JOURNAL OF ADVANCED TRANSPORTATION
J. Adv. Transp. 2015; **49**:568–580
Published online 1 October 2014 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/atr.1288

A method for measuring accurate traffic density by aerial photography

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SUMMARY

Traffic density can be accurately measured by counting the number of vehicles within 1 km; however, it is often calculated between macroscopic traffic parameters using the fundamental equation because of difficulty of observing traffic density directly in the field. Measuring density in this way may be inaccurate and may bias the analysis because the relationship between these traffic parameters can vary across the study sites. The purpose of this study is to find a method for measuring traffic density from aerial photography that is easy and accurate, and for this purpose, we investigated whether the measuring length (i.e., the length of a section of roadway from which observations of traffic are simultaneously collected) can be shorter than 1 km and yet retain the same measured traffic density. We divided an aerial photograph into several 20-m unit sections, counted the number of vehicles manually, and examined measured traffic density according to central limit theory. According to the results of this study, with the number of 20-m unit sections for observing traffic density at 15 (the measuring length is 300 m), the measured traffic density was almost the same as the density of a representative section of 1 km. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: traffic density; measuring length; CLT; aerial photography

1. INTRODUCTION

In macroscopic traffic parameters, traffic volume and speed refer to the number of vehicles passing along a road and their distance moved per unit of time, respectively, and density is the number of vehicles occupying a given length of highway or lane at a given time [1]. Traffic volume and speed are therefore time-dependent, whereas density is a distance-dependent variable. Newell [2] suggested that travel time per unit distance is a more meaningful way to provide link travel time. The traditional use of traffic density is as follows. May [3] noted that many traffic models set up the boundary value between congestion and non-congestion on the basis of density and predict the queue length and propagation velocity of congestion using the threshold value. Density is also used as the measure of effectiveness for road network performance and as a means of judging level of service (LOS) of the roads Highway Capacity Manual (HCM) [4]. Hall *et al.* [5] made it clear that density is a major element, together with mobility, travel time, road safety, and driving conditions, in the way a driver perceives the quality of road service. As intelligent transport systems (ITS) evolve, traffic density will play a significant role as an indicator of road network performance in the future [3].

Intelligent transport systems have been widely used in Korea since the 1990s, and following long-term experience of ITS operation, traffic forecast system is being considered to relieve severe traffic congestion in the center of cities. In order to implement this system, it is necessary to predict when

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the queue in bottlenecks disappears in terms of traffic engineering and to set a threshold between congestion and non-congestion using traffic density for accurate prediction. The information needed by a driver is not speed (the distance traveled in a given time) but travel time (the time to travel a given distance) from origin to destination [2]. Observing accurate density is necessary for satisfying these needs.

Despite the importance of traffic density in transportation analysis, it is difficult to observe it directly on location. The simplest method is to count the number of vehicles in a predetermined target road area by taking a picture; this is the most accurate method of observing density, but its high costs can be a drawback. Athol [6] conducted a study on the use of aerial photography in the Chicago Surveillance Project, collecting density data and comparing density with the occupancy rate collected from the detector. Koshi *et al*. [7] collected density data by putting an image-photographing device on an aircraft. To estimate not density but speed, O'Kelly *et al*. [8] developed a model for the automated matching of trucks in a sequence of aerial photos. A method using the occupancy rate collected from the loop detectors is also widely used and is based on the assumption that the occupancy rate is proportional to density. Hall [9], however, found that the relationship between density and occupancy rate was not always constant. The most common method uses the fundamental equation (flow rate or volume = speed × density) between macroscopic traffic parameters. Since Greenshield [10], there have been countless studies analyzing the relationship between traffic parameters and the construction of traffic models. The relationship between these traffic parameters is not general, rather varies according to the study sites. A researcher can introduce additional bias into an analysis, compounding errors, as pointed out by Duncan [11]. Because of the difficulties of determining traffic states from the limited amount of observed data on sites, some studies have tried to estimate traffic states, including density, using various approaches with measurable parameters. The well-known Kalman filtering technique is widely used [12–14]. Other than the Kalman filtering technique, neural networks were adopted for vehicle identification and traffic density estimation using traffic videos in Ozkurt and Camci [15]. Some studies have tried to improve estimation accuracy by using data from more than one source [13, 16].

