International Journal of Control and Automation
Vol. 10, No. 1 (2017), pp.239-250
http//dx.doi.org/10.14257/ijca.2017.10.1.22

Analyzing of the Delay Model Using the Mobile Facility Vehicle Data at the Signalized Intersection

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Abstract

The paper describes the method of delay calculation based on mobile facility vehicle (MFV) information at the signalized intersection. Supposing the MFV was at the first, in the middle and at the last vehicle location in the queue, considering the MFV's data, using the cumulative curve method, the delay models were deduced under different conditions. Using the data from the isolated signal intersection in Chongqing, China, it proved that the average MAPE of the estimated delay is 10.05% when the MFV was in the middle location of the queue vehicles, and the values of MAPE are 28.42% and 28.81% when the MFV was at the first and last location separately.

Keywords*: signalized intersection; mobile facility vehicle; delay model; cumulative curve method.*

1. Introduction

Delay is one of the core parameters on evaluation of the intersection's level of service, and it reflects the comfortable degree of the drivers, too. Since Webster published the famous Webster delay model, it has been widely researched that delay can be deduced through the traffic flow, saturation flow, signal timing and other parameters.

Now, with the advanced detecting facility widely used in traffic parameters detection, more and more traffic researchers are focused on extracting higher precision delay values through the advanced detecting facilities. But the obstacles in delay extraction are both the high cost in installing the advanced facilities and the limitation of the relative subject development. So, one of the key question is how to balance the facility setting cost and the parameters extraction.

In this paper, the delay models were deduced using the information, such as location, speed and other data. This information have already gotten through the mobile facilities, such as the GPS installed on the vehicles or the smart phones that the passengers are holding, so there is no extra facility setting requirement. Considering the speed, three delay models were deduced according to the mobile facility location.

2. Literature Review

The signalized intersection delay model has been researched from 1950s. Webster published the land-marking paper that described the famous Webster delay model in 1958(1), and it has been widely used up to now. The model is used at the fixed signal intersection and the analyzing period is 15 minutes. The model's referring is based on the assumption that the vehicles' arrival is sequential, another parts in the formula are the delays for the vehicles' random arrive that was modified using the simulation method and adding empirical values. The model can be used well when the saturation is below 0.85.

ISSN: 2005-4297 IJCA

The formula has been improved for different traffic conditions since then. Miller deduced the delay model can be used when the saturation rate is below 1.0(2). Akcelik has inferred the delay model can be used both under normal conditions and over-saturation conditions (3). The formula described in HCM 2010 can be used at different saturations, different signal methods, different distances between the adjacent intersection and other factors (4). Other researchers have modified the model considering other conditions (5, 6). But these models can not get high precision for not using the real vehicles' arriving or departure information. Peter Wagner has proved that the error caused by the second part of Webster delay model can arrive 4-40% (7).

Recently, with the wide using of the advanced detector in traffic engineering, more and more researchers have explored the delay extracting new methods through the new information that the advanced detector detected. Anuj Sharma *et al*. developed the automated delay extract method using the video detector. They set two virtual detectors on the video and supposed that the vehicles between the two virtual detectors obey the rule of first-in-first-out, and then match the vehicles information, so every vehicle's travel time was recorded. Using the recorded travel time of the vehicle minus the travel time the vehicle spent using free speed, every vehicles delay was calculated(8). Jianyang Zheng *et al*. have used the probability method to get the approach delay through setting two virtual detectors (9). Ahmed researched the delay extracting method by setting three virtual detectors, they are set at the stop bar (named Event-3), a point that beyond the maximum queue length (named Event-X), and the beginning of the turning lane (named Event-1). They used the Boolean detector function to judge the vehicle's change behavior between Event-X and Event-1, then using the time stamp to get the travel time between the different Events during the time interval, subtracting the free flow speed time between the Events, the delay can be inferred (10). Chun Shao *et al*. used the Partition method to divide the studied time interval into several parts between the input and output detectors, then according to the time stamps of the two detectors and calculated the approach delay (11). In developing country, for the mixed traffic condition, the rules that the researchers made is unrealizable, the vehicle tracking method in the field of digital image process technology was used to extract delay parameters(13). Taylor *et al*. extracted the approach average vehicle delay using the logic infer method through the detectors setting at the input and output of the approach, and using VISSIM simulation data, the different conditions were analyzed, such as through, through lane with turning bay, through lane with a mid-block driveway and also with different traffic flows(14).

