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Original article

A Study on Calculating Relevant Length of Left Turn Storages Using UAV Spatial Images Considering Arrival Distribution Characteristics at Signalized Intersections in Urban Commercial Areas

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Abstract

Calculating the relevant length of left turn storages in urban intersections is very crucial in road designs. A left turn lane consists of deceleration lanes and left turn storages. In this study, we developed methods for calculating relevant lengths of left turn storages that vary at each intersection using UAV (Unmanned Aerial Vehicle) spatial images. Problems of conventional design techniques are applying the same number of left turn vehicles (N) using Poisson distribution without considering land use types, using a vehicle length that may not be measurable when applying the length of waiting vehicles (S), and using same storage length coefficient (α), 1.5, for every intersections. In order to solve these problems, we estimated the number of left turn vehicles (N) using an empirical distribution, suggested to use headways of vehicles for (S) to calculate the length of waiting vehicles (S) with a help of using UAV spatial images, and defined ranges of storage length coefficient (α) from 1.0 to 1.5 for flexible design. For more convenient design, it is suitable to classify two cases when possible to know and impossible to know about ratio of large trucks among vehicles when planning an intersection. We developed formula for each case to calculate left turn storage lengths of a minimum and a maximum. By applying developed methods and values, more efficient signalized intersection operation can be accomplished.

Keywords : Urban Commercial Intersections, Left Turn Storages, UAV Spatial Images, Empirical Distributions, Headways, Storage Length Coefficients

1. Introduction

1.1 Purposes and backgrounds of this study

There are many reasons causing the rear-end collisions at urban signalized intersections. Among them, one of the critical reasons is the spill-back phenomenon of left turn vehicles due to shortages of left turn storage lengths. Actually, TAAS (Traffic Accident Analysis System) in South Korea showed that the rear-end collision is over 25 % in signalized intersection accidents during 6 years from 2007 to 2012 as shown in Table 1 (KoROAD, 2015).

This means that rear-end accidents can be reduced if a relevant left turn storage length is offered. Providing a relevant left turn storage length in urban commercial areas is very crucial since it is connected with efficient usage of urban spaces and a budget. But, the methods for calculating a relevant left turn storage length are not developed concretely.

This study tries to develop the methods for calculating a

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Table 1. Comparing ratio of rear-end collisions in total accidents at intersections

Types of accidents		Year	Total	2012	2011	2010	2009	2008	2007
Vehicle to vehicle accidents	Total	Number of accidents	543,289	81,367	94,246	97,221	99,016	88,621	82,818
	Rear-end collision		139,901	18,630	23,682	25,129	26,384	24,184	21,892
Ratio of rear-end collisions in total accidents at intersections (%)			25.75	22.90	25.13	25.85	26.65	27.29	26.43

relevant left turn storage length and to suggest a design manual that can be adaptable at signalized intersections in urban commercial areas using UAV (Unmanned Aerial Vehicle) spatial images.

The South Korea design manual suggests calculating a left turn storage length by multiplying three variables such as a storage length coefficient, the number of left turn vehicles, and the length of waiting vehicles. This method, however, is not clear enough in terms of how to count the number of left turn vehicles, how to measure the length of waiting vehicles, and what storage length coefficients to apply at real situations.

1.2 Scope and research flow

Urban intersections have variable shapes. Target intersections of the study are 4-leg urban intersections having only one left turn lane and 4 or 6 through lanes located in commercial areas. AM peak hour is selected for surveying time. Among 60 intersections in database systems of urban traffic volume survey in South Korea (Incheon metropolitan city, 2009), three intersections (Seokbawi, Su-in, Sungeuisijang) are selected as study intersections after checking out the land use maps.

Research flow contains introduction, literature review, problem identifications, developing a new method, and applying the new methodology followed by conclusions.

2. Literature Review

2.1 Left turn lanes on design manual of each country

Fig. 1 shows elements of left turn design on South Korea road design manual (KSCE, 2009).