Despite the improving performance of the density estimation technique, it is still better to measure accurate density to count the number of vehicles on the road. Thus, our study presents a method of measuring accurate traffic density by manually counting the number of vehicles in a section of road through aerial photographs. The number of vehicles counted in an aerial photograph varies according to the location or extension of the road area. Haberman [17] explained that when observing density directly on the road, that density could differ from actual traffic conditions according to the measuring length (the length of a section of roadway from which observations of traffic are simultaneously collected) used at a given time, which means that the representative density of the section at a given traffic condition could be accurately computed only by counting the number of vehicles within a road section with an appropriate length. Haberman [17] also warned that counting the number of vehicles in a short or long section could distort assessment of the actual traffic situation. Thus, in order to find an appropriate length for measuring accurate density from aerial photography, we investigated whether the measuring length can be shorter than 1 km in order that calculated traffic density by counting the number of vehicles is close to that when counting the number of vehicles within 1 km.

2. DATA PREPARATION

2.1. Study site

The study site is a 9.2-km section of road between An-Hyun Junction (JC) and Jo-Nam JC of the Seoul Ring Express Highway, which is an eight-lane two-way highway with an average lane width of 3 m and road shoulder width of 1.5 m. It is a straight line section with no radical change of horizontal or vertical alignment, and there is a median strip made of concrete (Figure 1).

The road and traffic conditions at the study site are as shown in Table I. It is a basic section of expressway without a weaving section and interchange. Approximately 80% of its traffic is passenger cars. Traffic congestion rarely occurs because this section is not affected by peak time. According to these road and traffic conditions, this study site is similar to the base condition highway in HCM [4], which suggests minimal error in the process of counting the vehicles.

DOI: 10.1002/atr

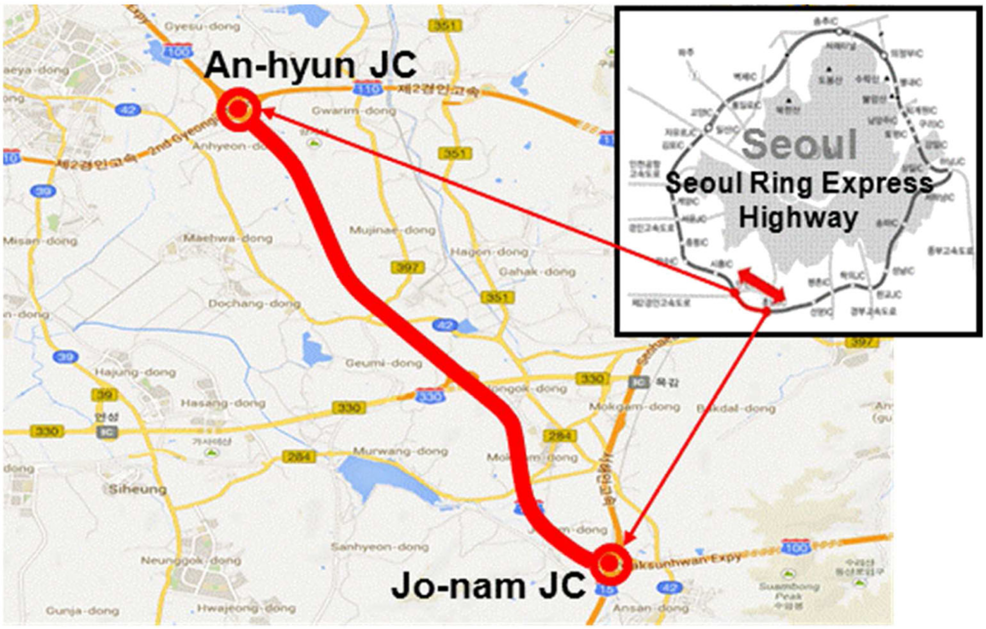

Figure 1. Study site image.

