

Queue Length Estimation Algorithm for Signalized Intersection Using Sectional Travel Time Information

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Abstract: The purpose of this research is to develop algorithm calculating the traffic queue length which is main variable for effective operation at signalized intersection. For the methods to calculate the traffic queue length, there are queue theory and shock wave theory. And, the estimation of traffic queue length by existing point detection system utilizes traffic queue theory calculating traffic queue length through the number of vehicles, this algorithm intended to estimate more accurate length of traffic queue by calculating the length of physical traffic queue through the shock wave theory. For the stream of algorithm, the information of individual vehicle's travel time is gathered by ground detector in upstream detector and downstream detector, the coordinate of individual vehicle on the working drawing is estimated and the speed of shock wave creating traffic queue through the value of coordinate estimated for one cycle is calculated. The suitability of algorithm is evaluated by Simulation.

Key Words: *Queue length, Traffic Flow Model, Shock wave Theory, ITS*

1. INTRODUCTION

The total population of South Korea, exceeded 50 million as of June 2012. Social stability and environmental changes increased the traffic demand. The total length of roads across the country has achieved 105,931Km as of December 2011. however, extension of road per 1,000 population are still 2.1Km despite continued investments in the road.

In 2012, social overhead capital(SOC), the government's budget accounted for 7% of the total budget, but declined 5.5% year-on-year. and Priority for road-building social overhead capital (SOC) is to decrease as compared to the financial investment capital needs of other. Therefore as a measure to solve Traffic Congestion Cost is continuously increasing, it must seek the efficiency measures road operation that increases the functionality of the existing road and improve efficiency.

The development of information and communication technique is currently promoting Intelligent transport system. Also the collection of traffic information, processing, providing, and has been used as the core technology underlying the field of control-related system.

Unlike the collection of traffic information in accordance with the development of information and communication and had to collect only a point detection system in the past. However road infrastructure and vehicle of individual through communications will collect path information between the individual vehicle. Interval detection system will be to enhance the quality of inaccurate traffic forecasts estimated from information of limited point detection systems of the past. This means that the intersection operations more efficient traffic management enforcement Urban service level of the road is determined depending on the efficiency of the control signal at the intersection is enabled.

In this study, sectional travel time information is collected via DSRC, to represent the information of the length of the queue in the signalized intersection. Which is based on traffic flow-density model and shockwave theory. The study objective is aimed at the development of queue estimation algorithm for signalized intersection using sectional travel time information.

2. BACKGROUND ISSUES

2.1 Fundamental Diagram

Newell's Simplified Traffic Flow Theory

Newell proposed model the relationship between the density and traffic volume by dividing previous parabolic type volume-density diagram into uncongested and congested condition. This is expressed simply by assigning uncongested state to free flow speed w_1 and congested state to w_2 . Volume-density relationship is displayed in linear form by dividing it into 2 areas of uncongested state and congested state. There is a difficulty in calculation if a previous parabolic graph is used, but this linear simplified traffic flow theory is convenient for calculation and the solution can be easily derived.

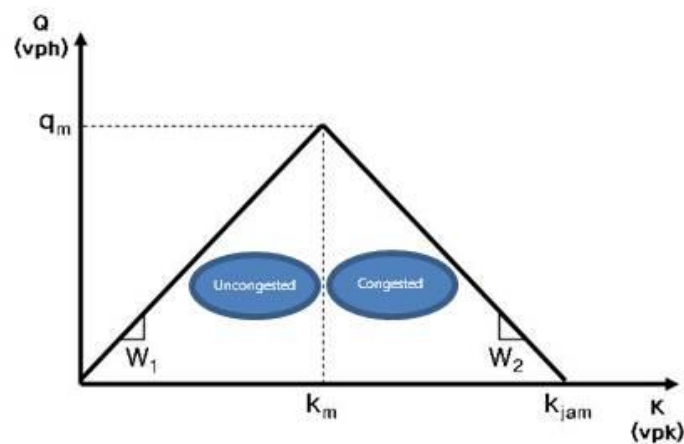


Figure 1 q-k diagram of Simplified Traffic Flow Theory

Shock wave Theory

shock wave is the propagation movement of wave in accordance with the change of traffic density and volume.

Two different density of the area A, B have erased the boundaries of the vertical moving with the speed of the traffic flow, the shock propagation speed can be estimated from the slope of a straight line connecting two points of traffic and density traffic density relationship.

