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양방향 2차로도로의 기하구조에 따른 서비스수준 분석에 관한 연구
A Study on Service Level Analysis According to Geometric Structure of Two-Lane Highway

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<Abstract>

양방향 2차로 도로에서는 보다 효율적으로 운영하고 도로의 안전성을 도모하기 위하여 오르막 차로 및 양보차로 추월차로 등의 부가차로를 설치하고 있다. 이러한 부가차로 효율성의 비교·분석을 통한 연구에 의하여 기존의 도로를 효율적으로 운영하는 방안이 제시되어야 된다. 본 연구에서는 이러한 부가차로 중 추월차로 및 양보차로가 포함된 구간을 조사하여 기하구조에 따른 교통류 특성을 분석하고 각 구간별로 서비스 수준분석을 실시하였다. 그 결과는 다음과 같다. (1) 각 기하구조별로 지점속도와 통행속도를 분석한 결과 지점속도는 통행속도보다 조사지점의 기하구조에 의한 영향을 많이 받아 변동이 심한 것을 알 수 있었으며, 통행속도는 그 기하구조에 따른 교통류의 특성을 잘 반영하고 있음을 알 수 있었다. (2) 차량별 지점속도의 비교·분석에서는 현재 차량성능의 진보로 인하여 조사구간의 설계속도에 반해 중차량 및 버스-트럭, 승용에 대한 차량별 속도차이가 거의 없는 것으로 분석되었다. 기존의 중차량에 대한 보정은 현장제한속도에 대하여 감안되어야 된다고 판단된다. (3) 모의실험모형과 현장조사에 의한 교통류특성을 비교해 보았을 때, 시뮬레이션은 도로의 전구간에 대한 결과는 잘 반영하고 있으나 짧은 구간에 대하여 교통류의 연속성을 파악하기에는 부족하다고 판단된다. (4) 추월가능구간과 양보차로구간의 효율성을 비교해 보면, 추월율에서 양보차로구간이 추월가능구간보다 22.5%나 높게 나왔으며 총지체비교에서는 추월가능구간보다 5.56sec/h의 지체감소를 보이고 있다. 서비스 수준분석에서는 같은 C의 수준을 보이고 있으나 양보차로의 영향으로 양보차로 후구간의 서비스 수준이 A까지 상향되었다. 따라서 대향교통류의 영향을 받는 추월차로의 확보보다는 효율성이 좋은 양보차로구간의 보급이 많아야 되겠다.

Key Words *: Annexed lane, LOS analysis, Two-Lane Highway, Geometrical structure etc.*

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1. Introduction

In two-lane highways, high-speed vehicles are easily interfered by low-speed vehicles and traffic delay will occur. To escape from the delay, vehicles usually overtaking low-speed vehicles using opposite lane, which makes big problems in traffic safety.

Due to two-lane highways show more congestions than other multi-lane highways. To analyze these problems, studies on two-lane highways have been performed in various methods. Additionally, two-lane highways are not operated in the same type of operation method throughout the highways. There are some kind of special operation mechanism such as 'No-overtaking', 'overtaking Zone' and 'Concession Zone'.

Because in a two-way highways a car has to overtake other cars using the opposite lane in overtaking zones, the overtaking rate varies according to the traffic volume of the opposite lane. Such overtaking zones are one of microscopic methods to enhance the efficiency of two-way roads by modifying the geometrical structure. Effective techniques for enhancing the efficiency of established two-way roads are improved line design to increase the chance of overtaking, give-way lanes in flats and slopes, uphill lane in steep areas, short four-lane zones, roadside driving, etc. Because these techniques induce overtaking through changing the geometric structure of roads, they purpose to change traffic flow and improve road efficiency.

2. Investigate to early studies and research

2.1 Early studies

In 1950 the *Highway Capacity Manual* (HCM) provided a standard method for highway capacity analysis in the United States. The manual was also translated into nine other languages. Besides basic capacity (capacity under ideal conditions) and possible capacity (capacity under prevailing conditions), HCM 1950 defined pratical (maximum traffic volume under prevailing conditions without traffic conditions becoming "unreasonable"). This indicated that traffic engineers were not interested on the maximum performance of the system only, but also on the traffic conditions as experienced by the road users.

The practical capacity of a rural two-lane highway under ideal conditions was 900pc/h. The performance measure for practical was operating speed.