2.2. *Aerial photograph*

We took aerial photographs on March 20, March 30, and June 23 in 2009 using a fixed-wing, Short Take-Off and Landing (STOL) aircraft that was flying between 180 and 200 km/hour, faster than the speed limit of the Seoul Ring Express Highway (i.e., 100 km/hour). It is assumed that the aerial photograph shows a new traffic situation as it flies a certain amount of distance. The road area covered in each photo is 500 to 1000 m. The light aircraft flew over the study site repeatedly to take pictures every second with a 39 million pixel camera (Phase One P45+) mounted. Table II shows the detailed information from the aerial images.

By using a high-resolution camera, it was easy to identify the types of vehicles, even at a low magnification. We selected pictures that showed areas where utility poles or loop detectors were positioned at the center of the pictures, so as to easily identify the same location in pictures for analysis.

3. AGGREGATION METHOD OF COUNTING THE NUMBER OF VEHICLES

3.1. *Division by unit section*

We counted the number of vehicles manually in a unit section after dividing the area, as shown in Figure 2, into intervals of 20 m. Because the length of broken white lines on the expressway in Korea is prescribed as 10 m, it was easy to divide a road area by the unit section and count the number of vehicles in that unit section. When counting the number of vehicles, it was also advantageous for this study to aggregate the number of vehicles in a unit section so that the possible error from passenger car unit (PCU) converting could be minimized. Accordingly, in the cases where the length of road in the aerial photograph was 700 m (Figure 2), the number of 20-m unit sections was 35.

The number of 20-m unit sections, in which the number of vehicles was aggregated by aerial photographs, was 1550 (March 20: 540, March 30: 800, and June 12: 210) in total. The number of unit sections aggregated in between An-Hyun JC and Jo-Nam JC was the same for each direction.

3.2. *Method of aggregating the number of vehicles in a unit section*

The number of vehicles counted in the aerial photographs in a 20-m unit section was converted into PCU. As the horizontal and vertical alignment of the road in the study site was very gentle, this study used passenger car equivalents, such as E_T (trucks and buses), 1.5 pcu and E_R (recreational vehicles),

DOI: 10.1002/atr

Table I. General characteristics of the study site.

Roadway condition				Traffic condition				Others		
Basic section	Weaving section	Lamp section	Design speed	Speed limit	Ratio of passenger car	ADT	Peak time	Median strip	Signpost	Weather
Yes	—	—	120 (km/h)	100 (km/h)	80%	About 170 000 (veh/day)	—	Yes	Yes (12)	Bright

DOI: 10.1002/atr

Table II. Detailed information from the aerial images.

Information	Values
Altitude	1200 m (4000 ft)
Focal length	50 mm
Space resolution	0.5 m × 0.5 m
Ground coverage	1000 m × 500–1000 m
Image size	7228 × 5428 pixel
Interval	1 second

Figure 2. Example of the divided sections in the aerial photograph.

1.2 pcu, which are the values of the even ground suggested by HCM [4]. Figure 3 shows the zoomed-in images of sections 3 and 5 in Figure 2.

Figure 3(a) shows the zoomed-in image of section 3 in Figure 2, which is an example of the road divided into 20-m unit sections. The shaded area inside dotted circle 1 in Figure 3(a) is an example of aggregating the number of vehicles where a vehicle is located across two 20-m unit sections. The vehicle in dotted circle 1 is a truck, which was originally 1.5 pcu, and it is over the half and half in both 20-m unit sections, so we consider it 0.75 pcu for one 20-m unit section and 0.75 pcu for the other. Figure 3(b) shows the zoomed-in image of section 5 in Figure 2, which is an example of applying PCU aggregation to a large bus, RV, and passenger cars. The shaded areas inside dotted circles 2,

(a) Zoomed-in image of Section 3 in Fig. 2 (b) Zoomed-in image of Section 5 in Fig. 2

Figure 3. Zoomed-in images of sections 3 and 5 in Figure 2.