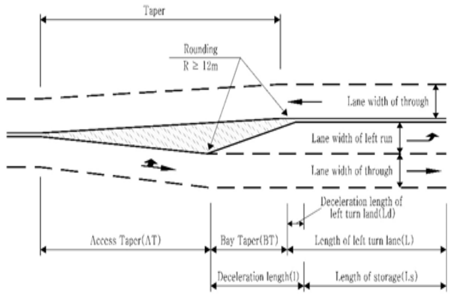


Fig. 1. Details of design rules of left turn storages

A left turn lane (L) consist of a left turn storage length (Ls) and a deceleration length (Ld) as shown in Eq. (1).

$$L = Ls + Ld \tag{1}$$

Ls can be obtained by multiplying a storage length coefficient (α), the number of arriving vehicles (N), and the length of waiting vehicles (S) as shown in Eq. (2).

$$Ls = \alpha \times N \times S \tag{2}$$

As to α, the values of 1.5 and 2.0 are used for signalized and unsignalized intersections, respectively. N is the number of arriving vehicles within 1 cycle for signalized intersections, or within 1 minute for unsignalized intersection.

In the case of Japan, a similar method applies. Calculating formula of right turn lane length in Japan is shown in Eq. (3) (JRA, 2005).

$$L = \ell d + \ell s \tag{3}$$

L is the length of right turn lane, ℓd is the length of taper, and ℓs is the length of storage lane as shown in Fig. 2.

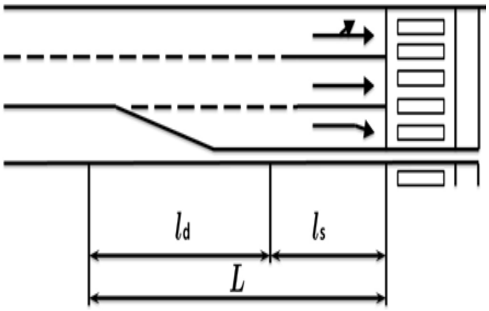


Fig. 2. Right turn lane length suggested in guidelines for road structures in Japan

ℓs can be obtained by multiplying a storage length coefficient (λr), the number of arriving vehicles (N) per 1 cycle, and the average headway (S) as shown in Eq. (4).

$$\ell s = \lambda r \times N \times S \tag{4}$$

A Policy on Geometric Design of Highways and Streets (AASHTO, 2011) says that a left turn lane consists of decelerating length of left turn lane, a taper, and a storage lane. At unsignalized intersections, the storage length should be determined by average arriving vehicles within 2 minutes at peak hours, or at least the length of 2 vehicles when the ratio of heavy vehicles is more than 10 %. At signalized intersections, the storage length should be based on one or one and half times to arriving vehicles. Even more, the storage length can be expanded to two times to arriving vehicles.

Urban Street Geometric Design Handbook (ITE, 2008) suggests to look up Urban Intersection Design Guide (TxDOT, 2005) about left turn lane designs. Urban Intersection Design Guide explains that left turn lane length is consist of decelerating length of left turn lane, a taper, and a storage lane, similar explanation to A Policy on Geometric Design of Highways and Streets (AASHTO, 2011).

2.2 Left turn lanes and U-Turns on papers and guidelines

Qi *et al.* (2007) developed a method for estimating the storage lengths of left-turn lanes at signalized intersections. The method was based on the discrete-time Markov chain simulation considering arrival rates and service rates of intersections. Kim (2002) calculated the length of storage and headways according to U-Turn existence. Lee (2009) pointed out problems about using Poisson distribution. He counted the number of observed vehicles after classifying intersections according to U-turn existence, and found that negative binomial distribution is more appropriate to explain arriving characteristics. When applying negative binomial distribution instead Poisson distribution, it is also found that the length of storage lane is calculated longer.

MNDOT (2008) developed formulas for calculating the storage lane length by classifying left turns into protected, permitted and yield as shown in Table 2.

