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버스 停留場의 容量 算定

ESTIMATING THE CAPACITY OF A BUS BERTH

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慶尙大學校 都市工學科 敎授
金 京 煥
(Kyung-Whan Kim, Ph.D.)

東亞大學敎 都市工學科 敎授
吳 允 杓
(Yun-Pyo Oh, D.Eng.)

交通環境硏究院 硏究員
金 錫 柱
(Seok-Ju Kim, M.S.)

Ⅰ. INTRODUCTION

The primary cause of today's traffic problems in Korea is that the improvements of transportation facilities are behind of the increase of car ownership and transportation demand. Several alternatives can be considered for countermeasures of the problems. However, increasing the ride share of transit is being recognized as the best alternative, considering the capital investment for the construction of highways and parking lots, the availability of right of way, energy consumption, urban environment, etc. Using transit can reduce traffic volume on streets and relieve traffic problems while providing the necessary travel for urban activities.

The first bus transit in Korea was operated in August, 1912 by a Japanese, Egawamijjimasa(繪川道正), between Chinju and Masan and between Chinju and Samchonpo in southern part of Korea[1]. Today the numbers of lines and buses of urban bus transit in Korea are 6,096 and 28,988 respectively, and the bus transit is serving as principal transit. Table 1 shows the modal split of urban travel of several cities in Korea. It can be ascertained that the bus transit is the primary transportation mode in urban areas in Korea.

Table 1. Modal Split of Urban Travel

City	Mode					Survey Year
	Bus	Subway	Taxi	Private Car	Other	
Seoul	38.6	25.6	11.8	14.6	9.8	1993
Pusan	38.3	8.6	18.7	21.1	13.3	1994
Taejon	36.1	-	22.9	17.7	23.4	1992
Ulsan	34.5	-	17.0	18.8	30.4	1992
Chinju	35.5	-	13.4	21.9	29.2	1994

The service level of bus transit is lower than that of rail transit, but the bus transit has the advantages of using existing highways, being easy to adjust the capacity and the level of service, and being easy to change the line. Especially, the bus transit is the most competitive transit in small/medium cities where the rail transit is not feasible economically, and the bus can be used as feeder lines of the rail transit in large cities.

The ride share of the bus transit should be increased in order to carry out its function as transit by providing high level of service. For the bus transit, the service level at bus stops composes moderate portion of the service level of a trip by bus.

In case of the shortage of the capacity at off-street bus stops, the bus has to wait on the travel lane of a street until the berth is available. In case of the excess of the capacity of linear bus stops, there is inconvenience for the passengers to ride a bus because the variance of stop position is large. For a bus to wait on the travel lane because of the shortage of bus stop capacity blocks a lane of the street and causes traffic accidents by making the following vehicles change the lane.

Therefore, the exact estimation of a bus berth is important in order to provide the adequate size of a bus stop and to plan the adequate operation of buses for a bus stop. In Korea, there is no research about the capacity of a bus berth, so the U.S. HCM models, which are developed for the exclusive bus lane, are used to estimate the capacity. But, most of the transit buses are operating by sharing the lane with other vehicles, so it is not possible to estimate the capacity exactly with the U.S. HCM methods.

In this study, the problems of U.S. HCM models for the estimation of the capacity of a bus berth is analyzed by using Korean data and new models suitable for Korean traffic conditions are suggested. The models may be used in China.

Ⅱ. LITERATURE REVIEW

In the research of bus transit in Korea, the numbers of the berth at bus stops was determined in order that the probability of queues forming behind the bus stop should be lower than a limit by using the queuing theory[2], and the berth capacity was determined using the U.S. HCM[3] models. The U.S. HCM divides the bus flow into unite uninterrupted flow(no delays caused by traffic signals) and interrupted flow by traffic signals, and estimates the capacity of each flow separately. The equations for the estimation are as follows.