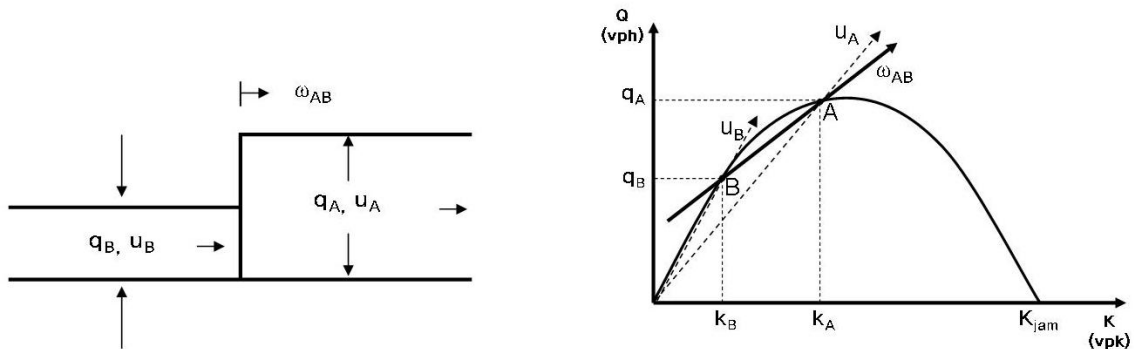


Figure 2 Shock wave in volume-density relationship

2.2 Queueing Theory

Definition of Queue

According to the Highway Capacity Manual 2000, queue is defined as “ a line of vehicles, bicycles, or persons waiting to be served by the system in which the flow rate from the front of the queue determines the average speed within the queue. Slowly moving vehicles or people joining the rear of the queue are usually considered part of the queue.” such a sentence means that not only car stopped stop line behind the signal control and includes all the cars that are affected to the traveling speed by the vehicle queues approaching the intersection.

Henry X. Liu(2009) was defined the length of the queue of the actual sum of both parts. "Standing Queue" is that the vehicle was stopped by a signal control and "Moving Queue " is that a vehicle speed of the vehicle is reduced to a certain level below.

There are two kinds of queue. First, "Maximum queue", refers to the length of queues formed to the rear of the stop line when the traffic light turns green equalization. Second, "Maximum back of queue", the maximum length of the stop line to the rear end of the queue has been created within the same cycle.

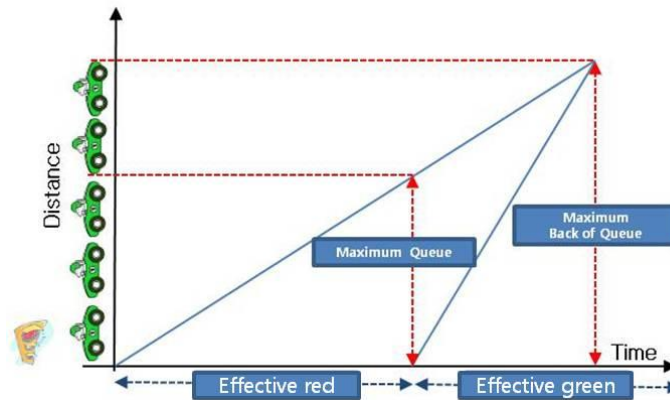


Figure 3 Definition of Queue length

Queue Length Estimation

Cumulative arrival and departure analysis queuing theory is that investigate the number of vehicles that passed through the stop line of the vehicle arrived at the stop line to determine queue length.

The number of vehicles that make up the queue at any given time consist of the subtraction of two parts. The two parts as follows: First, accumulated the vehicle arrives sequentially at effective red. Second, departure traffic volume obtained by accumulating the vehicle passed through the intersection of time effective green.

shock wave theory is to calculate the length of the queue unlike those using only data point traffic of cumulative arrival and departure analysis queuing theory.

First, shock wave theory is the basis of a correlation between traffic Volume, Density and Speed, therefore it must determine the volume-density relationship of the target area. Second, if it is to collect data in real time that it is possible to explain the speed of the shock wave. Third, Traffic volume of existing - the process of analyzing the shock wave ancillary density relationship occurs in the parabola is mathematically impossible. However, traffic volume parabolic volume- density relationship is accessible mathematically through the Simplified Traffic Flow Theory of Newell described above.

Type of shock wave generated by the signal intersection may be divided into three categories according to volume-density relationship.