Steven *et al*. defined the maximum vehicle delay, and analyzed the distribution function of the first vehicle's arriving time (15). Some researchers have tried to use the LWR model in the intersection extraction (16). Wenqing Chen *et al*. analyzed the first vehicle's delay when the vehicle was guided by the dynamic speed control system, then using car-follow theory and algorithm methods to get other vehicles' delay (17). Xuegang (Jeff) Ban *et al*. got the probe vehicles travel time using the stamp times that the vehicles passed through the virtual detectors set on the approach, then used the LWR model to deduce the approach delay, and this method does not use the signal timing, traffic flow and other information(18). Qing Cai *et al*. deduced the queue length extracting method using the probe vehicle's information (19). Mecit Cetin *et al*. deduced the queue length extraction using the LWR model when there were probe vehicles in the queue vehicles at the under-saturation and over-saturation condition, separately(20,21). Moreover, the Bluetooth can provide the useful information and can be used in the parameters extraction at the signal intersection (22).

Using the mobile online information provided by many facilities that include the probe vehicle, smart phone, Bluetooth and others, the delay model can be modified. The models are deduced separately when the mobile facility is located at different positions, such as first, middle or last one in the queue.

3. Intersection Delay Model Construction and Analyzing

3.1. Basis of Delay Model

In the research, the beginning of the cycle is set at the beginning of a red indication, so the first vehicle must wait for a long time to drive pass the intersection when it's arriving at the intersection. And the following vehicles would stop at the approach and until the green indication began, the vehicles' arriving time can be fitted an arriving curve using cumulative curve method. The queued vehicles will depart the intersection with the saturation flow, as Figure 1 shown.

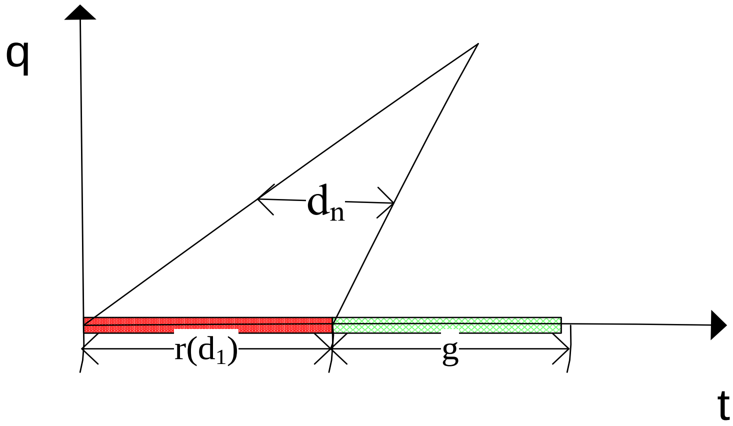

Figure 1. Delay of the Signalized Intersection

In Figure 1, it can be known the first queuing vehicle's delay is the difference between the vehicle's departure time and arriving time, it can be written as:

$$d_i = t_{si} - t_{qi} \tag{3}$$

Where

d_i = the stop delay of the *i*th vehicle;

t_{si} t_{qi} =the *i*th vehicle's starting and stopping time.

So the total stopping delay of the lane can be found as follow:

$$D = \sum_{i=1}^{n} d_i \tag{4}$$

Where D is the total lane delay, it is also the area of the triangle in the Figure 1.

