點與限制交換意見。

二、與會心得

AINA 是個大型國際會議，參加的成員來自世界各國，大半都是較年輕的學者或研究生。會議安排多個平行 sessions，發表各個資訊與網路應用的主題，涵蓋範圍非常廣泛，聽講的選擇性很多，可以了解各領域的最新發展。會議中以 Cloud Computing 與 Social Network Application 相關議題較多與會者參與討論。會議安排的 Ketnote 內容都相當引人，讓我學到新的知識。會中巧遇本系同仁林盈達教授，他介紹一位任 IEICE 期刊的主編，談論期刊投稿審查，以及提升期刊影響係數的方法。對我而言，算是增廣見聞。

三、考察參觀活動(無是項活動者略)

四、建議

五、攜回資料名稱及內容

1. AINA 2012 議程表.

2. AINA 2012 論文集光碟.

3. WAINA 2012 論文集光碟.

國科會補助計畫衍生研發成果推廣資料表

日期:2012/10/30

國科會補助計畫	計畫名稱: 利用智慧型手機以詢問回覆機制收集即時交通路況之設計與評估
	計畫主持人: 張明峰
	計畫編號: 100-2221-E-009-108-　　　　學門領域: 計算機網路與網際網路

無研發成果推廣資料

100 年度專題研究計畫研究成果彙整表

計畫主持人：張明峰			計畫編號：100-2221-E-009-108-				
計畫名稱：利用智慧型手機以詢問回覆機制收集即時交通路況之設計與評估							
成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	2	2	100%		侯羽豪,碩士論文,’’The Design of a Traffic Information System for Reducing Reports from GPS-equipped Probes.’’ 魏睦倫,碩士論文,’’The Design of Traffic Report System for Highway Congestions with GPS-equipped Probe Cars.’’
		研討會論文	0	0	100%		
		專書	0	0	100%		
	專利	申請中件數	1	1	50%	件	中華民國專利申請,’’報告行車時間之交通通告系統’’
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	3	3	100%	人次	
		博士生	1	1	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	0	1	0%	篇	投稿中
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	1	1	50%	件	US patent application,’’Traffic Notification System for Reporting the Travel Time.’’
		已獲得件數	0	0	100%		

	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)		無					

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：□已發表 ■未發表之文稿 □撰寫中 □無

專利：□已獲得 □申請中 ■無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

提供用路人即時交通資訊可避過塞車、節省行車時間及能源消耗。由於智慧型手機裝載 GPS 接收器與無線資料傳輸技術且逐漸普及，利用智慧型手機作為 GPS 探偵車回報車速，取得即時交通資訊成為可行的方式。相對於傳統固定式車輛偵測器而言，GPS 探偵車大幅降低佈建與維護成本。然而目前 GPS 探偵車的回報方法可分為：固定週期回報或是固定地點回報，無論是哪種，皆會造成回報資訊超載的問題，若使用條件式回報可降低回報量，但傳統的條件式回報方式交通資訊中心不易計算出精確之平均旅行時間。本計畫提出交通資訊中心提供下個交通號誌週期之最大旅行時間與最小旅行時間給 GPS 探偵車，探偵車根據收到的資料與自身旅行資料相比做選擇性回報，能有效降低交通資訊回報次數和成本，並掌握精確的交通資料。我們使用運輸模擬軟體 VISSIM 進行實驗模擬。模擬結果證實，我們所提供的資料的方法減少 70%探偵車回報之數量，減輕交通資訊中心之負載。而在最大及最小旅行時間的估計誤差約 10%，能精確掌握交通狀況之波動。此一成果相對於現有 GPS 探偵車的回報方法有顯著的改善，具有實用的價值。本計畫成果已申請中華民國及美國專利中。