1. Uninterrupted Flow, No Delays Caused by Traffic Signals.

The numbers of buses per berth per hour can be estimated from the following set of equations.

$$f' = \frac{3,600R}{h'} = \frac{3,600R}{D + t_c} \quad \cdots \text{(eq. 1)}$$

where:

h = minimum headway at the bus berth or stop, in sec;

D = dwell times at bus berth or stop, in sec;

t_c = clearance time between successive buses, in sec;

R = reductive factor to compensate for dwell time and arrival variations; and

f' = maximum buses per berth per hour.

In estimating the total time that buses spend at a stop, the time spent opening and closing doors should be taken into account. This normally approximates 4 to 5 seconds. This door opening and closing time is included in the clearance time between buses and the clearance time normally approximates 10 to 15 seconds.

The reductive factor R is 0.833 for maximum bus capacity. This occurs when one-third of all buses are waiting in approach queues, reducing the capacity of the berth to about three-quarters of the ideal value.

The minimum headway, h' , can be obtained as follows:

Boarding only; one way flow

$$h' = bB + t_c \quad \cdots \text{(eq. 2)}$$

Alighting only; one way flow

$$h' = aA + t_c \quad \cdots \text{(eq. 3)}$$

Two-way flow through door

$$h' = [aA + bB + t_c] \quad \cdots \text{(eq. 4)}$$

where:

A = alighting passengers per bus, in peak 15 min;

a = alighting survice time, in sec per passenger;

B = boarding passengers per bus, in peak 15 min; and

b = boarding service time, in sec per passenger.

Where passengers enter via the front door, and exit via the rear door, the greater result from eq. 2 and eq. 3 determines the minimum headway. For heavy two-way flow through a single door, the headways in eq. 4 could be increased by 20 percent.

2. Bus Flow Interrupted by Traffic Signals

The numbers of buses that can stop for passengers and then pass through a signalized intersection can be estimated from eq. 5 and 6. These equations assume that the time spent loading and/or discharging passengers on the green, g, and red, r, phases are proportional to the g/C and r/C ratios, respectively. The HCM states that the equations are precise for near side stops and provide a reasonable approximation for far side stops.

$$f_c' = \frac{g}{t_c + D(g/C)} \qquad \text{(eq. 5)}$$

$$f' = (g/C)\frac{3,600R}{t_c + D(g/C)} \qquad \text{(eq. 6)}$$

where:

g = green(plus yellow) time per cycle, in sec;

C = cycle time, in sec;

f_c = buses per cycle;

D = dwell time per bus, in sec;

t_c = clearance time per bus, in sec; and

f = buses per hour.

Note that as g/C approaches one, eq. 6 and eq. 1 become identical. Both equations assume that there is no other traffic in the bus lane and that buses do not pass and overtake each other.

3. Levels of Service and Berth Use Efficiency

Suggested levels of service for the number of buses per berth(i.e., per stop) are in Table 2. The levels of service are keyed to the approximate probability or likelihood of queues forming behind the bus stop.

Table 2. Levels of Service for Bus Stops[3)]

1 Level of Service (LOS)	2 R Value	3 Effective sec/hour (3,600R)	4 Index LOS E=1.00	5 Approx. Probability of Queue Forming behind Bus Stop
A	0.400	1,200	0.40	1
B	0.500	1,800	0.60	2.5
C	0.667	2,400	0.80	10
D	0.750	2,700	0.90	20
E(Capacity)	0.833	3,000	1.00	30
Capacity E-Perfect Condition	1.00	3,600	-	50

Each loading positions at a multiple-berth stop does not have the same capacity as a single berth stop. This is because it is not likely that the loading position at a multiberth stops will be equally used, or that passengers will distribute equally among loading positions. Buses also may be delayed in entering or leaving a berth by buses in adjacent loading positions.

Suggested "berth efficiency factors" in U.S. HCM are given in Table 3 for "on line" and "off line" stops.

Table 3. Efficiency of Multiple Linear Bus Berths[3)]

Berth no.	On-Line Stations		Off-Line Stations	
	Efficiency %	No. of Cumulative Effective Berths	Efficiency %	No. of Cumulative Effective Berths
1	100	1.00	100	1.00
2	75	1.75	85	1.85
3	50	2.25	75	2.60
4	20	2.45	65	3.25
5	5	2.50	50	3.75

NOTE: On-line station figures assume that bubes do not overtake each other.

