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□論 文□

The Gap-Acceptance of Left-Turn Drivers

左回轉 運轉者의 間隔受諾

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要 約

本 硏究의 目的은 主街路上 左回轉運轉者의 間隔受諾特性(gap-acceptance characteristics)을 把握하는 데 있다. 이 目的을 達成하기 위하여 포켓컴퓨터를 利用한 새로운 資料收集技法이 開發되었다. 이 技法은 적은 費用으로 正確한 資料의 收集을 可能하게 하였다. 硏究交叉路는 馬山市의 副都心에 位置한 2車線街路 및 4車線街路上의 典型的인 信號灯 非設置交叉路가 選定되었다.

正規分布 및 對數正規分布가 probit 分析을 利用하여 臨界受諾間隔分布(critical acceptance gap distribution)로 檢定되었다. 두 分布들은 5% 有意水準에서 棄却되지 않았다.

2車線街路의 臨界受諾間隔은 2.9～3.0秒의 範圍였으며 標準偏差는 1.2～1.5秒의 範圍였고, 4車線街路는 各各 3.3～3.4秒와 1.3～1.5秒의 範圍였다. 2車線街路의 臨界 lag는 2.6秒였으며 4車線街路의 臨界 lag는 3.2秒이었다.

國內 左回轉運轉者의 臨界受諾間隔이 美國人의 것에 比하여 짧은 것으로 나타났다. 이는 都市交通流의 主構成 車輛이 職業運轉者들이 運轉하는 소형 택시로 이루어지는 運轉者 및 車輛特性에 起因한 것으로 볼 수 있다.

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I. Introduction

An understanding of left-turn drivers' gap-acceptance characteristics at intersections is necessary for the development of engineering warrants for left-turn lanes/left-turn phasing and to study intersection capacity/delay. As shown in Table 1, there are many studies about the gap-acceptance characteristics of left-turn drivers in the countries where the traffic engineering is advanced, but few studies are conducted in this field in Korea. In order to understand the gap-acceptance characteristics of Korean drivers, it is needed to study them with Korean driver data.

Table 1. Critical and Median Gap of Left-Turn Drivers

Classification	Researcher	Value (sec.)	Highway Type	Left-Turn Lane	Signal	Speed (mph)
Critical Gap	Behnam[10]	4.5	1 lane	yes	yes	
	Michalopoulos[11]	4.75	2 lanes	yes	no	30-35
		4.50	1 lane	yes	no	"
		4.60	2 lanes	yes	yes	"
		4.27	1 lane	yes	yes	"
	Fambro[12]	4.5	2 lanes	yes	yes	—
	Hamelink[13]	6.0	2 lanes	no	no	—
		5.0	1 lane	no	no	—
	Hansson[14]	4.6-6.1	—	—	no	50-90
Median Gap	Wennell[2]	3.7-4.7	1 lane	yes	no	—
	Dart[1]	4.3	2 lanes	yes	yes	—
	Hamelink[13]	5.5	2 lanes	no	no	—
		4.3	1 lane	no	no	—

For gap-acceptance studies, a data collection technique which can accurately record the times or intervals of several variables simultaneously is needed. The most common techniques have utilized observers with stopwatches or photography methods. The stopwatch technique requires extensive manpower and does not produce accurate data whereas the photography technique does not require as much manpower as the stopwatch technique but does require high initial costs with moderate manpower needs to analyze them. Moreover, it is inconvenient to transport photographic equipment and to provide the necessary set-ups.

Dart[1] used a 20-pen recorder for his data collection but this is not a commonly available instrument. Wennell and Cooper[2] used a microprocessor-based system which was consisted of 10 modules[3]. The system was bulky and is not commonly available, also. The 20-pen record and the microprocessor-based system are rare particularly in developing countries with limited budgets. A data collection technique is needed which can collect the data accurately and inexpensively. Instruments used for the data collection should be convenient to carry in the field, simple to operate, and available at moderate costs.

The purpose of this study was to understand the gap-acceptance characteristics of left-turn drivers in Korea. In order to accomplish the purpose, a new data collection technique was developed. In this study, the gap-acceptance characteristics of left-turn drivers from major-streets on two-lane and four-lane streets will be studied.

II. A New Data Collection Technique

This new technique utilized a Radio Shack Model PC-4 pocket computer which has dimensions of 0.38 x 6.5 x 2.75 inches with a 60 lines per minutes (lpm) thermal printer. The system sells for approximately 120 dollars. The computer, which has a 544-character memory, is very compact and convenient for use in field studies. The system is shown in Figure 1.