Table 2. Models for left turn lane lengths by MNDOT

Speed	Storage length		
	Deceler-ation	Taper	Storage length
30	170	100	*LTprot* = 35.3 + 0.0203**TV* + 1.14**LTV* - 0.171**Sp* - 6.75**HVT* + 1.32**HVL* - 0.16**Gr*
35	170	100	
40	275	130	
45	340	130	*LTperm* = 45.2 - 0.00953**TV* + 0.0406**OV* + .610**LTV* + 0.348*Sp + 0.812**HVT*+ 1.76**HVL* + 0.35**Gr*
50	410	130	
55	485	130	
60	485	130	
65	485	130	*LTyield* = 0.00 + 0.00315**TV* + 0.0332**OV* + 0.345**LTV* - 0.149**Sp* + 0.224**HVT* + 0.629**HVL* - 0.080**Gr*
70	485	130	

TV : Through Vehicles
LTV : Left Turn Vehicles
Sp : Speed
Gr : Grade
HVT : Heavy Vehicle Through
HVL : Heavy Vehicle Left Turn
OV : Opposite vehicle

3. Problem Identification and Finding Improved Methodology

As mentioned above, Problems of existing design techniques are applying the same number of left turn vehicles (N) using Poisson distribution without considering land use types, using a vehicle length that may not be measurable when applying the length of waiting vehicles (S), and using same storage length coefficient (α), 1.5 for every signalized intersections.

3.1 Finding improved methodology

To get the number of arriving vehicles at signalized intersections, most cases apply Poisson distribution as shown in Eq. (5).

$$P(x) = \frac{m^x e^{-m}}{x!} \tag{5}$$

where, x is the number of arrival vehicles in a given unit time, $P(x)$ is arrival probability that x vehicles occur, and m is the average number of left turn vehicles in one unit time. Mean and variance of x are m. As all know, Poisson distribution is only suitable for the events that are random and rare (Do, 2005). Therefore, using Poisson distribution is not relevant to apply urban intersections specially in commercial areas. Indeed, it is very hard to find a suitable distribution model to fit into real situations.

This study suggests using an empirical distribution. In many situations we might want to use the observed data themselves to specify directly (in some sense) a distribution, called an empirical distribution, from which random values are generated during the simulation, rather than fitting a theoretical distribution to the data (Law and Kelton, 2007). For continuous random variables, the type of empirical distribution that can be defined depends on whether we have the actual values of the individual original observations $X1$, $X2$, ..., Xn rather than only number of $X(i)$'s that fall into each of several specified intervals. Let $X(i)$ denote the ith smallest of the Xj's, so that $X(1) \leq X(2) \leq \ldots \leq X(n)$. Then F is given by Eq. (6). Fig. 3 gives an illustration for n=6.

$$F(x) = \begin{cases} 0 & \text{if } x < X(1) \\ \frac{i-1}{n-1} + \frac{x - X(i)}{(n-1)(X(i+1) - X(i))} & \text{if } X(i) \leq x \leq X(i+1) \text{ for } i = 1, 2, \ldots, n-1 \\ 1 & \text{if } X(n) \leq x \end{cases} \tag{6}$$

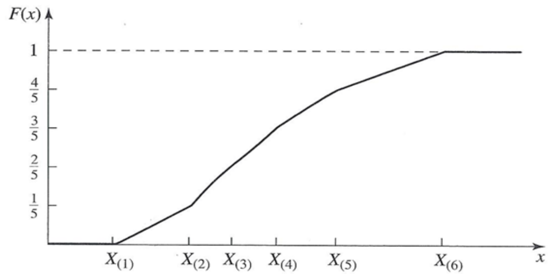


Fig. 3. Empirical cumulative distribution illustration when n=6

3.2 Methodology for improvement getting the length of waiting vehicle (S)

In Eq. (2), the length of waiting vehicles can be only obtained by observation. Then, the design value of lengths, S, might be an average value or a sum of every observed vehicle type lengths.