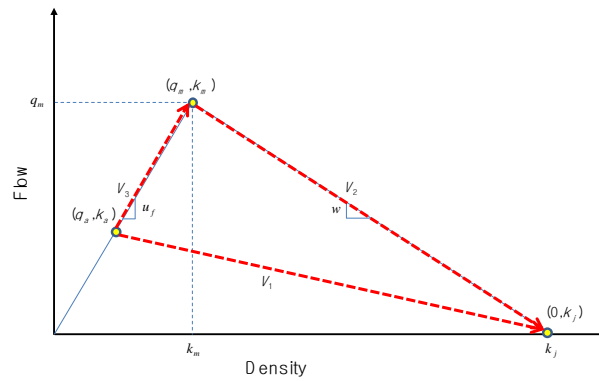


Figure 4 in volume-density relationship at signalized intersection

There is a difference from the calculated queue length of the queue is calculated through cumulative arrival and departure analysis queuing theory and shockwave theory to estimate. Length is determined based on the cumulative arrival and departure analysis queuing theory, be calculated by multiplying the average length of the vehicle in an amount mathematical vehicle stored vertically with respect to the time they arrived at the stop line. thus the error due to the length of the average car length.

The length of previously defined queue includes not only vehicles stopped in the queue but also vehicles that decelerated speed by the queue. As an increase in the number of vehicles are moving the end point of the actual queue to upstream. Thus, end points of the queue are different between cumulative arrival and departure analysis queuing theory and shockwave theory to estimate.

3. DEVELOPMENT OF QUEUE LENGTH ESTIMATION ALGORITHM

3.1 Detection system configuration

In order to calculate sectional travel time of the path by sectional detection system, it is necessary to specify the exact ending and starting point. At this time, it is necessary to select the ending and starting point which is regarded by considering the factors that could affect the passage time of the vehicle.

Elements that have the greatest effect on the travel time of the vehicle at signalized intersection consecutive is the signal time. Therefore, the detector are Installed ahead of the intersection. and There is a single intersection between the two detectors.

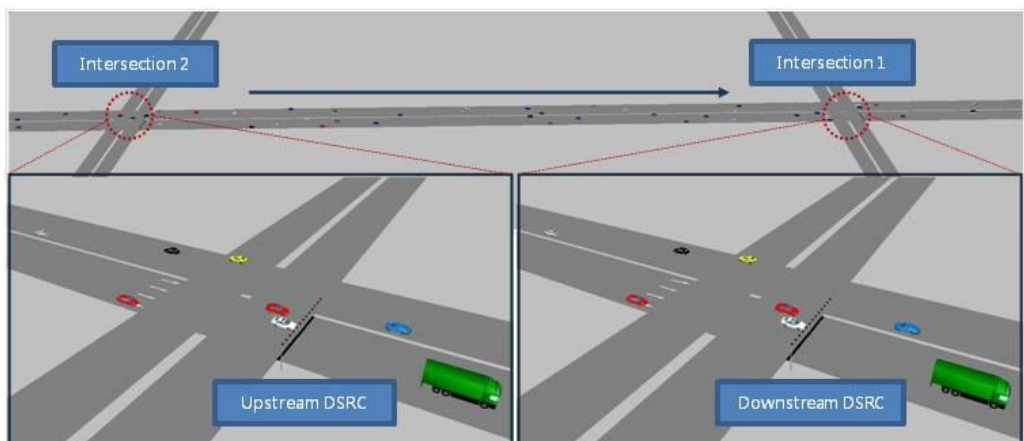


Figure 4 volume-density relationship at signalized intersection

3.2 Delay calculation of the individual vehicle

measuring the time of the pass points and the ID of each vehicle is possible to calculate the passage time of individual vehicles. Travel time of individual vehicles is a value that includes a delay time of the signal in the signalized intersection.

$$t_{ABi} = t_{Bi} - t_{Ai} \tag{1}$$

Where : t_{Ai} = Time the vehicle i has passed through the upstream detector
 t_{Bi} = Time the vehicle i has passed through the downstream detector
 t_{ABi} = Passage time from A to B

Delay of the individual vehicle is calculated from the difference between time at free flow speed and actually travel time of each vehicle.

$$Delay_i = t_{ABi} - \frac{L}{v_f} \tag{2}$$

Where : L = Distance of the segment AB
 v_f = Free flow speed
 $Delay_i$ = Delay time of vehicle i in the segment AB

3.3 Estimating position of individual vehicles in the shock wave

There are four points on the trajectory through travel time of the individual vehicle. Point 1 and Point 4 is estimated by the value of time and the position of upstream and downstream detector.