3.2. Analyzing of the Model

Since there is no other vehicle's information, the classic delay has been deduced using the traffic flow, saturation flow, signal timing information and supposing that the vehicles' arriving is Possion distribution. Now, with the advanced detector widely used in traffic, other information can be collected in real time, and this phenomenon provides the opportunity in modification the delay models. Shown as Figure 2, there are same queue length, traffic flow, saturation flow and signal control timing in these two cycles, but the first vehicles' arriving times are different, they are t_{qf1} and t_{qf2}, separately; the departure times t_{sf1} and t_{sf2} maybe equal, so the real delay value should be different，but the calculated delay could be same when the classic delay model was used. If the first vehicle's arrival and departure times can be recorded, the higher precision delay value can be calculated. Steven *et al*. researched that the first vehicle's arrival time was random for low and moderate conditions *(15)*. So, if one of the queue vehicle's information can be recorded, maybe the delay models can be changed and the precision can be improved.

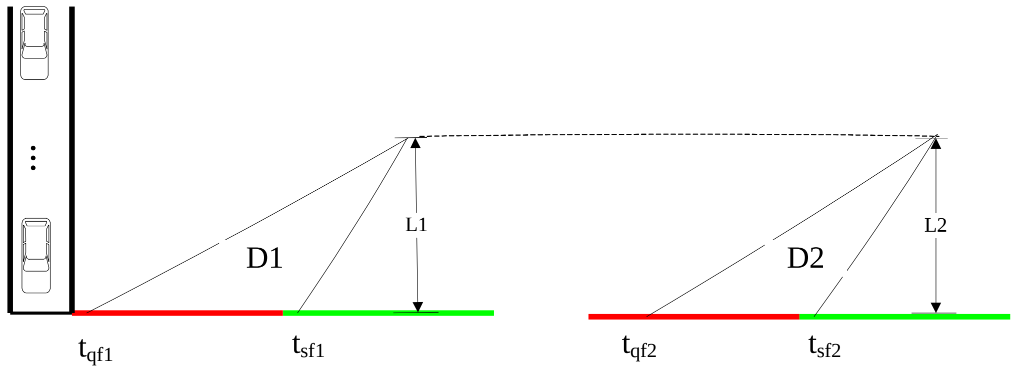

Figure 2. Delays between Two Cycles

Now, with the wide usage of the smart phone, vehicle infrastructure integration (VII), and the global position system (GPS), more and more convenient data can be used in traffic engineering. And this phenomenon provides good opportunities for the extraction of the intersection parameters. The vehicles that can provide real time mobile data can be called mobile facility vehicle (MFV) in the paper. Using the MFV data, building on the model inferred, the delay models are modified in the paper.

4. Methodology

4.1. Problem Definition

The vehicle's real time speed, situation, time and other data can be recorded through the MFV, these MFV data provides more useful information for extracting the intersection characteristic parameters, such as delay.

In order to get the delay parameters when adding the MFV information, we had to suppose that the intersection is not impacted by the upstream or downstream and the other assumptions as follow:

- The vehicle's arrival time is random, and it is not impacted by the upstream intersection nor the downstream intersection;
- The vehicles are the same kind of cars;
- Just one MFV in the queue and all queued vehicles can pass the intersection in this cycle;
- The vehicles' effective length (the vehicle's length adding the gap between two adjacent vehicles) are equal when the vehicles are in the queue.

4.2. Model Inferring

For the MFV's different queuing situation will have different impacts on the intersection delay model reconstruction; three conditions are considered in this research, they are the MFV in the front of the queue, at the middle and at the last one.

Case 1

Queuing at the first location

When the MFV is the first queuing vehicle, the time of queue forming and dispersing can be recorded, and the position is shown in Figure 3.

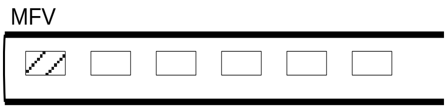

Figure 3. MFV at the First Location

The delay of the vehicle is shown in Figure 4.