In existing methods, 7 m is used for an average value and 6 m for passenger cars and 12.0 m for trucks. This procedure does not consider the spacing between vehicles causing shorter length of storage lanes.

Therefore, this study suggests to apply the average headway based on empirical distribution of arriving vehicles and using UAV spatial images instead of using the length of vehicles.

3.3 Methodology for selecting the values of storage length coefficients

As mentioned earlier, the values of storage length coefficients (α) are 1.5 for signalized intersections and 2.0 for unsignalized intersections. This method is too strict and not efficient to various intersections in urban commercial areas.

This study suggests to use different values for each intersection considering different environments discussed later.

4. Application of Developed Methodology

4.1 The number of left turn vehicles (N) at signalized intersections

To get the number of left turn vehicles by building up empirical distribution, field survey should be preceded.

We had field surveyed intersections satisfying 4-leg, no U-turns, only one left turn lane, and four or six through traffic lanes located in commercial areas. Within 60 intersections, we found only three signalized intersections satisfying conditions mentioned, Seokbawi, Su-in, and Sungeuisijang intersections located in Incheon metropolitan city, South Korea. Characteristics of field investigation for study intersections are shown in Table 3.

Based on field survey, we collected data such as the number of arrival vehicles per cycle, observation frequency per cycle, total volume, observation probability, accumulated observation frequency and accumulated observation probability as shown in Table 4.

Table 3. Characteristics of study intersections through field investigation

Classification	Investigation date and time	Investigation direction	Signal cycle	Left turn time
Seokbawi intersection	7/4/2013 (Fri) 07:30~08:30	Gyeonginno (old civic center intersection) → Gyeonginno (direction to Seokam intersection)	170 sec	30 sec
Su-in intersection	7/8/2013 (Mon) 07:15~08:15	Injoongno (Shinkwang intersection) → Seohaedaero (direction to Lotte mart)	160 sec	30 sec
Sungeuisijang intersection	9/27/2013 (Tue) 08:00~09:00	Chamwoijunno (Enterance of Namgu office three legs intersection) → Sukjungro (Soongeui rotary)	160 sec	30 sec

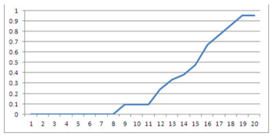
Table 4. Contents of field investigation about study intersections

Classification	Number of vehicle/cycle	Observation frequency	Total volume	Observation probability	Accumulated observation frequency	Accumulated observation probability
Seokbawi intersection	0	0	0	0	0	0
	1	0	0	0	0	0
	2	0	0	0	0	0
	3	0	0	0	0	0
	4	0	0	0	0	0
	5	0	0	0	0	0
	6	0	0	0	0	0
	7	0	0	0	0	0
	8	2	16	0.095238	2	0.095238
	9	0	0	0	2	0.095238
	10	0	0	0	2	0.095238
	11	3	33	0.142857	5	0.238095
	12	2	24	0.095238	7	0.333333
	13	1	13	0.047619	8	0.380952
	14	2	28	0.095238	10	0.47619
	15	4	60	0.190476	14	0.666667
	16	2	32	0.095238	16	0.761905
	17	2	34	0.095238	18	0.857143
	18	2	36	0.095238	20	0.952381
	19	0	0	0	20	0.952381
	20	1	20	0.047619	21	1