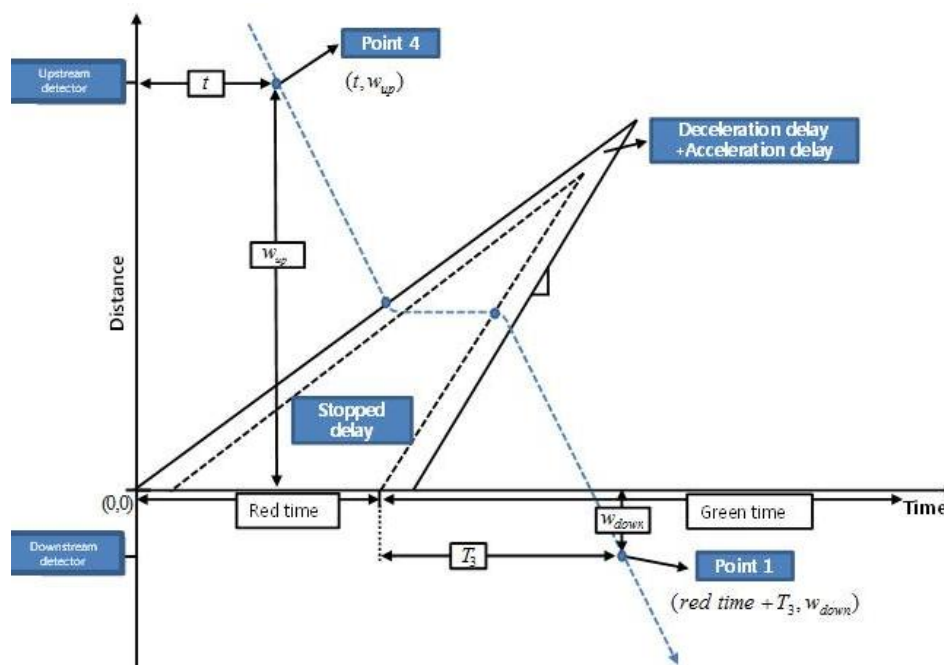


Figure 5 Estimating the coordinates of Point 1 and Point 4

The sum of h_i and w_{down} representing the width of the downstream intersection is the same as the moving distance of the vehicle during time(T_2).

$$h_i + w_{down} = t_{re} + \frac{1}{2}at_f^2 + v_f(T_2 - t_f)_1 \tag{7}$$

Where : t_{re} = response time

t_f = Acceleration time required to restore the free speed

The value of T_3 can be expressed as the sum of t_1 and T_2 . Therefore, the value of T_2 can be calculated through the following.

$$T_1 \cdot Shockwave_2 + w_{down} = t_{re} + \frac{1}{2}at_f^2 + v_f(T_2 + t_f) \tag{8}$$

$$Shockwave_2 \cdot (T_3 - T_2) + w_{down} = t_{re} + \frac{1}{2}at_f^2 + v_f(T_2 + t_f) \tag{9}$$

$$T_2 = \frac{Shockwave_2 \cdot T_3 - (\frac{1}{2}at_f^2) + v_f \cdot t_f - t_{re}}{Shockwave_2 + v_f} \tag{10}$$

The coordinates of the Point3, there is acceleration delay difference between Point2.

Point 3(Re dtime + $T_1 - (Delay_i - AccelerationDelay), h_i$)

(11)

3.4 Estimate queue length

The speed of the shock wave is estimated using the coordinate values for the detection of individual vehicles Point3. During one cycle of the coordinate values are represented by the value of the slope of the speed of the shock wave through the method of least squares.

Find $\tan \theta$ minimize $\sum_{i=1}^n \frac{|t_i \times \tan \theta - d_i|}{\sqrt{\tan^2 \theta + 1}}$ (12)