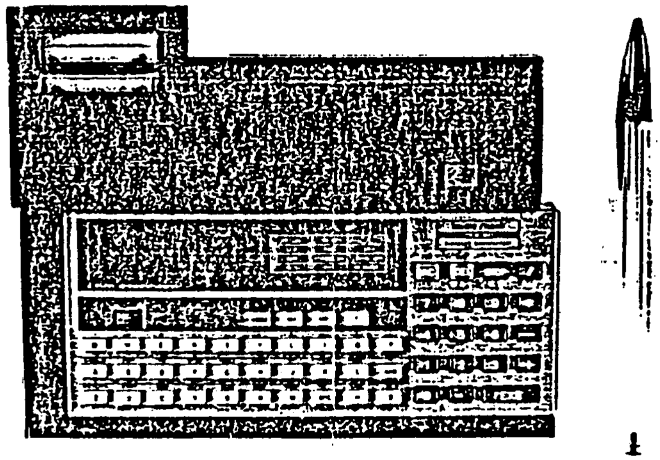

Figure 1. PC-4 Pocket Computer and Thermal Printer

The following variables were measured by field studies for each observation period:

1. The time interval of opposing vehicles in the intersection center (gap).
2. The time interval between the arrival of each left-turning vehicle and that of the next opposing vehicle (lag).
3. The gap/lag accepted and rejected.
4. The time interval for each left-turning vehicle from arrival to clearing the advancing lane (blocked time).
5. The time interval for each left-turning vehicle from accepting a gap to clearing the advancing lane (maneuver time).
6. Traffic volumes for both direction of major-streets and left-turning vehicles.
7. The length of each observation period.

The program shown in Figure 2 was programmed in Basic language for the purpose of collecting gap-acceptance data.

```
10   I=0: J=0: K=0: L=0: M=0: D=0: Q=0: S=0: C=0
20   A$ = KEY
30   I = I+1
40   IF A$ = "0" THEN 310
50   IF A$ = "Q" ; Q = Q + 1
60   IF A$ = "W" ; L = L + 1
70   IF A$ = "7" THEN 200
80   IF A$ ≠ "8" THEN 110
90   L = L+1
100  C=I: J=1: K=1: M=I
110  IF A$ ≠ "9" THEN 140
120  G = I-M: K=2
130  D = D+G
140  GOTO 20
200  X = I-C
210  S = S+1
220  C = I
230  IF J=1; IF K=2; PRINT "AL"; X
240  IF J=0; IF K=2; PRINT "AG"; X, G
250  IF J=1; IF K=1; PRINT "RL"; X
260  IF J=0; IF K=1; PRINT "RG"; X
270  IF K=0; PRINT "G"; X
280  IF K=2; K=0
290  J=0
300  GOTO 20
310  PRINT "TC"; I
320  PRINT "NO"; S
330  PRINT "NL"; L
340  PRINT "NA"; Q
350  PRINT "TD"; D
360  END
```

Figure 2. Data Collection Program

The unique part of this program is the key function for in put. The key function is used to read one character into the character variable by pressing a single key during program execution. Even when there is no key input, the program will be executed continuously. A counter is programmed in the program. The units of the counter are not time, but the units can be converted to actual time by measuring the elapsed time during which the counter operates.

At the field study site, the data collection is started by simultaneously turning on the computer and activating a stopwatch. Whenever a vehicle from the opposing stream enters the intersection, press the key "7" (any key can be chosen at your convenience) then the printer prints a letter "G" (explained later) and numerical digits, which are the counter units representing the interval of events. When a left-turning vehicle enters the intersection, press the key "8". If the left-turning vehicle accepts a lag, press the key "9". The printer prints the letters "AL" and digits. When a left turn vehicle is waiting for an acceptable gap, if the key "7" is pressed directly after pressing the key "8", the printer prints the letters "RL" and digits. Until the left-truning vehicle accepts a gap, each time the key "7" is pressed, the printer prints the letters "RG" and digits. When the left-turning vehicle accepts a gap, press the key "9". Next, when the key "7" is pressed, the printer prints the letters "AG" followed by digits and other digits on the next line which represent delay time. Whenever an advancing vehicle enters the intersection, press the key "Q". When a queue of left-turning vehicles accept a gap simultaneously, press the key "W" whenever each left-turn vehicle except the first one accepts the gap. After the completion of the data collection, simultaneously press the key "0" and stop the stopwatch. Then, the print prints the letters "NO", "NL", "NA", "TD", and their associated values. To determine the total delay time of the left-turning vehicles, measure the delay time of left-turning vehicles except the first one in each queue and add the sum to the value of "TD".

An example of the output and its interpretation is shown in Figure 3.

Output	Interpretation	
G 20	Gap of opposing stream	; 3.0 sec.
RL 10	Rejected lag	; 1.5 sec.
AG 35	Accepted gap	; 5.3 sec.
20	Blocked or delay time	; 3.0 sec.
AL 40	Accepted lag	; 6.1 sec.
TC = 125	Total counter units	; 125
NO = 4	No of opposing vehicle	; 4
NL = 2	No of left-turning veh.	; 2
NA = 2	No of advancing vehicle	; 2
TB = 20	Total blocked time	; 3.0

Figure 3. Computer Output and Its Interpretation

The observation was conducted for 19.0 seconds and the total counter units during the observation were 125. The conversion factor of 6.58 (counter units per second) is obtained by dividing the total counter units, 125, by the elapsed time interval of the observation period, 19.0 seconds. The counter units for the variables measuring time are divided by 6.58 to convert the computer output to seconds.

It is possible to input and output more information.However, the more sophisticated the program, the lower would be the accuracy of the output, for it will require a longer processing time and the processing time between events will be unequal. In order to obtain accurate outputs, the key press technique should be practiced to input a key at a time and it is recommended that observations be conducted when the traffic flow is relatively uniform.