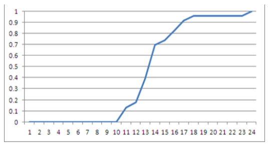
Seokbawi intersection	0	0	0	0	0	0
	1	0	0	0	0	0
	2	0	0	0	0	0
	3	0	0	0	0	0
	4	0	0	0	0	0
	5	0	0	0	0	0
	6	0	0	0	0	0
	7	0	0	0	0	0
	8	0	0	0	0	0
	9	0	0	0	0	0
	10	3	30	0.130435	3	0.130435
	11	1	11	0.043478	4	0.173913
	12	5	60	0.217391	9	0.391304
	13	7	91	0.304348	16	0.695652
	14	1	14	0.043478	17	0.73913
	15	2	30	0.086957	19	0.826087
	16	2	32	0.086957	21	0.913043
	17	1	17	0.043478	22	0.956522
	18	0	0	0	22	0.956522
	19	0	0	0	22	0.956522
	20	0	0	0	22	0.956522
	21	0	0	0	22	0.956522
	22	0	0	0	22	0.956522
	23	1	23	0.043478	23	1
Sungeuisijang intersection	0	0	0	0	0	0
	1	1	1	0.043478	1	0.043478
	2	2	4	0.086957	3	0.130435
	3	1	3	0.043478	4	0.173913
	4	2	8	0.086957	6	0.26087
	5	6	30	0.26087	12	0.521739
	6	3	18	0.130435	15	0.652174
	7	2	14	0.086957	17	0.73913
	8	0	0	0	17	0.73913
	9	2	18	0.086957	19	0.826087
	10	3	30	0.130435	22	0.956522
	11	0	0	0	22	0.956522
	12	1	12	0.043478	23	1

Accumulated observation probabilities of each intersection are shown in Fig. 4.

Seokbawi intersection



Su-in intersection



Sungeuisijang intersection

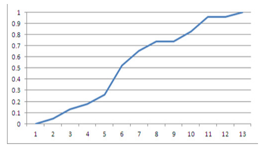


Fig. 4. Accumulated observation probabilities of study intersections

Since three intersections show similar characteristics, it is possible to combine field survey data into one set to get one accumulated empirical probability distribution. It is notable that this procedure may not appropriate to other cases where study intersections are located different sites such as residential, commercial, industrial, and office areas, and having different characteristics. Obtained data sets for three intersections are shown in Table 5.

Table 5. Data for diagraming empirical distributions

Number of vehicle/cycle	Observation frequency	Observation probability (%)	Accumulated observation frequency	Accumulated observation probability (%)	Percentage difference (%)
0	0	0	0	0	-
1	1	0.9	1	0.9	0.9
2	2	1.8	3	2.7	1.8
3	1	0.9	4	3.6	0.9
4	2	1.8	6	5.4	1.8
5	6	5.4	12	10.8	5.4
6	3	2.7	15	13.5	2.7
7	2	1.8	17	15.3	1.8
8	2	1.8	19	17.1	1.8
9	2	1.8	21	18.9	1.8
10	6	5.4	27	24.3	5.4
11	4	3.6	31	27.9	3.6
12	8	7.2	39	35.1	7.2
13	31	27.9	70	63.1	27.9
14	3	2.7	73	65.8	2.7
15	6	5.4	79	71.2	5.4
16	4	3.6	83	74.8	3.6
17	3	2.7	86	77.5	2.7
18	2	1.8	88	79.3	1.8
19	0	0.0	88	79.3	0.0
20	1	0.9	89	80.2	0.9
21	21	18.9	110	99.1	18.9
22	0	0.0	110	99.1	0.0
23	1	0.9	111	100.0	0.9

The accumulated empirical probability distribution is shown in Fig. 5.

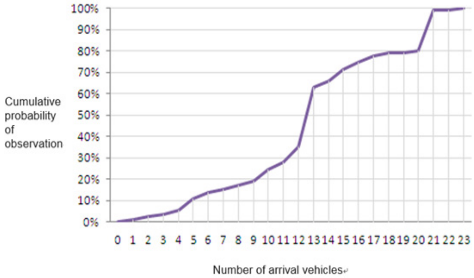


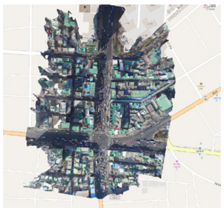
Fig. 5. Empirical left turn arrival distribution diagram in urban signalized commercial intersections

Fig. 5 explains a lot. If you have enough budgets and spaces for left turn vehicles, you can provide the length of storage lane containing 21 vehicles. However, if you have budget and space constraints, you may provide the length of storage lane containing only 12.5 vehicles satisfying only 50% of arriving vehicles. Once getting this type of accumulated empirical probability distribution diagram, planners and engineers can get help how to decide intersection design of left turn lanes.