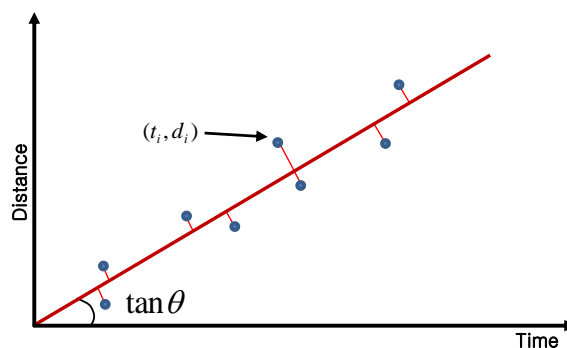
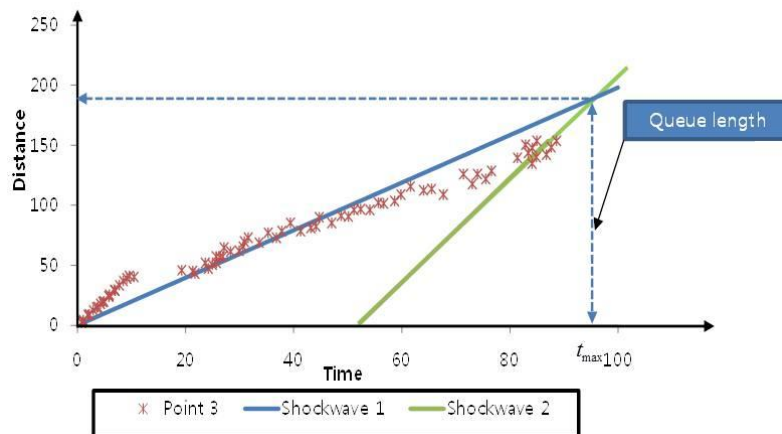


Figure 7 Least-squares method for the estimation of the speed of the shock wave. Every cycle using the slope calculated by the least squares method to calculate the length of the queue.

$$\text{Queue Length} = \tan \theta \times t_{\max} \quad (13)$$

Where : t_{\max} = Time *Shockwave*₁ and *Shockwave*₂ meet



4.SIMULATION ANALYSIS

4.1 Description of the analysis

In this study, VISSIM model is adopted to simulate the signal intersection operation. VISSIM is a microscopic, behavior-based multi-purpose traffic simulation program. A pseudo network was developed as followings:

- Roadway Characteristics and signal conditions
 - a. 500m distance at intersection
 - b. 2 lanes per direction
 - c. Cycle : 100s
 - d. Green interval : 50s
- Traffic/other conditions
 - e. 100% passenger car (No truck)
 - f. Capacity : 2,750 vehicles per hour per lane
 - g. Jam density : 450 vehicles per Km
 - h. Average free flow speed: 50 km/h

4.2 Development of scenario / Assessment tools

In this study, was performed four scenarios depending on the saturation of the access.

- Scen 1. $v/c = 0.35$
- Scen 2. $v/c = 0.55$
- Scen 3. $v/c = 0.70$
- Scen 4. $v/c = 0.90$

Mean Absolute Percent Error(MAPE) was used in order to evaluate the fit of the algorithm.

$$MAPE(\%) = \frac{\sum \left| \frac{A_i - F_i}{A_i} \right|}{n} \times 100 \tag{13}$$

Where : A_i = Measurements
 F_i = Estimates

4.3 Simulation result

Each scenario was performed three times, according to the seed number.

Table 1 scenario result

	Scen 1			Scen 2			Scen 3			Scen 4		
Seed number	42	678	911	42	742	873	42	573	1843	26	42	2109
A_i (m)	33.3	32.8	37.3	59.9	60.3	63.8	92.0	97.4	96.0	137.7	135.2	127.8
F_i (m)	32.6	61.7	70.6	61.5	58.8	63.1	91.6	97.6	94.9	139.8	141.9	130.2
MAPE(%)	22.6	183.7	91.3	16.8	10.3	9.8	5.6	8.6	6.6	8.1	9.8	7.1

The MAPE values decrease, increasing the saturation simulation results. The case of Scenario 1, the value is different for each seed. In other words, the low saturation means that the error of the estimated speed of the shock wave.

MAPE value of scenario 3 is the best scenario than scenario 4 saturation is high. This is due to long queues in Scenario 4. In other words, the longer the length of the queue is too great error.

The approach to saturation is better the higher the fitness of the algorithm. Scenario 1 is the difference between the value of each seed. Thus, the minimum approach, additional research is needed for saturation.

5. CONCLUSION

The purpose of this study is the development of an algorithm for estimating the length of the queue through the sectional travel time information. Analyzed prior research on how to estimate the length of the queue and Algorithm through the interval travel time and the shock wave theory was developed. Finally, evaluate the fitness of the algorithm through simulation. The higher saturation simulation results showed that queue estimation error is less.

If the studies for appropriate method of queue theory are continued, this study shows how to estimate the queue, the possibility of utilizing the sectional travel time information and it can be utilized in advanced signal system.

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