Ⅲ. DATA COLLECTION AND ANALYSIS

1. Conditions of the Study Bus Stops

Two bus stops were selected as the study bus stops which were multiple linear berth and off-line stops. The stops are positioned at both side of a street and are located in downtown of Chinju City, in the southern part of Korea. One of them, Nonghyup Building Stop, is positioned 30m away backward from the stop line of a signalized intersection, so the stop is regarded as a typical near side bus stop. Another stop, Daewoo Building Stop, is positioned 50m away forward from the signalized intersection, so the stop is regarded as a typical far side bus stop. The buses share a lane with other traffic on the street. The traffic signal timing of the intersection is shown in Figure 1.

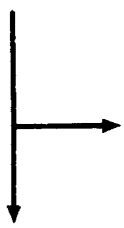
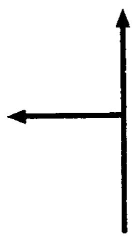
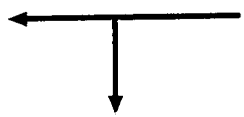
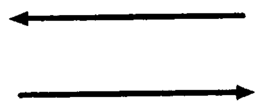
Phase(Ⅰ)	Phase(Ⅱ)	Phase(Ⅲ)	Phase(Ⅳ)
			
36(3) sec	37(3) sec	37(3) sec	27(3) sec

Figure 1. Signal Timing of the signalized Intersection

In the field study, two notable characteristics of bus operation were observed. At the Nonghyup Building Stop, the bus which has completed alighting and boarding services during the red traffic signal has to wait at the berth until the traffic signal changes to green signal because other vehicles occupy the lane from the bus stop to the intersection. At the Daewoo Building Stop, all buses entered the stop during the green signal of the opposite approach of the intersection, so the stop is very crowded during the signal. But the stop is distant enough from the forward signalized intersection, so there is not the leaving characteristics like the Nonghyup Building Stop.

2. Data Collections and Analysis

In the field study, provided that the signal waiting times of the near side bus stop can be estimated reliably, it is judged that the waiting times could be used as a variable for the estimation of the bus stop capacity. Thus, the waiting times were observed.

For the estimation of the dwell times which is the main variables in the estimation of the bus stop capacity, the alighting and boarding service times were observed. For the observation a 8 mm video camera was used.

1) Alighting and Boarding Times

The alighting and boarding time distributions of each bus stop are shown in Figure 2 and 3, respectively. The summary of the alighting and boarding times per passenger are shown in Table 4. The average alighting time was analyzed to be 1.7 seconds and the average boarding time was done to be 1.9 seconds.