4.2 The headways (S) at signalized intersections

We used UAV spatial images to measure left turn storage lengths of three intersections and headways. The UAV took photos from the top of the each site and imposed to an opened portal map service in public to precisely find left turn storage lengths. Details about headway and left turn storage length of each intersection are shown in Table 6. Buses were not observed during field survey in Su-in intersection.

Table 6. Storage lengths and headways of study intersections

<table>
<tr><th rowspan="2">Classification</th><th rowspan="2">Left turn storage length (m) (A)</th><th rowspan="2">Number of storage vehicles (vehicle) (B)</th><th rowspan="2">Headway (m) (A/B)</th><th colspan="2">Number of storage vehicles when mixing the trucks (vehicle)</th><th colspan="2">Headway per vehicle (m)</th></tr>
<tr><th>Bus</th><th>Large truck</th><th>Bus</th><th>Large truck</th></tr>
<tr><td rowspan="2">Seokbawi intersection</td><td>172</td><td>26</td><td>6.61</td><td colspan="2">24</td><td colspan="2">13.2</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="2">Su-in intersection</td><td>135</td><td>18</td><td>9.56</td><td>-</td><td>16</td><td>-</td><td>19.1</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="2">Sungeuisijang intersection</td><td>110</td><td>14</td><td>7.86</td><td colspan="2">12</td><td colspan="2">15.68</td></tr>
<tr><td colspan="7"></td></tr>
</table>

Then, average headways for vehicle types are calculated as shown in Table 7 using UAV spatial images. Calculated average headways are 8.01 m for passenger cars, 14.44 m for buses, and 15.99 m for trucks, respectively.

Table 7. Average headways of study intersections by vehicle types

Classification	Passenger car (m)	Bus (m)	Large truck (m)
Average headway	8.01	14.44	15.99
Seokbawi intersection	6.61	13.2	13.2
Su-in intersection	9.56	-	19.1
Sungeuisijang intersection	7.86	15.68	15.68

Table 8 shows comparisons between investigated headways and vehicle lengths of design standard.

Table 8. Comparing investigated average headways with vehicle length of design standards

Classification	Vehicle length by design standards	Existing vehicle length (A)	Investigated average headway (B)	$\lvert A\text{-}B \rvert$
Passenger car	6.0	6.0	8.01	2.01
Bus	13.0	12.0	14.44	2.44
Large truck	16.7		15.99	3.99

We found length differences of 2 m for passenger cars, 2.5 m for buses, and 4m for trucks, respectively. This result means that existing methodology calculates shorter left turn storage than needed lengths at fields and generates congestions.

It is helpful if we have information about the ratio of heavy vehicles in commercial areas in Incheon metropolitan city when using Table 8. After additional investigation, we found the ratio of heavy vehicles (buses and trucks). Among left turn vehicles, the ratios of heavy vehicles are found to be 4.45 %(buses occupy 2.83 % and trucks occupy 1.62 %, respectively) as shown in Table 9. This result can be used to calculate the left turn storage length at other similar intersections in commercial areas located in Incheon metropolitan city.

Table 9. Rates of large trucks among left turn vehicles at urban commercial areas

Classification	Total number of vehicles	Passenger car (vehicle)	Bus (vehicle)	Large truck (vehicle)
Rate (%)	-	95.55	2.83	1.62
Sum	742	709	21	12
Seokbawi intersection	296	277	18	1
Su-in intersection	308	298	0	10
Sungeuisijang intersection	138	134	3	1

4.3 Storage length coefficient (α) at signalized intersections

The developed method may not need to use a storage length coefficient theoretically since it directly uses the number of arriving vehicles from an empirical distribution and the average headways. However, in real traffic situations, an uncertainty always inherits. Empirical distribution may change over time and the ratio of heavy vehicles can be changed. Vehicle types and specifications may also change over time.