A total of 5 observations at an intersection on a two-lane street and 3 observations at an intersection on a four-lane street were conducted with this technique. The counter units per second for each observation are given in Table 2. Without inputs, the counter units per second was 6.85 units/second. The low variance of the counter units per second shown in Table 2 ascertains that the counter can be used as a timer. The counter in the program can measure time intervals as small as 0.15 second. This degree of accuracy is sufficient for this type of study.

III. Data Collection

Two typical unsignalized intersections located in an urban area in Korea were selected as study sites. The intersections are located in Masan City (population is 500,000), in the southern part of Korea. One of the intersections is located on a two-lane street and the other is located on a four-lane street. These intersections are located in residential areas but there is also limited commercial roadside development. The grades at the intersections are level or moderately steep with adequate sight conditions. The minor-streets were only two-lane streets. The speed limits of the streets were 50 kph. Most of left-turning vehicles were passenger cars operating as taxicabs. The traffic volumes on the minor-streets were not high enough to influence the left-turns from the major-streets for either intersection. For left-turning traffic from the major-streets, one approach dominated over the other for both intersections.

A schematic diagram of the intersection of the two-lane street is shown in Figure 4. Two observers were stationed at Location F. One observer operated the computer while the other with two stop-watches measured the length of the observation period and the delay time of left-turning vehicles except for the first one when there was a queue of left-turning vehicles. When an opposing vehicle passed Location E, the event was inputed; the time to travel the leading distance, s, was computed considering average speed and added to the lags later. The length of the observation period was selected as 20-30 minutes. Left-turning vehicles that forced their turns were not considered to have accepted normal gaps and were not recorded.

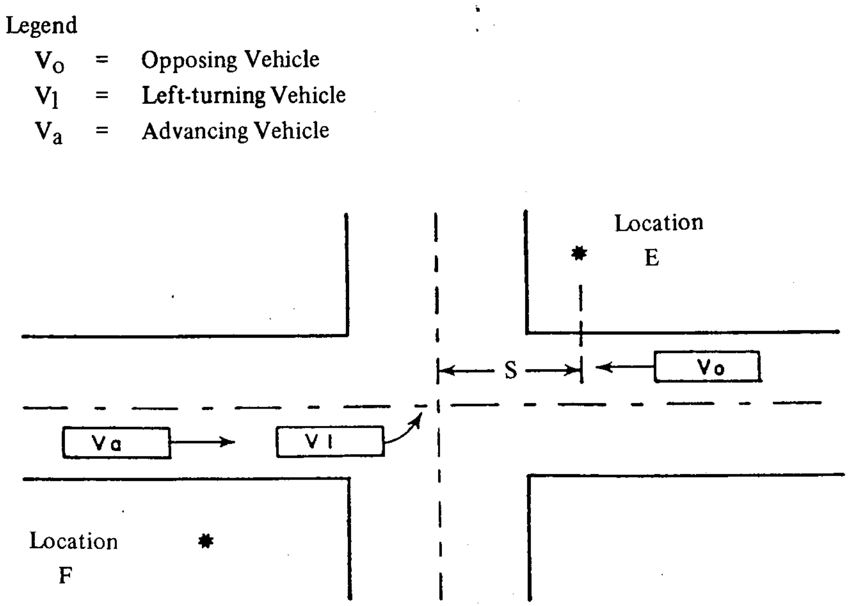

Figure 4. Schematic Diagram of the Intersection for the Two-Lane Street Study Site

A summary of the data collected for the intersections is given in Table 2. The data given in this table has been converted to an hourly basis except for the counter units. The blocked time is the time during which the advancing lanes are blocked by delayed left-turning vehicles. The fact that the differences among the observations in each table are small illustrates that the traffic flow of each street was stable and uniform. The counter units on a per second basis computed by dividing the total counter units by the observation period have almost identical values.

Table 2. Summary of Observations at Study Sites

Two-Lane Street

Observation	Units	Observation Number				
		No 1	No 2	No 3	No 4	No 5
Opposing Vehicles	v/h	477	501	505	466	459
Left-Turn Vehicles	v/h	73	56	66	56	57
Advancing Vehicles	v/h	310	342	372	319	309
Blocked Time	sec./h	111	120	98	101	82
Delay Time	sec./h	149	176	145	147	131
Counter Units/Second		6.56	6.56	6.56	6.56	6.58

Four-Lane Street

Observation	Units	Observation Number		
		No 1	No 2	No 3
Opposing Vehicles	v/h	620	647	536
Left-turn Vehicles	v/h	150	187	180
Blocked Time	sec./h	332	384	345
Delay Time	sec./h	498	592	431
Counter Units/Second		6.73	6.53	6.52

IV. Data Analysis

The proportions of gaps which were accepted at the two study intersections are given in Table 3, and plotted in Figure 5. In Figure 5, the two curves of the two intersections are nearly parallel with the curve of the two-lane street shifted to the left by about 0.5 second from the curve of the four-lane street.