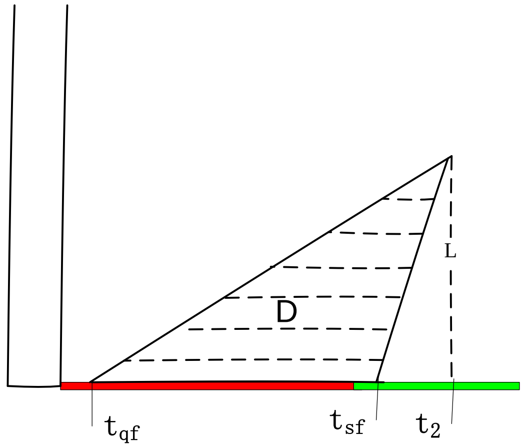

Figure 4. The Diagram of the Delay When the MFV at the First Location

Supposing the cycle is beginning at the time when the red indication is beginning, as shown in Figure 3, the total delay is the area of the shadow, and it can be written as:

$$D = \frac{1}{2}(\mathrm{t}_{sf} - \mathrm{t}_{qf})\,\mathrm{L} \tag{3}$$

Where t_{sf} and t_{qf} are the time that the MFV starts dispersing and queuing time, separately; L is the vehicle's queue length.

The formula (3) is the delay model when the first queue vehicle is MFV.

Case 2

In the middle of the queue

When the MFV is in the middle of the queue, that is to say it is neither at the first queuing pition nor at the last one, and the location is shown in Figure 5.

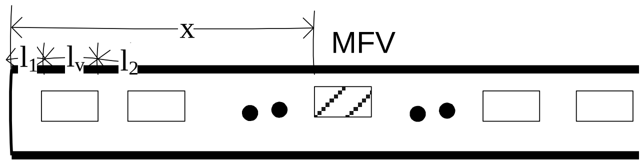

Figure 5. The MFV in the Middle Location

Supposing that the MFV is the *n*th queue vehicle, then from the Figure 5, it can be deduced:

$$n = \frac{x_f - l_1 - (\mathrm{n}-1)l_2}{l_v} \tag{9}$$

Where x_f is the distance between the MFV's position and the stop line; l_1 is the distance between the first queuing vehicle's position and the stop line, l_2 is the gap between the adjacent queuing vehicles, and l_v is the length of the vehicle.

For the intersection has a long distance between the upstream or the downstream intersections, and the vehicle's arrival time is random, so the first vehicle's arrival time can be written as:

$$t_1 = \frac{t_{qf}}{n} \tag{10}$$

When the MFV is at the middle of the queue, the delay is shown in Figure 6.

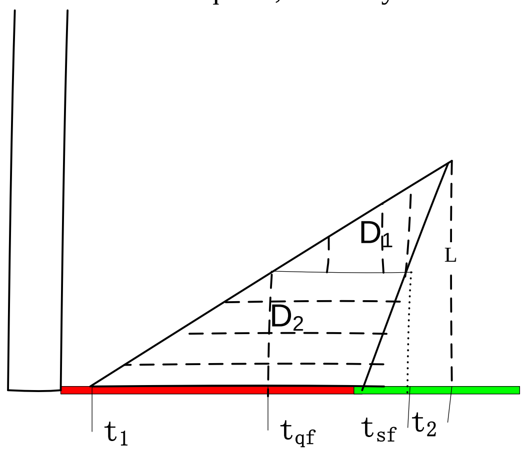

Figure 6. The Diagram of the Delay When the MFV in the Middle Location

In Figure 6, there are two parts for the total delay, they are D_1 and D_2. If the green lost time is ignored, the shadow area of D_2 can be calculated as:

$$D_2 = \frac{1}{2}\left[(t_{Sf} - t_{qf}) + (r - t_1)\right] * n \tag{11}$$

Considering formulas (9) and (10), it can be changed as:

$$D_2 = \frac{1}{2}\left[(t_{Sf} - t_{qf}) + (r - \frac{t_{qf}}{n})\right] * \frac{x_f - l_1 - (n-1)l_2}{l_v} \tag{12}$$

The delay of D_1 deduced as the case 1, and it can be written as:

$$D_1 = \frac{(t_{Sf} - t_{qf})(L - n)}{2} \tag{13}$$

Case 3
At the last one
When the MFV vehicle is queuing at the last one, the condition is shown in Figure 7.