Already in 1942 O. K. Normann had suggested 800veh/h as the practical capacity for a two-lane "level tangent rural highway carrying few trucks." In the light of later developments, the performance measures of Normann are of special interest:

- The proportion of headways less than nine seconds
- The ratio of actual passings to desired passings
- The average number of passings per vehicle
- Speed differences between successive vehicles.

Normann was especially concerned about "the time that slow-moving cars must be trailed" and "freedom of movement" as indicated by speed differences between successive drivers. In his article Normann presented many of the central ideas of traffic performance analysis.

The headway criterion, although with a five-second limit, and the (percent) time spent following slower vehicles were later adopted as service measures in the third edition of HCM. Wardrop as well as Morrall and Werner have suggested the use of the overtaking ratio as a service measure. The idea of speed changes while trailing slower vehicles was further developed by Greenshields and Drew.

At the beginning of 1960's Bruce Greenshields developed a quality index for traffic flow based on "frustration factors." He considered the frequency and amount of speed changes as undesirable factors, which irritated drivers and increased the cost of operation. the quality index was $Q = \frac{1000S}{\Delta_s \sqrt{f}}$. where S was the average speed(mi/h), Δ_s was the absolute sum of speed changes per mile, and f was the number of speed changes per mine. The data were collected either with an instrumented vehicles or by using aerial photographs. According to Greenshields, quality of flow could not be measured at a point.

In 1965 the second edition of HCM extended the idea of practical capacity to the well known six levels of service (A-F), still in use today. The level of service(LOS), was expressed in terms of operating speed as the governing service measure and the traffic volume limitation as a supplementary service measure. Both the operating speed and maximum service volume limits had to be satisfied.

A few years later Donald Drew extended the earlier ideas of Greenshields. Instead of the frequency and amount of speed changes, Drew studied acceleration noise;i.e.,standard deviation of accelerations, including decelerations as negative accelerations. According to Drew, acceleration noise could describe the discomfort experienced by a motorist, as well as operating costs and safety, better than travel time or average speed.

He also developed an energy-momentum approach to LOS. The total energy for a traffic stream over a section of a road is the sum of kinetic energy and internal energy, where acceleration noise represents internal energy. On a freeway the kinetic energy reached its maximum and internal energy its minimum when traffic was about 8/9 of possible capacity. This was used as a boundary condition between levels of service D and E. The upper limit for LOS A was 35% of possible capacity, at which volume kinetic energy was equal to internal energy.

Recently, Werner Brilon has used a similar approach in a study of traffic efficiency. He estimated that the efficiency reaches its maximum at a flow rate mear 90% of capacity. The maximum is lower than capacity only on freeways and multi-lane highways, which have a convex speed-flow curve. On two-lane highways, where the speed-flow curve at uncongested conditions is linear or concave, the maximum efficiency is reached at capacity.

2.2 Highway Capacity Manual 1985

In the development of the third edition of HCM the mean speed was considered as an inadequate measure of the balance between passing demand and passing supply. The mean speed was also found to be less sensitive to traffic flow rated than was previously supposed.

HCM 1985 adopted *percent time delay* (PTD) as the service measure. PTD was defined as "the average percent of time that all vehicles are delayed while traveling in platoons due to inability to pass." Motorists were defined to be delayed when traveling behind a platoon leader at speeds less than their desired speed and at headways less than five seconds. The percent of vehicles traveling at headways less than five seconds could be used as a surrogate measure of PTD in field studies. Accordingly, the estimation of PTD was much easier that the estimation of Greenshield's quality index or acceleration noise. For specific grades the level-of-service measure was the average upgrade travel speed.

The 1985 HCM model adjusted the volume-to-capacity ratio for the combined effect of terrain type and percent no-overtaking zones. Service flow rate was adjusted for directional distribution, but the combined effect of no-overtaking zones and directional distribution was not cosidered.

2.3 Highway Capacity Manual 2000

The expression "percent time delay" in HCM 1985 was a slight misnomer, because the criterion was not delay but time spent traveling in platoons. HCM 2000 uses a more descriptive term *percent time spent following* (PTSF), which is defined as the average percent of travel time that vehicles must travel in platoons behind slower vehicles due to inability to pass. Simulation studies indicated that PTSF can be estimated as the percentage of vehicles traveling at headways of three seconds or less.