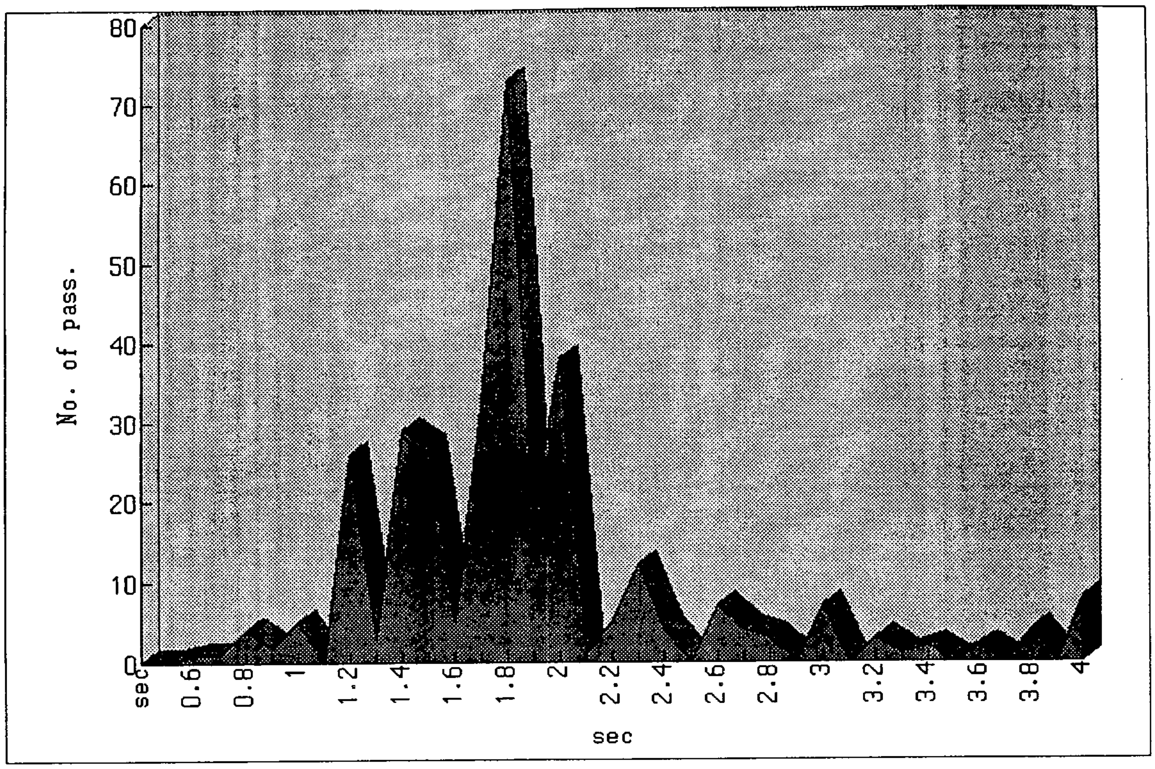
Table 4. Summary of Alighting and Boarding Times per Passenger

Boarding/ Alighting	Bus Stops	No. of Data	Average of the Times	Total Average of the Times
Boarding	Nonghyup Building	327	1.88	1.9
	Daewoo building	418	1.90	
Alighting	Nonghyup Building	421	1.69	1.7
	Daewoo Building	453	1.64	

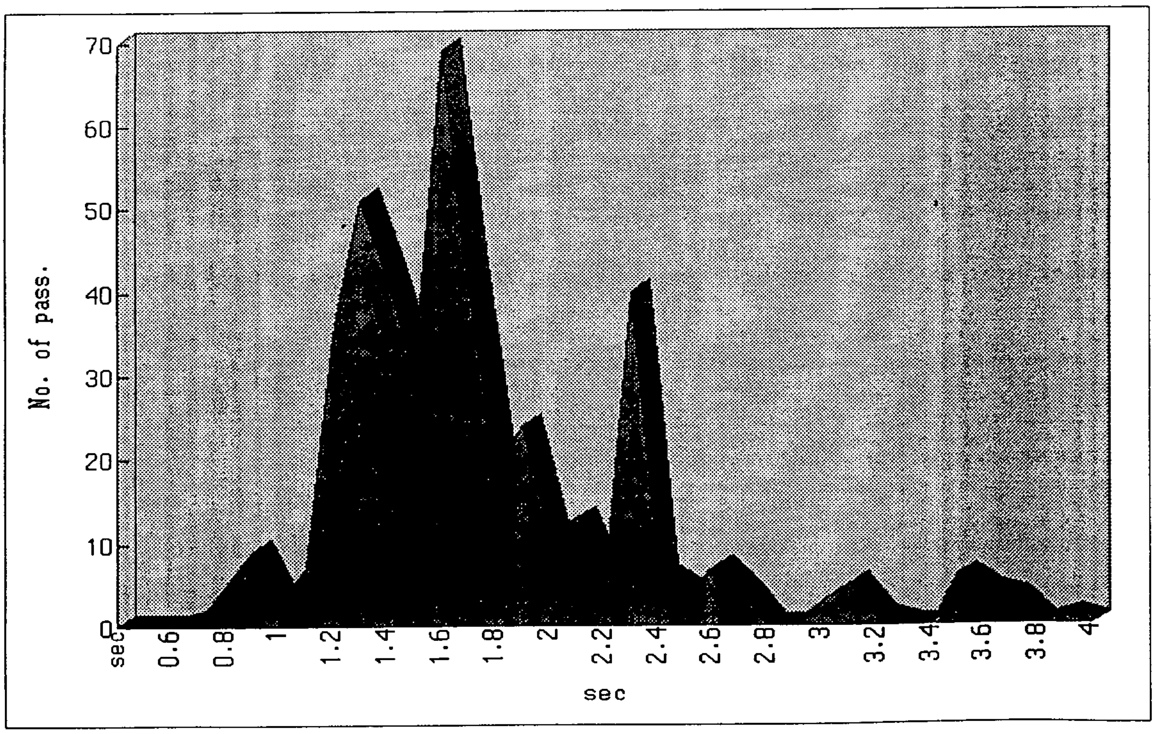
The bus passengers in Chinju City are charged single fare of prepayment, and enter via the front door and exit via the rear door, and carry very little hand baggage/parcels. As the observed value in U.S. on similar conditions is that the alighting and boarding times are 1.5~2.5 seconds and 2~3 seconds respectively[4)], the boarding time is moderately larger than the result of this study.