Therefore, for sustainable design and safety purposes, flexibility should be provided at most of the design standard manuals.

From the literature review and other considerations, this study suggests to apply the values of 1.0 through 1.5 for the storage length coefficients as shown in Table 10.

Since 1.0 means only considering the minimum headway of arriving vehicles and 1.5 means providing maximum

Table 10. Current and suggested coefficients for left turn storage lengths

Classification	Coefficients of signalized intersection	Note
Existing coefficient	1.5	
Suggested coefficient	1.0~1.5	Standard is 1.0 When considering secure safety, 1.0 ~ 1.5 can be applied

safety countermeasures considering uncertainty for design purposes at signalized intersections, fixing the value of coefficient at the level of design manual is not appropriate.

It is rather better for engineers to survey and determine the value of coefficient according to the environment of intersections considering.

4.4 Calculating relevant length of left turn storages at signalized intersection

Table 11 summarizes the developed calculating method for relevant length of left turn storages.

For more simplicity, Table 12 provides formulas for the cases whether we know the ratio of heavy vehicles or not.

Table 11. Developed method for calculating length of left turn storages for signalized intersections in urban commercial areas

$Ls = \alpha \times N \times S$
Ls : Length of left turn storage α : Length coefficient (signalized intersection : 1.0~1.5) N : The number of left turn vehicles (vehicle) (arrival vehicles per 1 cycle) S : Average headway by vehicle types (m)

5. Conclusions

This study developed a method for calculating relevant length of left turn storage lengths based on an empirical arriving distribution at signalized intersections in urban commercial areas in Incheon metropolitan city, South Korea. This study show several results.

First, empirical distributions are developed for arriving distributions at signalized intersections in urban commercial areas to count the number of arriving vehicles. This empirical distribution method can be applied practically in any intersections where the number of arriving vehicles is concerned.

Secondly, this study suggests using an average headway using UAV spatial images instead of using an average length of vehicles for the waiting vehicles. Using an average headway of waiting vehicles can be more practical and efficient to accommodate characteristics of waiting vehicles.

Thirdly, the relevant range of storage length coefficients is designed to add flexibility of designing left turn storages instead of using some specified values that are not realistic in most cases.

Table 12. Formula for length of left turn storages in urban commercial area

When impossible to know about ratio of heavy vehicles	Minimum length	$Ls_{\min} = 8.322N$ where $Ls_{\min}$: Minimum length of storages N : Number of left turn vehicles (vehicle)
	Maximum length	$Ls_{\max} = 12.483N$ where $Ls_{\max}$: Minimum length of storages N : Number of left turn vehicles (vehicle)
When possible to know about ratio of heavy vehicles	Minimum length	$Ls_{\min} = \frac{N}{100} \times (8.01P + 14.44B + 15.99T)$ where $Ls_{\min}$: Maximum length of storages N : Number of left turn vehicles (vehicle) P : Ratio of passenger cars (%) B : Ratio of buses (%) T : Ratio of large trucks (%)
	Maximum length	$Ls_{\max} = \frac{1.5N}{100} \times (8.01P + 14.44B + 15.99T)$ where $Ls_{\max}$: Minimum length of storages N : Number of left turn vehicles (vehicle) P : Ratio of passenger cars (%) B : *Ratio of buses (%)* T : Ratio of large trucks (%)

Fourthly, formulas are developed to calculate relevant length of left turn storages when impossible to know, and possible to know ratio of heavy vehicles at urban commercial areas based on vehicle types.

By applying the develop method and values, rear-end collisions caused from irrelevant left turn storage lengths can be decreased and more efficient signalized intersection operation can be accomplished.

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