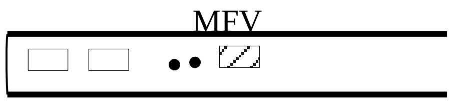

Fig 7. The MFV at the Last Location

As shown in Figure 7, when the MFV is the last queuing vehicle, and the queue length is n, it can be written as:

$$n = \frac{x_f - l_1 - (n-1)l_2}{l_v} \tag{18}$$

Where the meaning of l_1, l_2 and l_v is same as above, so the delay is the area of the shadow in the Figure 8.

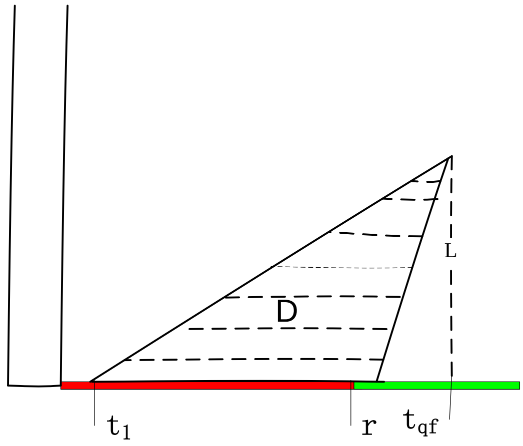

Figure 8. The Diagram of the Delay When the MFV at the Last Location

Ignoring the green lost time, and the total delay can be written as:

$$D = \frac{(r - t_1)}{2} * n \tag{19}$$

The first vehicle's stop time t_1 can be calculated by:

$$t_1 = \frac{t_{qf}}{n} \tag{20}$$

So the total delay can be deduced as:

$$D = \frac{(r - \frac{t_{qf}}{n})}{2} * n = \frac{(nr - t_{qf})}{2} = \frac{(\frac{x_f - l_1 - (n-1)l_2}{l_v} r - t_{qf})}{2} \tag{21}$$

Where r is the time of the red signal.

5. Data Collection and Application

5.1. Data Collection

Considering the problem definition in the paper, the northbound of the Yunanfenliu road and Minzhuxinjie road intersection in Chongqing was selected as the field survey site. The distance between upstream is more than 1400 meters, and the downstream traffic has no influence also. There are 3 branches along the road, but the vehicles are not impacted by them. The location is shown in Figure 9.

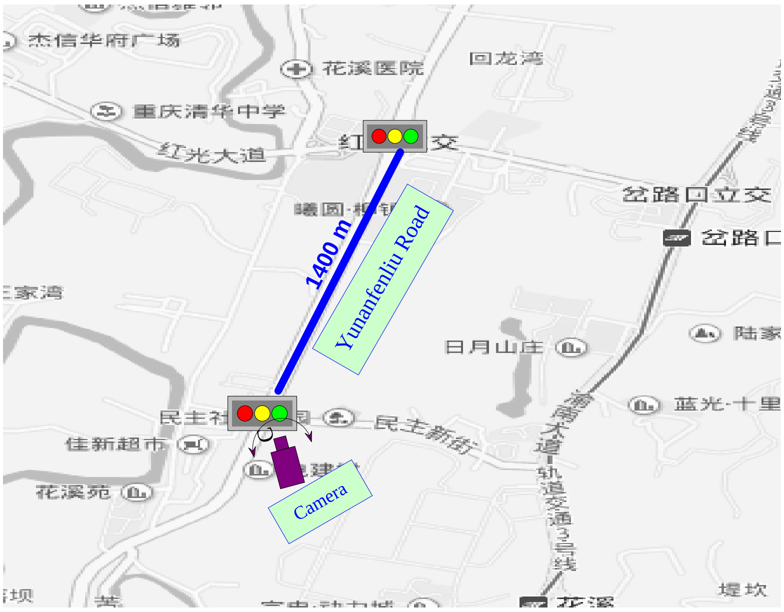

Figure 9. The Field Survey Site Selected In Chongqing, China

There are 4 lanes on the northbound approach, including 1 left turn lane, 1 right turn lane and 2 through lanes. The lanes are shown in Figure 10.