DOI: 10.1002/atr

3, and 4 in Figure 3(b) represents three vehicles: dotted circle 2 contains a large bus, counted as 1.5 pcu, the dotted circle 3 contains an RV, counted as 1.2 pcu, and dotted circle 4 contains a passenger car, counted as 1.0 pcu. The ratio of vehicles counter by type is presented in Table III.

4. ANALYSIS METHODOLOGY

4.1. Overview

The methodology used in this study was based on Haberman's warning, which is described in Section 1, and Figure 4 shows variations of density values resulting from the length of measuring intervals as described by Haberman [17].

Figure 5 plots densities, estimated in this study through aerial photographs, according to the measuring length. When estimating traffic density by aggregating the number of vehicles in a short measuring length below 200 m, the values of density greatly vary. However, as the measuring length increases more than 200 m, density seems to converge on a constant value without much variation.

Table III. Ratio of vehicles in the study site by type and photograph date.

Date	Passenger cars (%)	Trucks and buses (%)	Recreational vehicles (%)
March 20	75	11	14
March 30	72	12	16
June 12	72	13	15
Average	73	12	15

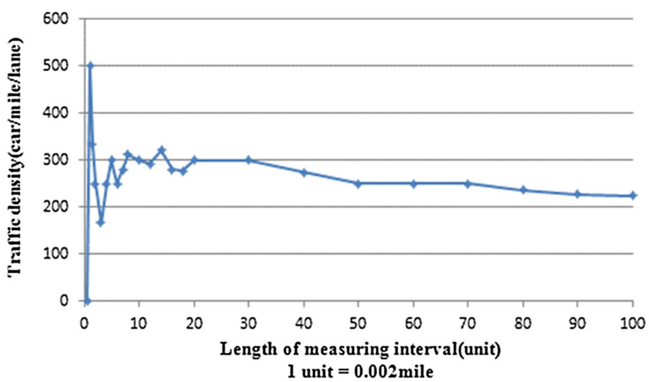

Figure 4. Variation of density depending on length of measuring interval.

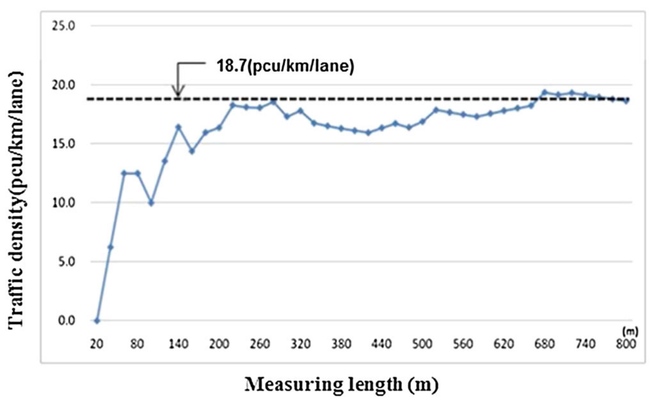

Figure 5. Variation of density according to measuring length in aerial photograph 1039-12-1 (Jo-Nam).

DOI: 10.1002/atr

We assume that there is an appropriate measuring length where estimated density converges on the value reflecting the real traffic situation. Experiments observing the number of vehicles within a specified section or time can be explained by Poisson [18, 19], binomial [20–22], or negative binomial distribution [23, 24]. In this study, we determined that binomial distribution was the most suitable basis for the statistical explanation because variance becomes smaller than the average of the number of vehicles in a unit section based on our experimental data. Explaining the vehicular distribution through binomial distribution by applying the number of vehicles in a 20-m unit section suggests the number of unit sections (i.e., measuring length) that would make estimated density reflect the real traffic situation. Accordingly, the key to finding the measuring length for accurate density lies in finding appropriate numbers of samples (i.e., unit sections) where the estimate density is almost the same as the representative density of a whole section.