2) Signal Waiting Time

The signal waiting time is defined to be the interval from a bus completing the service at a bus stop to leaving the bus stop. If buses arrive uniformly, the average

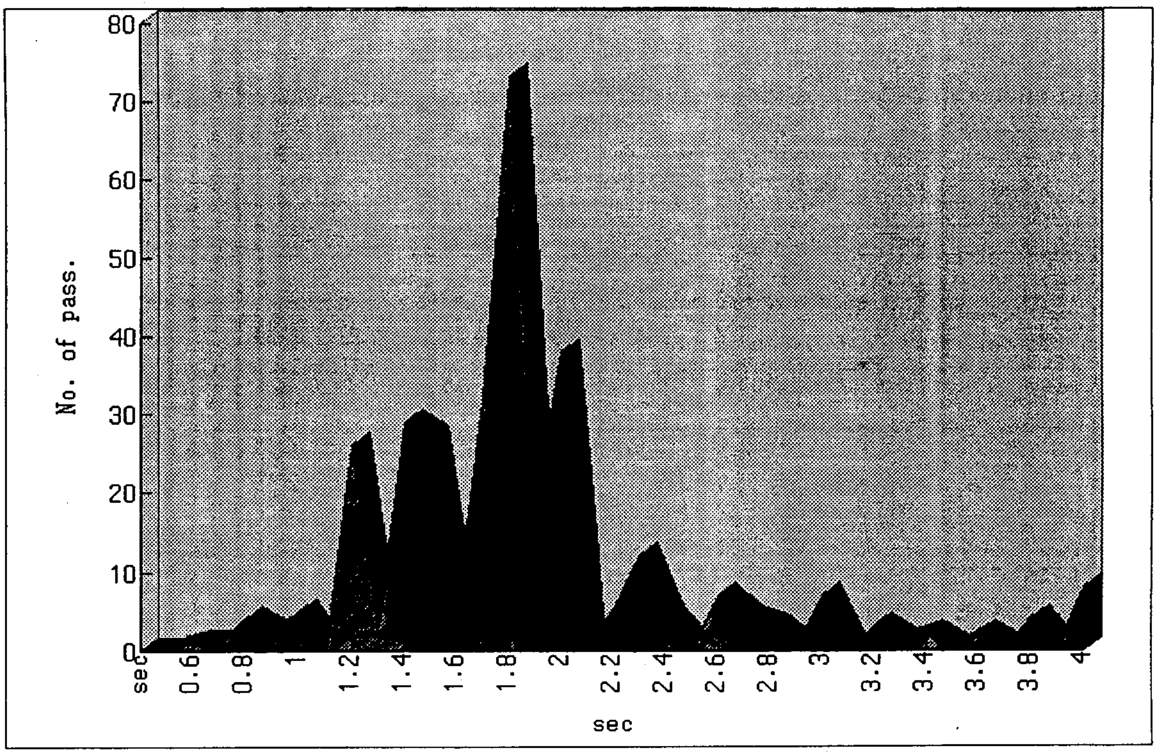


(a) Boarding Time

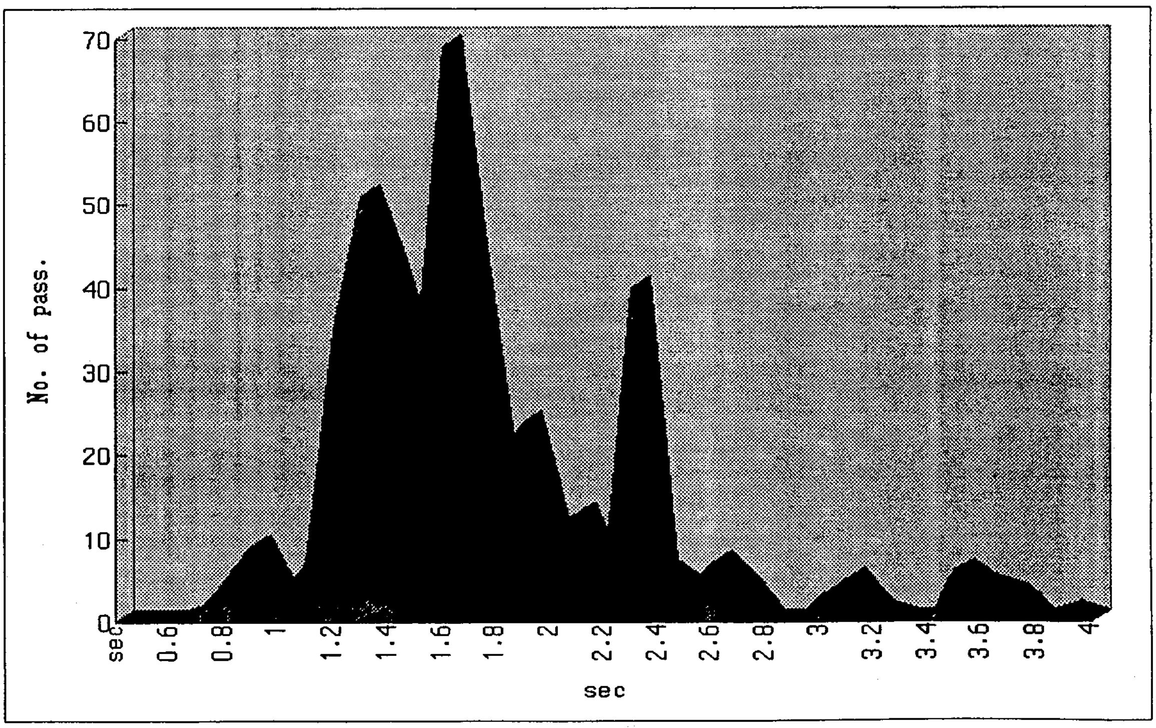


(b) Alighting

Figure 2. Boarding and Alinghting Time Distribution at the Nonghyup Building Bus Stop



(a) Boarding Time



(b) Alighting

Figure 3. Boarding and Alinghting Time Distribution at the Daewoo Building Bus Stop

waiting time of the buses which arrive during red traffic signal will be a half of the red signal time. And, the total waiting time of all buses which enter the bus stop will be obtained by multiplying the number of buses which arrive during the red signal by the average waiting time of them. The average waiting time(t_w) of all buses can be obtained by dividing the total waiting time by the total number of buses. The above statement can be represented as following equations:

$$T_w = \frac{r}{2} \times q\frac{r}{C} \qquad \cdots \text{(eq. 7)}$$

$$= \frac{qr^2}{2C}$$

$$t_w = \frac{T_w}{q} \qquad \cdots \text{(eq. 8)}$$

$$= \frac{r^2}{2C}$$

where:

T_w= total waiting time per cycle, in vehicle-sec;

r = red signal time, in sec;

q = vehicles per cycle;

C = cycle time, in sec; and

t_w = average waiting time per vehicle, in sec/vehicle.