Figure 10. Snapshot of the Video Collection about the Approach

For the model is not considering different kind of vehicles, checking the video, the data was collected from the through lane adjacent to the right turn lane for there is just one kind of vehicle, which were cars, in most of the cycles. The red indication length has 65 seconds for the through lane, and the green indication length has 47 seconds, there are 3 second intervals between green and red light. The signal time of the through lane is shown in Figure 11.

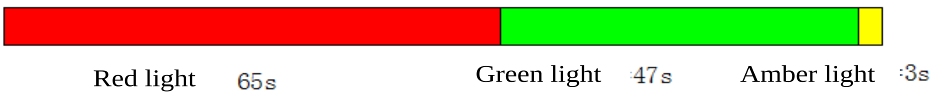

Figure 11. Signal Planning of the Approach

Data collected between 20th-21st Jan., 2015. There were 3 investigators that participated in the field survey. For the camera can not get the signal information, one of the investigators observed the signal information and if the signal changed to the next phase, she would make a gesture previously agreed upon. One of them estimated the distance between the stop line and the first stopped vehicle according to the line drawing on the road and recorded the number of every circles. And the third one operated the camera to record the vehicles information and the investigator's gesture, shown in Figure 10. In order to get the same vehicle's information, the three investigators used the same beginning time if the investigator begins the gesture. Moreover, considering the person's response time, the signal time of the approach was recorded before the survey for the intersection signal control time was fixed.

Through the video and records, the vehicles' stop time, departure time and other data in each cycle can be recorded manually. In order to minimize the error that produced for the human's response time, the data extraction assistants and the investigators were the same persons.

5.2. Application Result

The beginning and finish time of green and red indication, the stop and departure time of each vehicles' in every cycles were recorded using excel sheet manually and the real delay can be deduced. Then the MFV data can be set, that means the first, middle or the last vehicle in each cycle can be set as the MFV separately. The calculated delay can be got using the deduced formula in this paper. The real delay and the calculated delay are shown in Figure12.

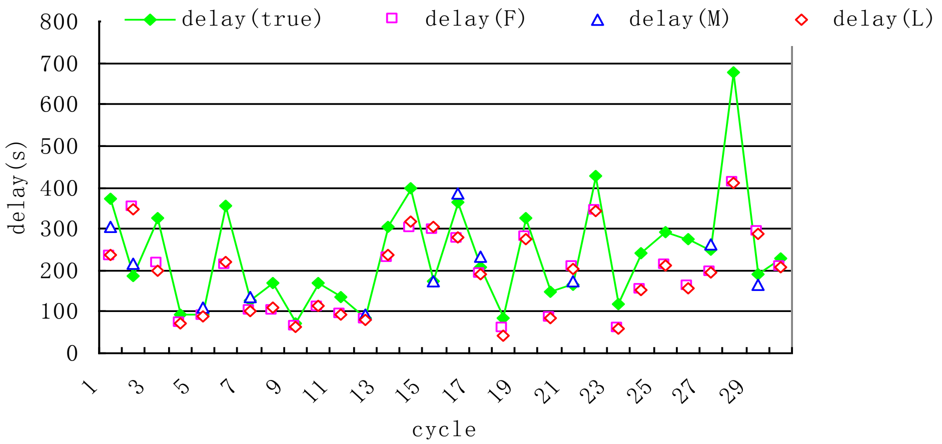

Figure 12. The Calculated Delay and Real Delay *

The MAPE was used as the error index. As showing in Figure 13, the calculated delays that the MFV is at the middle location are more close to the real delay, and the average MAPE value is 10.05%. The MAPE values are 28.42% and 28.81% when the MFV are at the first location and the last location, respectively. Moreover, the calculated values are closer to each other when the MFV are at the first location and the last location, even at

*(1) delay(true) is the real delay; delay(F) ,delay(M) and delay(L) are the calculated delay when the MFV at the first, middle and last queue location; (2) some cycles have not the value of delay(M) for these cycles' queue vehicles are less than 4 vehicles.

the cycles, such as 22nd, 23rd, 24th, 25th, 27th, and 28th cycles, the MAPE has the same values, and the average MAPE between the first and last MFV is 2.95%, shown in Figure 13.