Finding an appropriate number of samples to represent real traffic situations can be explained using central limit theory (CLT), which states that as more unit section samples are aggregated, the distribution of the average number of vehicles ($\overline{d}$) increasingly approximates the normal distribution whose average is μ (average number of vehicles of population) and whose distribution is $\sigma^2 n$ as shown in Equation (1). The use of CLT makes it possible to collect the average number of vehicles in unit sections of population (μ: pcu/20 m/4 lanes, this study used the average number of vehicles per four lanes other than one lane) by using the average number of vehicles in unit sections of samples ($\overline{d}$: pcu/20 m/4 lanes) obtained from the measured samples, and variance of $\overline{d}$ (σ^2/n), which varies according to the number of samples.

$$\overline{d} \sim \mathrm{N}\left(\mu, \frac{\sigma^2}{n}\right) \tag{1}$$

where $\overline{d}$ is the average number of vehicles in samples (20-m unit section) (pcu/20 m/4 lanes), μ is the average number of vehicles of population unit section (pcu/20 m/4 lanes), σ^2 is the variance of the average number of vehicles in unit section of population (pcu/20 m/4 lanes), σ^2/n is the variance of the average number of vehicles in 20-m unit sections of samples (pcu/20 m/4 lanes), and n is the number of samples (20-m unit sections).

Putting together the aforementioned inferences, the measuring length for accurate density can be found by measuring the number of samples and again multiplying the number of samples by 20 m, that is, the length of a unit section.

4.2. *Methodology for calculating number of samples (n)*

It is necessary to secure a considerably large number of samples (n) in order to enhance the accuracy of density data collection; however, in reality, it is impossible to secure countless numbers of samples. Hence, we introduce the concept of error tolerance (E) and suggest a formula based on the CLT for calculating the number of samples (n) through E. If it is possible to allow a certain level of errors, then we arrive at Equation (2) as follows. In other words, by taking into account the error range in the average number of vehicles in the sample, we can define a pseudo number of vehicles.

$$\mathrm{D}^* = \overline{d} \pm \mathrm{E} \tag{2}$$

where D^* is pseudo number of vehicles and $\overline{d}$ is average number of vehicles in sample (pcu/20 m/4 lanes).

In addition, we suggest E according to the CLT and the definition of a confidence interval of $(1-\alpha) \times 100\%$ for the average number of vehicles of population.

$$\mathrm{E} = z_{\alpha/2}\sqrt{\frac{\sigma^2}{n}} \tag{3}$$

where E is limit of error (pcu/20 m/4 lanes), α is level of significance, and $z_{\alpha/2}$ is standard normal probability statistics.

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In this study, α and $z_{\alpha/2}$ were used as 0.05 and 1.96, respectively. If Equation (3) is properly converted, the formula for calculating the number of samples (n) that we want to obtain can be drawn as follows:

$$n = \left(\frac{z_{\alpha/2}\sigma}{\mathrm{E}}\right)^2 \tag{4}$$

According to Equation (4), the measuring length for observing density can vary according to E, significance level (α), and $z_{\alpha/2}$. Further, what determines the variance of the average number of vehicles in a unit section could be vehicular distribution depending upon the vehicle group, so the smaller the error tolerance, the longer the measuring length becomes when the significance level (α) and $z_{\alpha/2}$ are fixed. This means that an inverse relationship forms between the number of samples (n) and E as follows:

$$\mathrm{E} \propto \frac{1}{n} \tag{5}$$

In other words, if the number of samples (n) increases infinitely ($n \to \infty$), E can only decrease ($\mathrm{E} \to 0$). Even the inverse holds true. If $z_{\alpha/2}$ is big and E and the level of significance (α) are fixed, the measuring length becomes longer because more samples (n) are needed.

Therefore, as shown in Figure 6, as the standard deviation of the vehicle group becomes smaller, it might be possible to compute a density value that represents the real traffic situation with a shorter measuring length. In addition, as more samples (n) are included, E can be reduced.