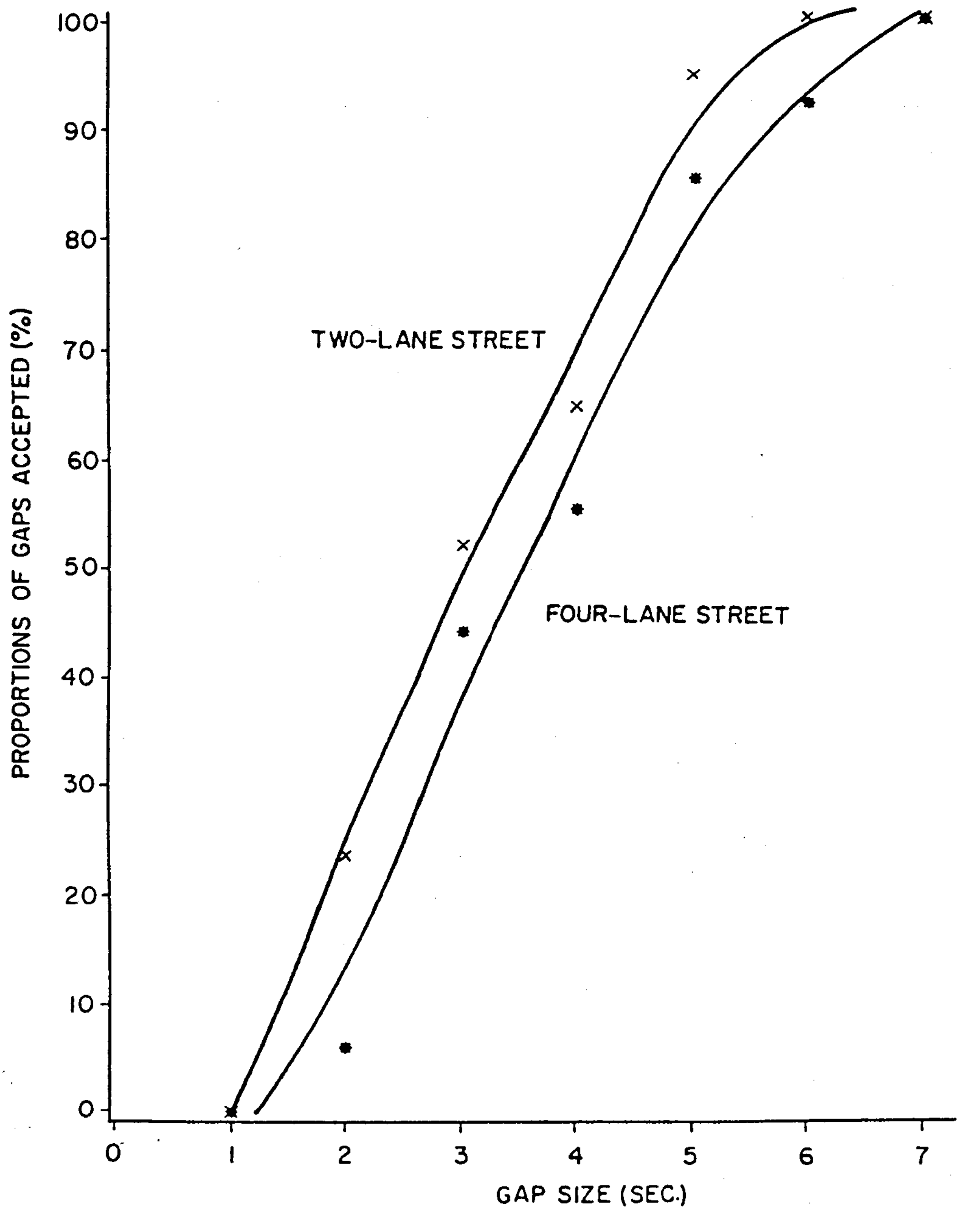

Figure 5. Gap-Acceptance Curves

Table 3. The Proportions of Gaps Accepted

Gap Size (sec.)	Two-Lane Street Total Number	Two-Lane Street Accepted Number	Two-Lane Street %	Four-Lane Street Total Number	Four-Lane Street Accepted Number	Four-Lane Street %
0.0 – 1.4	69	0	0.0	40	0	0.0
1.5 – 2.4	51	12	23.5	50	3	6.0
2.5 – 3.4	25	13	52.0	41	18	43.9
3.5 – 4.4	17	11	64.7	36	20	55.5
4.5 – 5.4	20	18	90.0	27	23	85.2
5.5 – 6.4	12	12	100.0	13	12	92.3
6.5 – 7.4	5	5	100.0	11	11	100.0
7.5 – 8.4	7	7	100.0	9	9	100.0
8.5 – 9.4	6	6	100.0	7	7	100.0
9.5 –	42	42	100.0	43	43	100.0
Total	254			277		

The normal and lognormal distributions have been shown by previous studies to fit the critical aceptance gap distribution of minor-street drivers at intersections[4),5)]. In this study, the two distributions were employed to fit the critical acceptance gap distribution of left-turn drivers on the major-street at unsignalized intersections. The Probit of Categorical Data Analysis in SAS[6)] was used for the statistical analyses. The chi-square value, χ^2, of the goodness of fit test of the two distributions on the proportions of gaps accepted are shown in Table 4. All values fail to reject the null hypothesis that the distributions are the normal or lognormal distributions, but better results are obtained using the lognormal distribution.