Other service measures were also considered, such as average travel speed, delay rate(s/veh-km), density, and overtaking ratio. Delay rate and overtaking rate were considered impossible to measure in the field. PTSF was assumed to describe traffic conditions better than density, because density is less evenly distributed on two-lane highways than on multilane highways and freeways. The *average travel speed*(ATS) was selected as an auxiliary criterion for high-class highways, because it makes LOS sensitive to design speed and enables the use of the same criteria for both general and specific terrain segments. Specific upgrades and downgrades can be analyzed by a directional-segment procedure.

HCM 2000 will have two classes of highways :

- Class I highways are two-lane highways on which motorists expect to travel at relatively high speeds. These highways function as major intercity routes, primary arterials connection major traffic generators, daily commuter routes, or as primary links in state and national highway networks.
- Class II highways are two-lane highways on which motorists do not necessarily expect to travel at high speeds.

For Class I highways the LOS is defined by threshold values of both percent time spent following and average travel speed. For Class II highways the service measure is percent time spent following alone.

The PTSF crieria for Class I highways have been obtained by adding five percent to the PTD criteria in HCM 1985. A further increase of five percent was made to the PTSF thresholds for Class II highways, because motorists' expectations were considered to be lower on Class II highways than on Class I highways. As the headway criteria was lowered from five to three seconds and LOS criteria for PTSF are higher than in th 1985 HCM, especially on Class II highways.

3. Field investigation and methods

To analyze the characteristics of traffic flow influenced by low-speed vehicles by the geometric structure of roads, this study investigated the section between Seongsan IC and Goryeong IC of the 88 Expressway in Figure 1, dividing it into no-overtaking zones, overtaking zones, give-way lane zones, and zones after a give-way lane zone.