4.3. Example of calculating the measuring length

According to the proposed method, we calculated the measuring length for collecting density data that represents a real traffic situation using aerial photograph 1039-12-1 (An-Hyun direction). Table IV shows the aggregated number of vehicles in 20-m unit sections (pcu/20 m/4 lanes). For example, if a measuring length is 60 m, the number of pcu in first, second, and third 20-m unit sections is 0, 1, and 2 respectively in aerial photograph 1039-12-1 (An-Hyun direction). The road area included in aerial photograph 1039-12-1 runs for 800 m, so the longest length of the aggregated section is 800 m. In this case, the total number of samples (20 m unit sections, n) is 40. The average number of vehicles and the variance of the forty 20-m unit sections obtained from aerial photograph 1039-12-1 (An-Hyun direction) were 1.49 (pcu/20 m/4 lanes) and 0.94 (pcu/20 m/4 lanes), respectively.

Table V shows the results of calculating the number of samples (20-m unit sections, n) and measuring length by E using Equation (4). Assuming E is 1.0 (pcu/20 m/4 lanes), it means that there is a significant equivalence between the density achieved by 3.6 samples of 20-m unit sections and the density

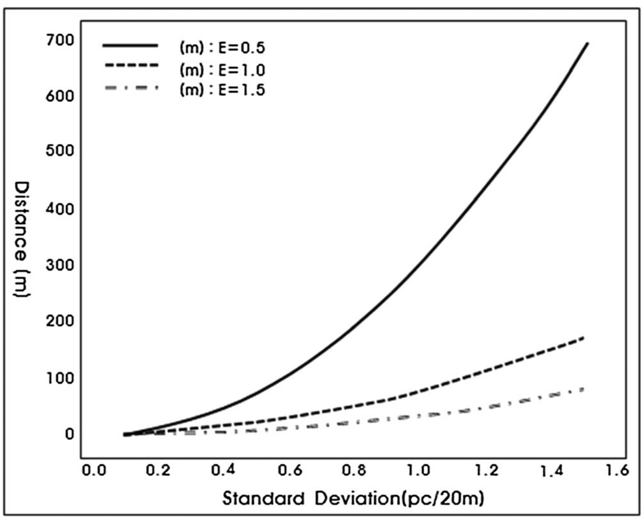

Figure 6. Measuring length depending on standard deviation and error tolerance of sample groups ($\alpha = 0.05$).

DOI: 10.1002/atr

Table IV. Number of pcu in each 20-m unit section in An-Hyun direction.

Measuring length (m)	20-m unit section																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	…
20	0																				
40	0	1																			
60	0	1	2																		
80	0	1	2	1																	
100	0	1	2	1	0																
120	0	1	2	1	0	2.5															
140	0	1	2	1	0	2.5	2.7														
160	0	1	2	1	0	2.5	2.7	0													
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮					
340	0	1	2	1	0	2.5	2.7	0	2.3	1.6	3	1.3	1.4	2	0	2	0				
360	0	1	2	1	0	2.5	2.7	0	2.3	1.6	3	1.3	1.4	2	0	2	0	1			
380	0	1	2	1	0	2.5	2.7	0	2.3	1.6	3	1.3	1.4	2	0	2	0	1	1		
400	0	1	2	1	0	2.5	2.7	0	2.3	1.6	3	1.3	1.4	2	0	2	0	1	1	1	
⋮																					

collected by counting all vehicles in a section of 800 m, which is the overall distance of roads in the aerial photographs, within a 95% confidence interval.

In Table V, the change in measuring length using E between 0.5 and 1.0 (pcu/20 m/4 lanes) is insignificant, but it sharply changes with E of less than 0.5. An error tolerance of 1(pcu/20 m/4 lanes) means that there might be at most a discrepancy of one between the number of vehicles in a 20-m unit section of a four-lane road and the number of vehicles in a 20-m section of road population. We calculated the measuring length for collecting density data by setting error tolerance (E = 0.5 pcu/20 m/4 lanes) as a basis. As mentioned by Son [25], supposing that the spacing is 8 m in jam density, there could be 10 vehicles in a four-lane 20-m unit section of a road. In this case, error tolerance of 0.5 (pcu/20 m/4 lanes) means that there might be at most 0.5 vehicles of error for 10 vehicles.