Table 4. χ^2 Values of Two Distributions

Distributions	Two-Lane Street (df = 4)	Four-Lane Street (df = 5)
Normal Distribution	6.51	6.44
Lognormal Distribution	3.05	3.30

For the lognormal distribution, the mean and variance can be estimated using following equations[7)]:

$$\bar{x} = \exp(m + ½ \times \sigma^2),$$
$$s^2 = \exp(2m + \sigma^2) \times \{ \exp(\sigma^2) - 1 \}$$

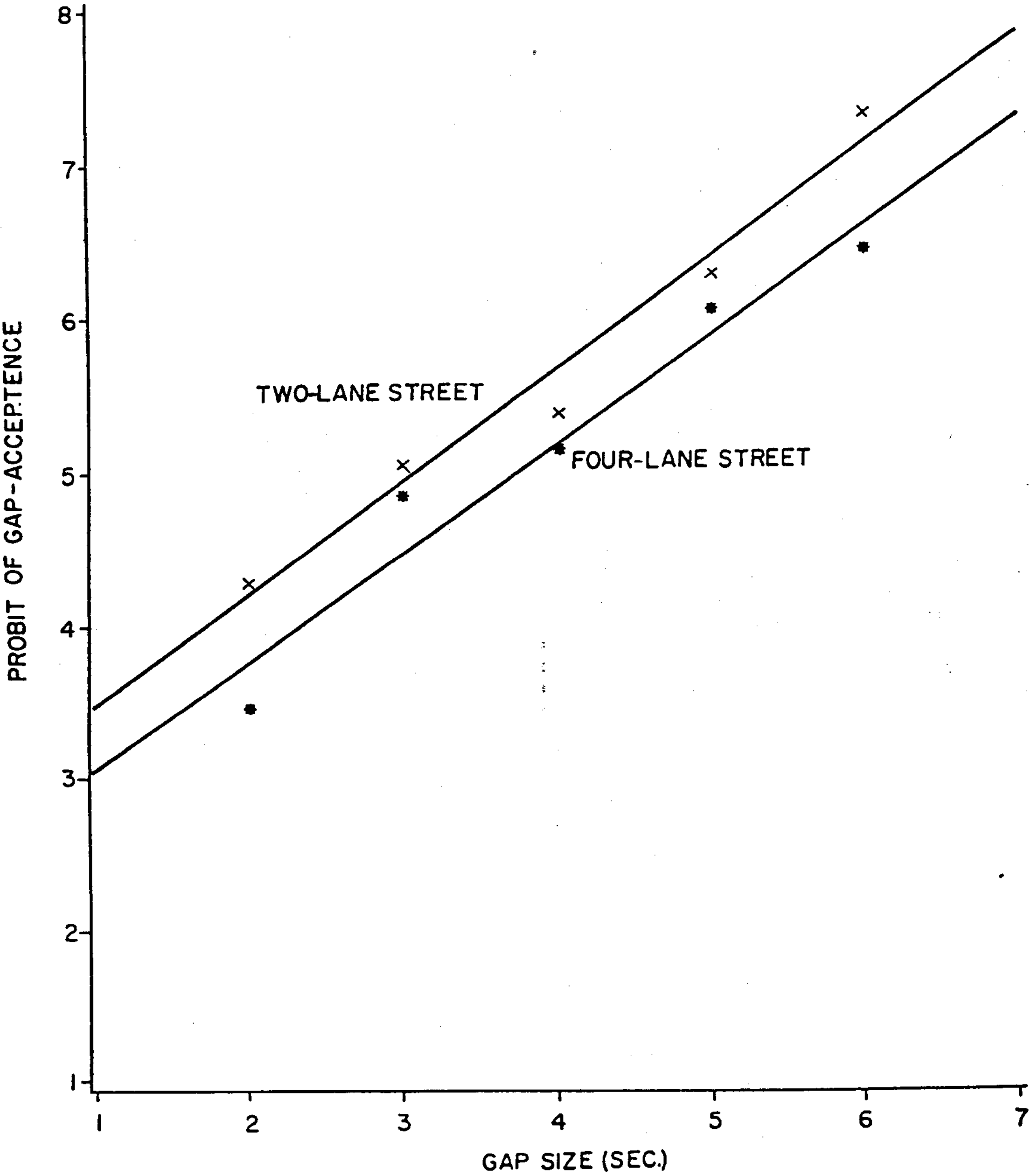

Figure 6. Probit Regression Line of Normal Distribution

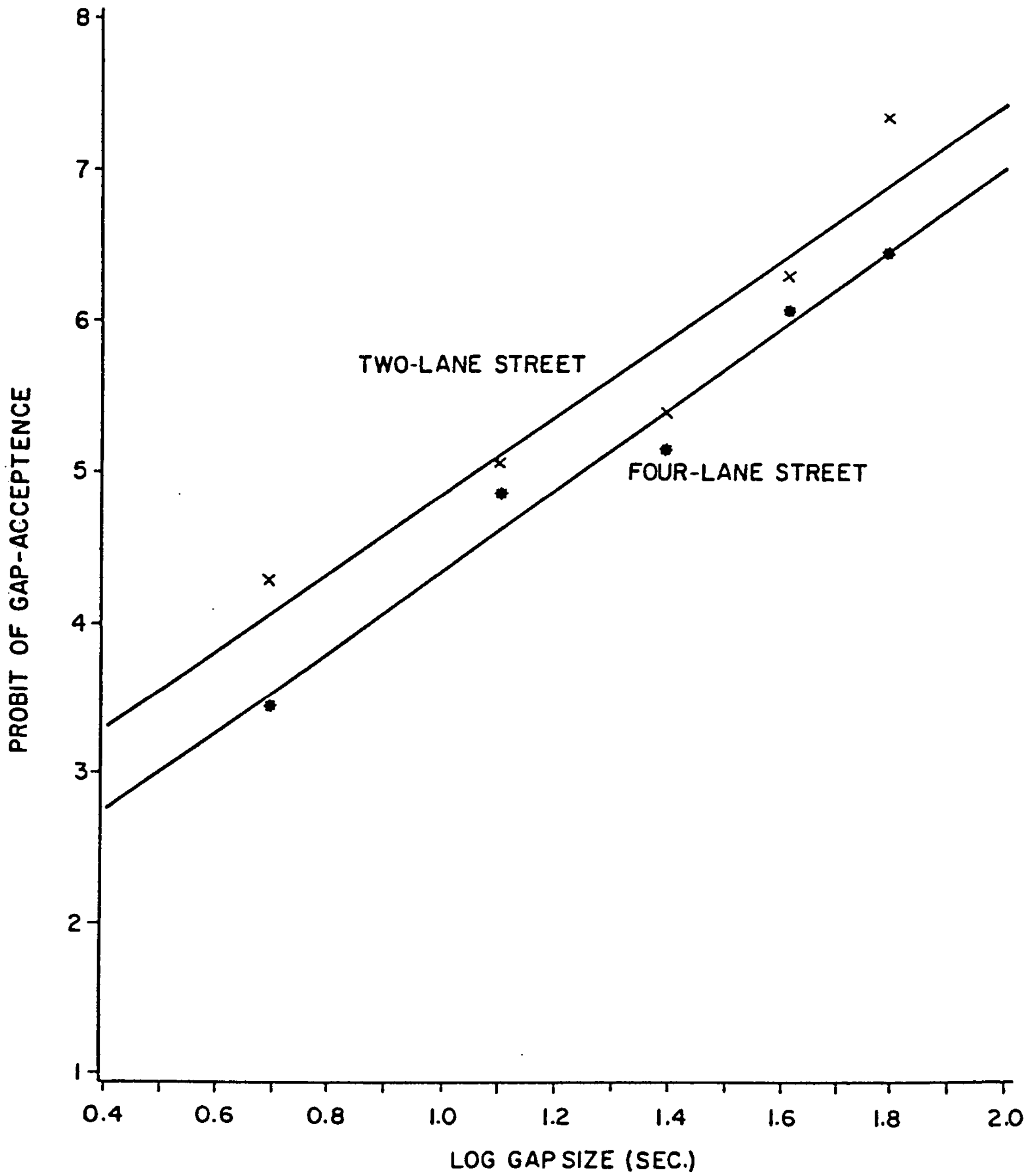

Figure 7. Probit Regression Line of Lognormal Distribution

where m and σ^2 are the estimated value of the mean and variance of the logarithmic values.

The results of probit analyses for the two intersections are shown in Figures 6 and 7 and listed in Table 5. In Figures 6 and 7, the plotted points lie close to the regression lines; so it can be inferred that the distributions are the normal or lognormal distributions. In Figure 6, the regression line of the four-lane street is shifted to right by about 0.6 second from that of the two-lane street.

Table 5. Probit Analysis Results of Critical Acceptance Gap

Distribution	Parameter	Two-Lane Street	Four-Lane Street
Normal Distribution	Sample Mean (sec.)	3.18	3.66
	Corrected Mean (sec.)	2.98	3.38
	Standard Deviation (sec.)	1.21	1.26
Lognormal Distribution	Sample Mean (sec.)	3.20	3.71
	Corrected Mean (sec.)	2.93	3.34
	Standard Deviation (sec.)	1.46	1.45

The corrected values in Table 5 were obtained by correcting the bias using Ashworth's technique[8]. Between the two distributions, while the sample means of the lognormal distribution are slightly larger than those of the normal distribution. The corrected means of the normal distribution are slightly larger than those of the lognormal distribution. For the variance, the variances of the lognormal distribution are a little larger than those of the normal distribution.

Comparing the two streets, the largest difference was 0.51 second for the sample mean of the lognormal distribution while the smallest difference was 0.4 second for the corrected mean of the normal distribution. The standard deviations are almost the same.

The rejected and accepted lags of the two intersections are plotted in Figure 8 and Figure 9 respectively considering only lags. The critical lag[9] of the two-lane street is 2.6 seconds and that of the four-lane street is 3.2 seconds. Using lags/gaps rejected or acdepted, the critical gaps of the two-lane and the four-lane street was 3.0 and 3.5 seconds respectively. The critical gaps of this study are much shorter than those of Table 1. This fact will be discussed later.