As shown in eq. 8, the average waiting time per vehicle is the function of the red signal time and the cycle time if buses arrive uniformly. When the eq. 8 is applied to the Nonghyup Building Stop,

$$t_w = \frac{r^2}{2C}$$

$$= \frac{114^2}{2} \times 150 = 43.3\,\text{sec}.$$

The observed data in the field study of the Nonghyup Building Stop, the number of buses per cycle, the waiting time of individual bus, and the average waiting time per bus per cycle during 19 cycles are shown in Table 5. The average waiting time and its variance were 45.2 seconds and 57.3 seconds^2, respectively.

Table 5. Distribution of Signal Waiting Time of Buses per Cycle

Cycle No.	No. of Buses Arrived	Signal Waiting Time per Bus	Average of the Waiting time
1	2	61, 4	32.5
2	2	67, 7	37.0
3	3	3, 119, 13	45.0
4	2	85, 7	46.0
5	2	55, 4	29.5
6	3	3, 5, 112	40.0
7	2	91, 9	50.0
8	2	88, 7	47.5
9	2	69, 11	40.0
10	3	48, 88, 17	51.0
11	2	24, 74	49.0
12	3	30, 2, 83	38.3
13	3	42, 99, 19	53.3
14	2	70, 35	52.5
15	3	91, 77, 5	57.7
16	2	76, 37	56.5
17	3	44, 90, 8	47.3
18	3	69, 33, 18	40.0
19	2	79, 13	46.0
Total	46		859.1
Average	2.42	-	45.2
Variance	-		57.3

For the hypothesis test of the average waiting time, 43.3 seconds, which was calculated by the eq. 8, the "t" value was calculated and compared with the criterion as follows:

$$\hat{t} = \frac{\bar{x} - \mu_0}{s\sqrt{n}}$$

$$= \frac{45.2 - 43.3}{\sqrt{57.3}/\sqrt{19}} = 1.083 < t_{0.025,\ 18} = 2.101$$

Thus, as the calculated average waiting time, 43.3 seconds, is moderately less than the surveyed 45.2 seconds, it is concluded that the eq. 8 can be used to estimate the average signal waiting time at the near side bus stop.

Ⅳ. ESTABLISHMENT of CAPACITY ESTIMATION MODELS

In the field study, it was observed that the bus operation at the bus stop in the flow interrupted by traffic signal does not follow the assumptions of the U.S. HCM model. Therefore, the models to estimate realistic capacity at the bus stop are to be suggested in this study.

1. Capacity Estimation of Near Side Bus Stops

It was observed and noted that the capacity of the near side bus stop at a signalized intersection is influenced greatly by the signal waiting time, and the waiting time can be estimated reliably.

Using the waiting time, the minimum headway of buses at the bus stop can be represented as t_c+D+t_w, and the capacity, the number of buses per hour per berth at the near side bus stop, can be estimated applying follow equation.

$$f_c' = \frac{3,600R}{t_c + D + t_w} \qquad \cdots\cdots\cdots\cdots \text{(eq. 9)}$$

where:

$$t_w = \frac{r^2}{2C}.$$

The result of applying the eq. 9 to the Nonghyup Building Stop is as follows:

Dwelling time; as the average boarding and alighting passengers are 6.5 and 4.8 pass./bus respectively, the dwelling time, governed by the boarding time, is 12.4 seconds,

Clearance time; apply 15 seconds as suggested normally,

Signal waiting time; apply 43.3 seconds calculated using the eq. 8, and

$$f_c' = \frac{3,600 \times 0.833}{15 + 12.4 + 43.3} = 42.4 \text{ buses per berth per hour.}$$

Comparing the result of this study with that of the HCM, as the capacity by the HCM model(eq. 6) is 40.0 buses, the capacity of this study is a little larger than that of the HCM.

Applying the same conditions in clearance time and dwelling time, the result that compares the capacities by this study model with those by the HCM model by varying the cycle time and g/C is shown in Table 6. The capacity increases by increasing the g/C, but this study model is less sensitive. The HCM model is independent of the cycle time, but in this study model the capacity decreases as the cycle time increases; it is caused by the increased waiting time resulted from lengthening the cycle time. Excepting the realm where the cycle is long and the g/C is large, this study model has larger capacity than that of the HCM model. Especially, this study model has much larger capacity in the realm where the cycle is short and g/C is small. To the point that the capacity decreases as the cycle increases, this study model is thought to be more realistic.