5. RESULTS AND DISCUSSIONS

Table VI shows the calculated number of samples (n) and the measuring length by putting the photographs from this study site together by direction and aggregating the number of vehicles in a 20-m unit section. In the An-Hyun direction, taking into account an E of 0.5 in a 20-m unit section by lane, the number of samples (20-m unit sections) and the measuring length are 15.45 and 309 m (i.e., $15.45 \times 20 = 309$), respectively. In the Jo-Nam direction, taking into account an E of 0.5 in a 20-m unit section by lane, the number of samples (20-m unit sections) and the measuring length are 14.90 and 298 m (i.e., $14.90 \times 20 = 298$), respectively. Accordingly, in the section of the study site that is uninterrupted road, the measuring length should be more than 300 m in order to collect density data that represent the actual traffic situation during non-congestion period.

From these results, it can be seen that the measuring length for the section with less traffic tends to be short because the average number of vehicles and variance within the 20-m unit section are small. Thus, for observing density during non-congestion period, the smaller the number of vehicles, the smaller the number of samples (20-m unit sections) that needs to be collected.

Conversely, we can draw the inference that the measuring length for density during congestion period is longer because the average number of vehicles increases. In order to prove this inference, we calculated the measuring length for density during congestion period using photographs collected during that congestion period. Because, at the time of photographing the Seoul Ring Expressway, traffic congestion did not occur, in an effort to analyze congestion, we used photographs taken at a time of congestion on the Gyeongbu Expressway. Figure 7 shows a photograph of the Gyeongbu Expressway at around 2PM on a weekday, taken with a high-resolution camera. The design speed of this expressway is 100 km/hour, and the average running speed at that time was less than 40 km/hour. This photograph thus shows a typical congestion with LOS F.

DOI: 10.1002/atr

Table V. Measuring length in An-Hyun direction.

Error tolerance (pcu/20 m/4 lanes)	Number of samples (20-m unit sections)	Measuring length (m)
1	3.60	72
0.9	4.44	89
0.8	5.62	112
0.7	7.34	147
0.6	9.99	200
0.5	14.39	288
0.4	22.49	450
0.3	39.98	800

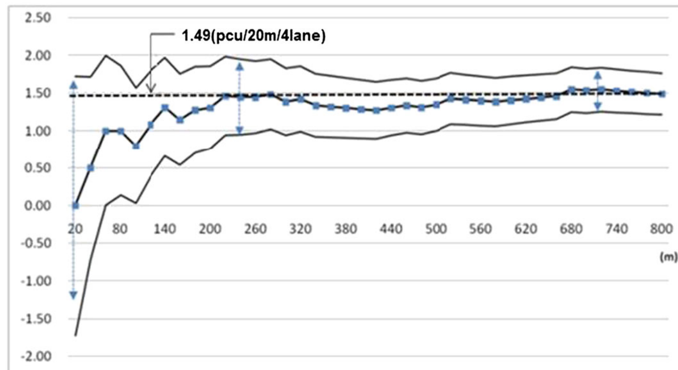

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Table VI. Measuring length in all photographs.

Direction	Error tolerance (pcu/20 m/4 lanes)	Number of samples (20-m unit sections)	Measuring length (m)
An-Hyun	1	3.86	77
	0.9	4.77	95
	0.8	6.04	121
	0.7	7.88	158
	0.6	10.73	215
	0.5	15.45	309
	0.4	24.15	483
	0.3	42.93	859
Jo-Nam	1	3.72	74
	0.9	4.60	92
	0.8	5.82	116
	0.7	7.60	152
	0.6	10.35	207
	0.5	14.90	298
	0.4	23.28	466
	0.3	41.39	828

Figure 7. Photograph of the Gyeongbu Expressway.