The median gaps for the two-lane and the four-lane highway obtained from Harmelink's data[13] were 4.7 and 5.5 seconds respectively. Assuming a normal distribution, the median gaps of this study are 3.2 and 3.7 seconds for the two-lane and the four-lane street respectively. These median gaps are much shorter than those of Harmelink's comparable study. The gap-acceptance curves of this study were compared with those of Harmelink's and the results are shown in Table 6. There is no evidence that the two distributions are the same for either streets.

The fact that the critical and median gaps of this study are much shorter than those of comparable studies can be explained in terms of driver and vehicle characteristics. The major proportion of the urban traffic stream in Korea consists of compact sized vehicles driven by professional drivers and

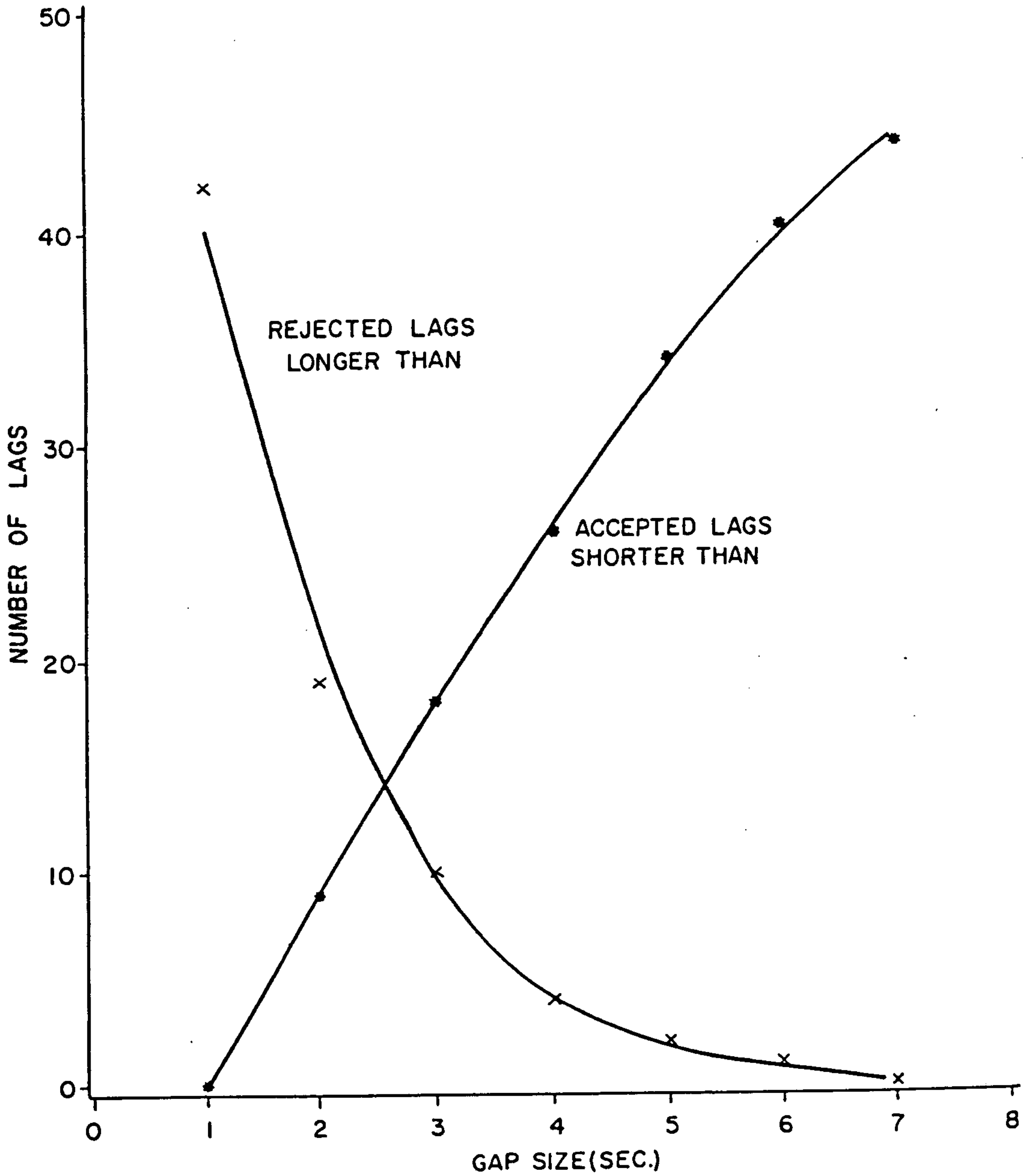

Figure 8. Critical Lag of the Two Lane Street

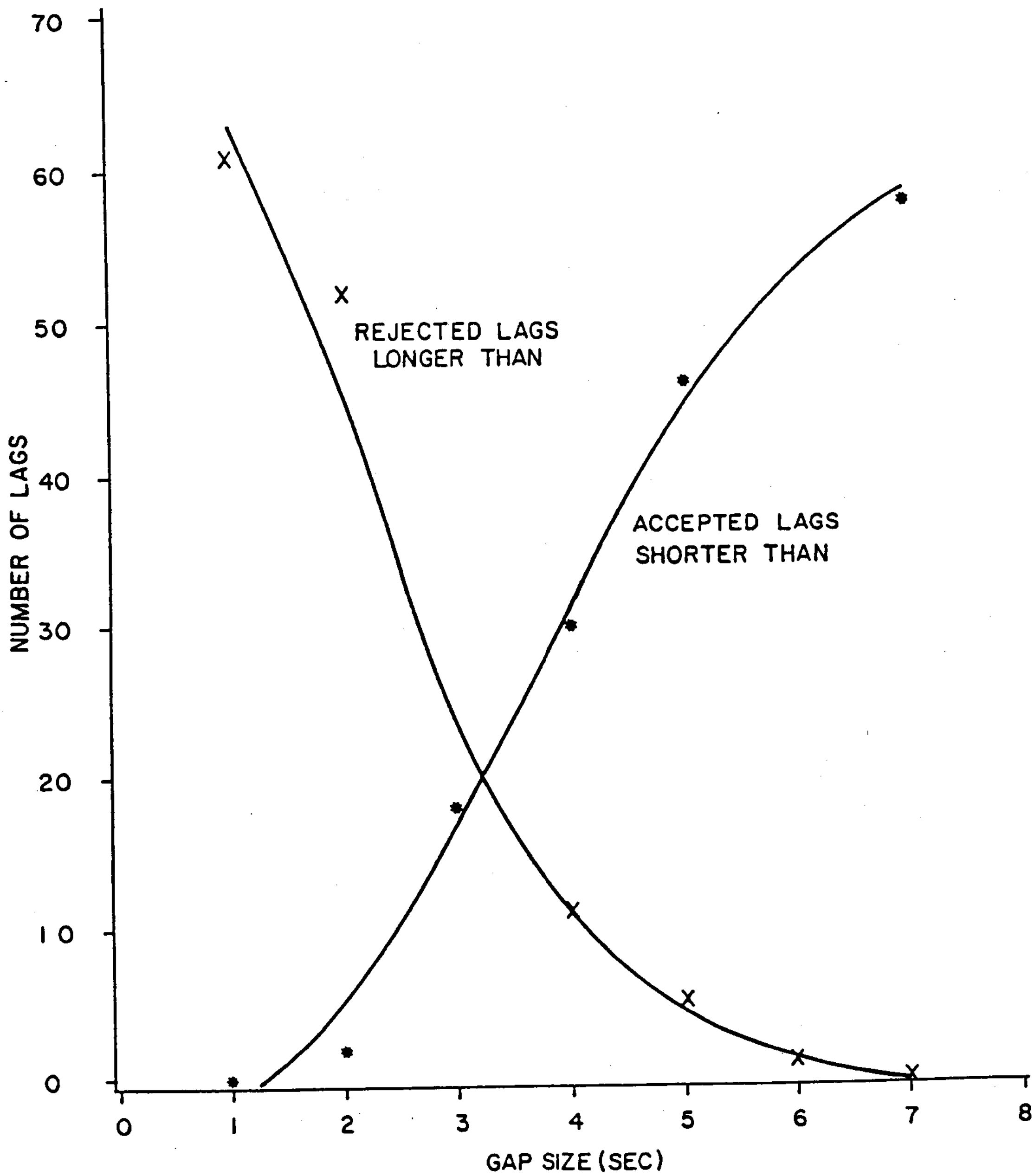

Figure 9. Critical Lags of the Four Lane Street

used as taxis. Taxis were involved in 48% of all urban traffic accidents.[15]. The amount of the taxi fare is determined solely on the basis of the distance traveled except Seoul City, which encourages the drivers to perform in an efficient manner.

Table 6. Comparison of Gap-Acceptance Curves

Studies	Observations (No.)	Median Gap (sec.)	S.T.D. (sec.)	df	χ^2
		Two-Line Street			
This study	254	3.2	1.21	6	110.0
Harmelink	354	4.7	1.63		
		Four-Lane Street			
This Study	277	3.7	1.26	6	142.8
Harmelink	354	5.5	1.79		

V. Conclusions

A new data collection technique was developed and demonstrated in this study. The technique utilizing a pocket computer made it possible to collect accurate data at low costs. In this study, using a Radio Shack PC-4 pocket computer, time intervals as small as 0.15 second were measured. This technique can be used not only for headway studies but also for the measurement of time intervals in other studies.

The lognormal and normal distributions were tested for the critical acceptance gap distribution using the probit analysis. Both distributions were not rejected at the 5 percent significance level for both streets. The mean of the critical acceptance gap for the two-lane street ranged from 2.9 to 3.0 seconds and the standard deviation ranged from 1.2 to 1.5 seconds while those for the four-lane street ranged from 3.3 to 3.4 seconds and from 1.3 to 1.5 seconds. The critical lag of the two-lane street was determined to be 2.6 seconds and that of the four-lane street was 3.2 seconds.

The critical acceptance gaps of left-turn drivers are much shorter than those of American drivers. This difference can be explained by the driver and vehicle characteristics. The major proportion of the urban traffic stream in Korea consists of compact sized vehicles driven by professional taxi drivers and the taxi fare is determined solely on the basis of the distance traveled except Seoul City.