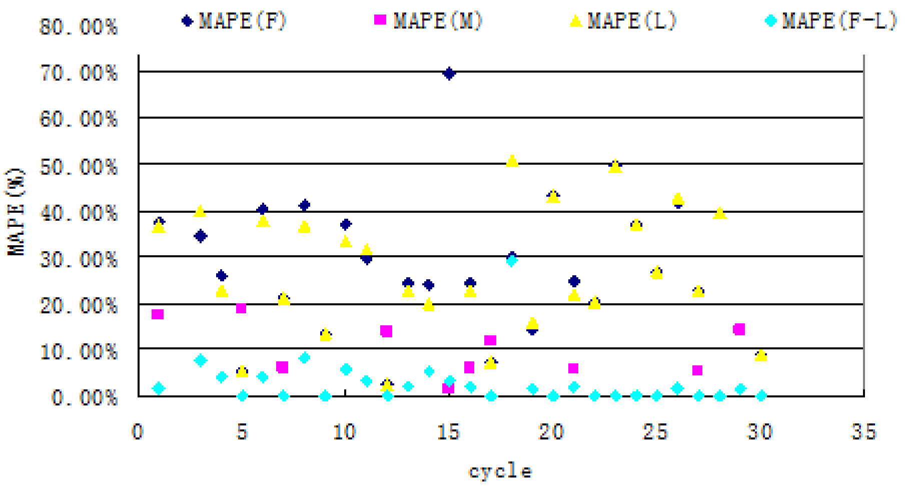

Figure 13. MAPE for the Calculated Delay *

Through analyzing the data recorded in excel, the MFV can get the yielding point for the fitting arrival time in cumulative curve when the vehicle at the middle location, so the calculated model has more high precision, as the Figure 14 shows.

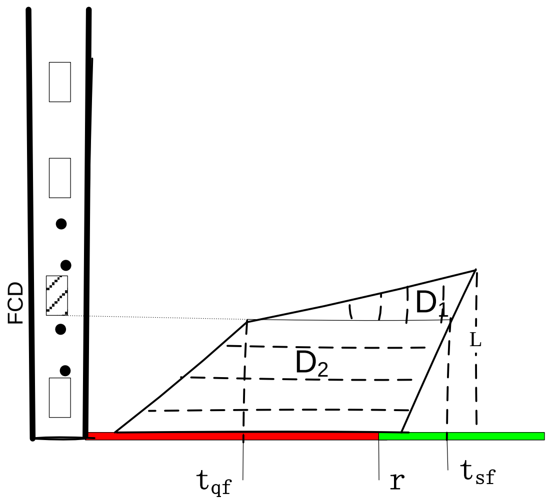

Figure 14. MFV as the Yielding Point

6. Conclusion and Future Research

Now, more and more mobile data can be collected, whatever the mobile phone, probe vehicle and other infrastructure, these mobile's data provide the opportunity to get more high precision traffic parameters. At the same time, some traffic parameters had to be extracted by the traditional model and there is limited online data when the models are deduced. With the coordinates of the stop and start-up spots and the time of the MFV, the stopped delay at the signalized intersection was deduced through analyzing the delay

*The MAPE (F-L) means the difference value between the delay (F) and the delay (L).

model based on the cumulative curve. Three conditions were analyzed according to the MFV's location in the queue. The delay models estimated were compared with the real delay recorded manually. The results have shown that it has more high precision when the MFV is at the middle spots in the queue.

In this paper, just one MFV data is used and the traffic condition is under saturation, so in the future research, more than one MFV data should be considered. Moreover, the MFV's location in the queue should be judged besides the MFV at the first location. Also, the MFV's data mistake should be paid attention to in future research.

Acknowledgement

This study was jointly supported by the Natural Science Foundation of China (No. 51508061).

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