Table VII shows the results of the measurement length on the Gyeongbu Expressway. The average of the number of vehicles in a 20-m unit section in each of the seven aerial photographs is 5.6 (pcu/20 m/4 lanes) and the variance is 3.70 (pcu/20 m/4 lanes). When taking into account the E of 0.5 vehicles in a 20-m unit section, the number of samples (20-m unit sections) and the measuring length are 50 and 1000 m (i.e., $50 \times 20\,\text{m} = 1000\,\text{m}$), respectively.

Table VII. Measuring length on Gyeongbu Expressway (during congestion period).

Error tolerance (pcu/20 m/4 lanes)	Number of samples (20-m unit sections)	Measuring length (m)
1	14.21	284
0.9	17.55	351
0.8	22.21	444
0.7	29.01	580
0.6	39.48	790
0.5	50.0	1,000

DOI: 10.1002/atr

As the E of the congestion period is greater than that at non-congestion period, fewer samples (n) were needed to measure density in a way that reflected reality. The vehicle distribution formed by the existence of the vehicle platoon eventually had an influence variation in the average number of vehicles in a unit section. We can see that the vehicle distribution during congestion period, represented by LOS F, was more uniform than that during non-congestion period, often represented by LOS A and B. At LOS F in which the vehicle distribution is uniform, and the variation in the average number of vehicles in a unit section becomes smaller as traffic flow approaches forced flow with an increasing number of vehicles. It is not easy for a driver to change lanes at LOS F, which is an extreme traffic jam condition often called forced flow, so drivers may tend to demonstrate driving behavior dependent on the car in front of them as a result of low speed, forming a mass of traffic flow, a uniform vehicle platoon. In a sense, a vehicle platoon formed in LOS F can be interpreted as very small or large, according to the analyst's preference. In other words, even in LOS F, it is possible to calculate various measuring lengths by the changes of variance. For example, we used density of about 70.0 pcu/km/lane at a time of congestion, but if we analyze the change of variance for the average number of vehicles in a unit section of jam density, 125 pcu/km/lane, as suggested by Son [25], it would be difficult to exclude the possibility that as analysis results, the measuring lengths at LOS F could differ from the suggested ones in this study.

6. CONCLUSIONS

We looked into measuring length (the length of a section of roadway from which observations of traffic are simultaneously collected) for observing accurate on-site density using aerial photography. We analyzed the number of samples (i.e., how many unit sections should be photographed in each time slot) that should be gathered in order to measure the reliable density. The use of a statistical method based on the CLT made it possible to calculate the measuring length necessary at the time of collecting density data by the number of samples aggregating. As a result of finding the measuring length during the time slot where the study site was photographed, the measured density of the study site, which is the basic section on non-congestion uninterrupted roads at LOS C, could demonstrate the real traffic situation with E, 0.5 pcu/20 m/4 lanes, only if the measuring length was 300 m (i.e., 14–15 samples measuring the number of vehicles in a 20-m unit section).

Korea plans to observe traffic density through the automatic detection of vehicles on a length of road, which is composed of several screenshots obtained from closed-circuit televisions (CCTVs) installed on the roadside. Until now, with current CCTV technology, one CCTV installed at a height of 10 m on the roadside can detect vehicles within a length of 100 m without any error. Thus, 10 CCTVs are needed to count the number of vehicles within 1 km. According to the results of this study, if we can find a measuring length in which the density calculated by counting the number of vehicles is almost the same as that by counting the number of vehicles in 1 km, it would be possible to observe accurate density in the field using only three CCTVs.

We proposed a method of measuring accurate density that is simpler than the existing method, by analyzing the appropriate measuring length. In brief, density representing the real traffic situation can be understood as the number of vehicles in the measuring length. Further study of the measuring length is required to be able to explain diverse service levels (A to F) of uninterrupted roads and particularly the transition process from E to F. With the changing processes of speed and volume, the study of density change will serve as an impetus to study an old problem: predicting the transition stage (the boundary at which congestion switches to non-congestion).

ACKNOWLEDGEMENTS

This research was supported by a grant from a Strategic Research Project (Developing of Real-Time Traffic Tracking Technology Based on View Synthesis) funded by the Korea Institute of Civil Engineering and Building Technology.

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DOI: 10.1002/atr