Table 6. Comparision of Capacities of a Bus Berth for two Models

Cycle(sec)	g/C	U.S. HCM Model (buses/berth)	This Study Model (buses/berth)
60	0.2	34.31	64.35
	0.3	48.06	71.23
	0.4	60.10	78.50
	0.5	70.73	85.93
90	0.2	34.34	53.36
	0.3	48.06	60.64
	0.4	60.10	68.78
	0.5	70.73	77.59
120	0.2	34.31	45.57
	0.3	48.06	52.80
	0.4	60.10	61.20
	0.5	70.73	70.73
150	0.2	34.31	39.77
	0.3	48.06	46.75
	0.4	60.10	55.13
	0.5	70.73	64.98

2. Capacity Estimation of Far Side Bus Stops

Quite different from the near side bus stop, it was observed at the far side bus stop that buses arrive during certain phase of the traffic signal as the departure is not interrupted.

Among the phases of the traffic signal, when the phase which has highest arrival rate of buses is g′ , the model to estimate the capacity of the far side bus stop is suggested as follows:

$$f = \frac{3,600R(g'/C)}{D+t_c} \quad \text{. . . . . (EQ. 10)}$$

All the buses enter the Daewoo Building Stop during the through signal of the opposite approach, and the capacity of the stop can be estimated as follows using eq. 10:

Dwelling time; as the average boarding and alighting passenger are 3.7 and 8.7 pass./bus respectively, the dwelling time governed by the alighting time, is 14.8 seconds,

Clearance time; apply 15 seconds,

g′ /C ; 0.32, and

$$f_c' = \frac{3,600\times 0.833\times 0.32}{14.8+15} = 32.2 \text{ buses per berth per hour.}$$

Comparing the result of this study with that of HCM, as the capacity by the HCM model(eq. 6) is 48.6 buses, that is much larger than the capacity of this study. It is natural because the HCM model does not consider the arrival concentration

3. Validation of the Model

The model was validated by comparing the probability of queues forming behind the bus stop when the required number of berths were provided at the bus stop. As the bus arrival rates of the Nonghyup Building Stop and the Daewoo Building Stop were 91.0 and 89.0 buses per hour, respectively. The required numbers of berths based on the capacities of this study were 2.15 and 2.76, respectively. Thus, the number of berths at the Daewoo Building Stop exceeds the maximum of the number of cumulative effective berths in Table 3, the validation of the model of far side bus stops is excluded.

The comparison is shown in Table 7. The observed probability of queues forming behind the bus stop was obtained dividing all of the buses entering the bus stop into the number of buses forming queues when the required number of berths were provided. If it is regarded to reach the capacity like HCM that 30% of all buses are waiting in approach queues, it can be concluded that the capacity estimated by this study model is more accurate.

Table 7. Comparison of the Probability of Queues Forming for the Required Number of Berths

Models	Required Number of Berths	No. of Cumulative Effective Berths	Observed Prob. of Queues Forming behind Bus Stop(%)
This Study	3	2.15	28.2
HCM	4	2.28	12.8

V. CONCLUSIONS

In this study, the models to estimate the capacity of a bus berth in the flow interrupted by traffic signal were studied based on field studies.

For the near side bus stop, a model was developed by considering the average signal waiting time as a variable. Comparing this study model with the U.S. HCM model, this study model is less sensitive for the variable of g/C. While the HCM model is independent of the cycle time, the capacity of this study model decreases as the cycle time increases. Excepting the realm where the cycle is long and the g/C is large, this study model has larger capacity than that of the HCM model. In the comparison of the probability of queues forming behind the bus stop when the required number of berths are provided, this study model is thought to be more accurate.

For the far side bus stop, a model was suggested by considering the arrival concentration of buses during a signal phase.

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