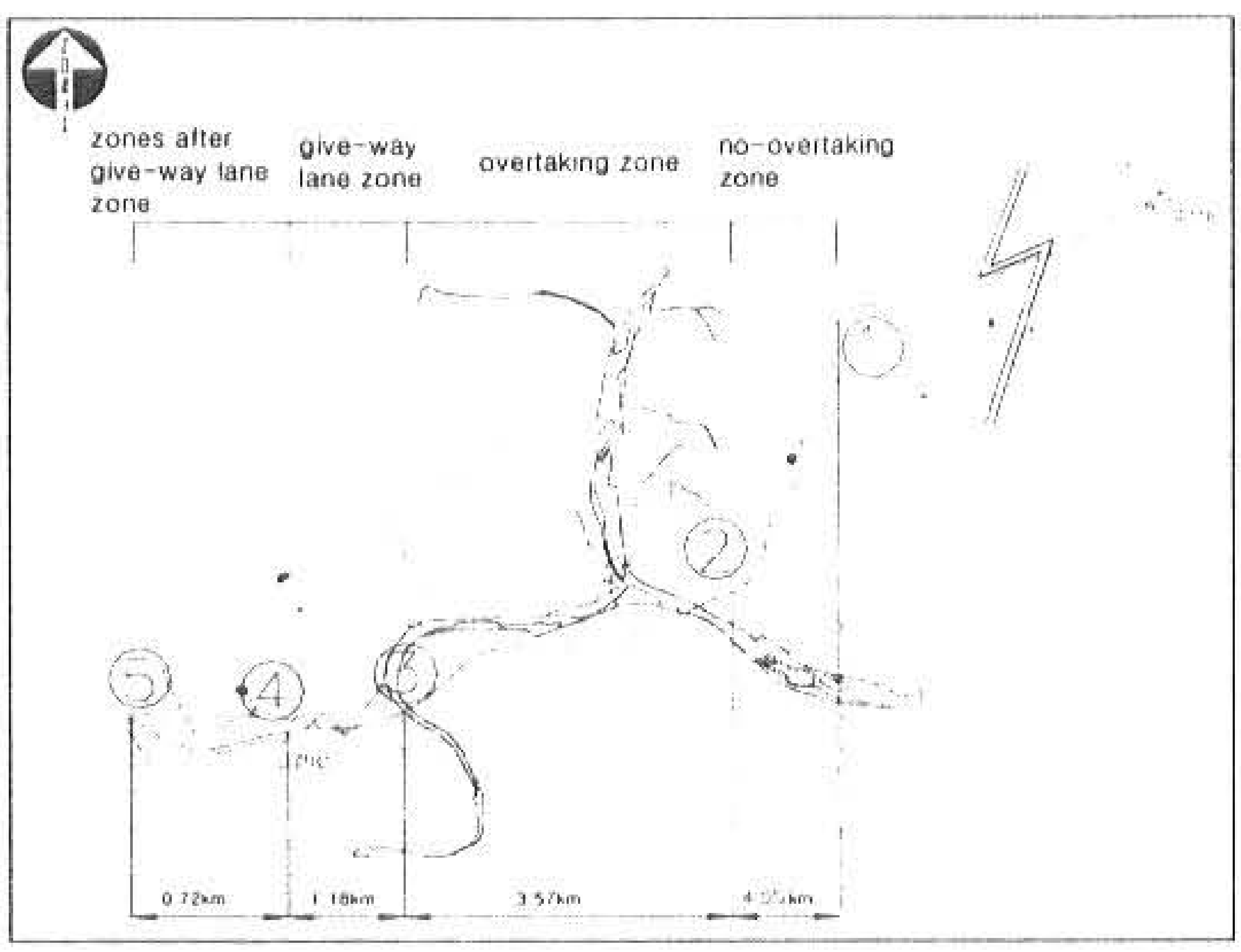

Fig. 1 Figure of field investigation section

The road condition of the investigated section is as shown in Figure 2~Figure 5.

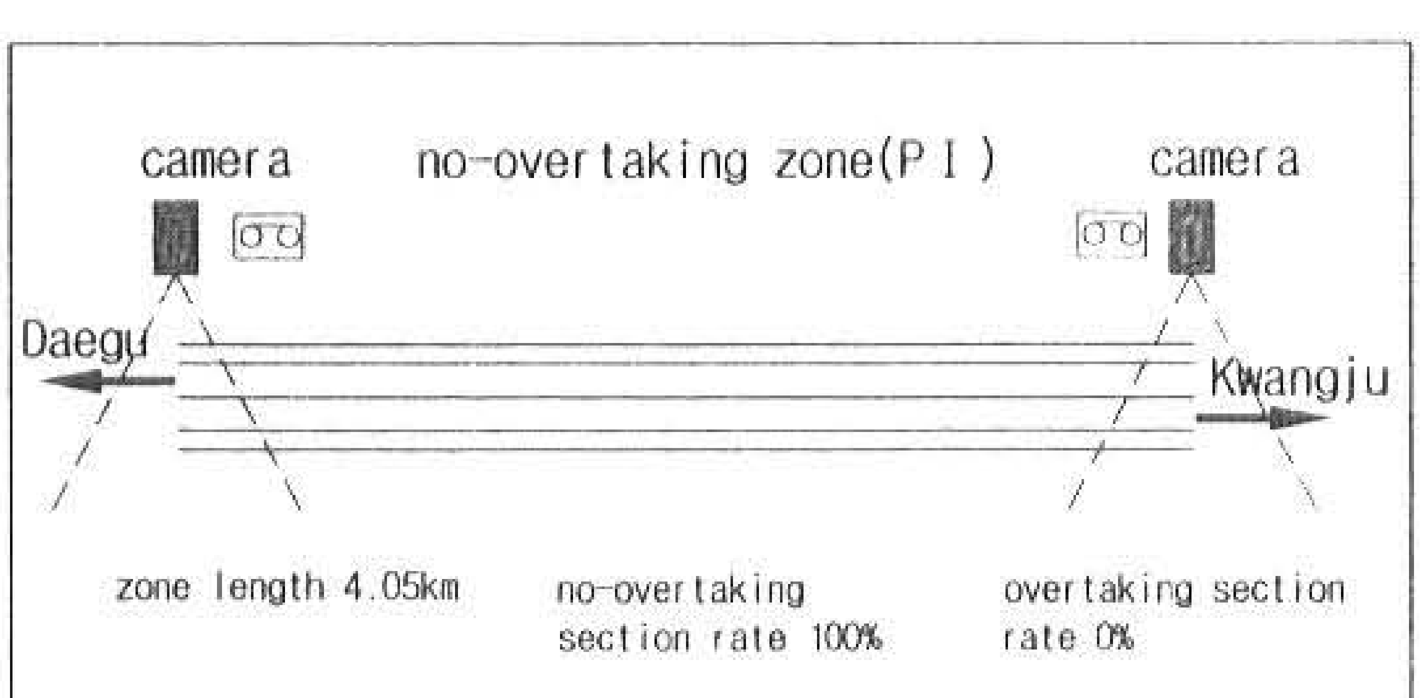

Fig. 2 No-overtaking zone (P I)

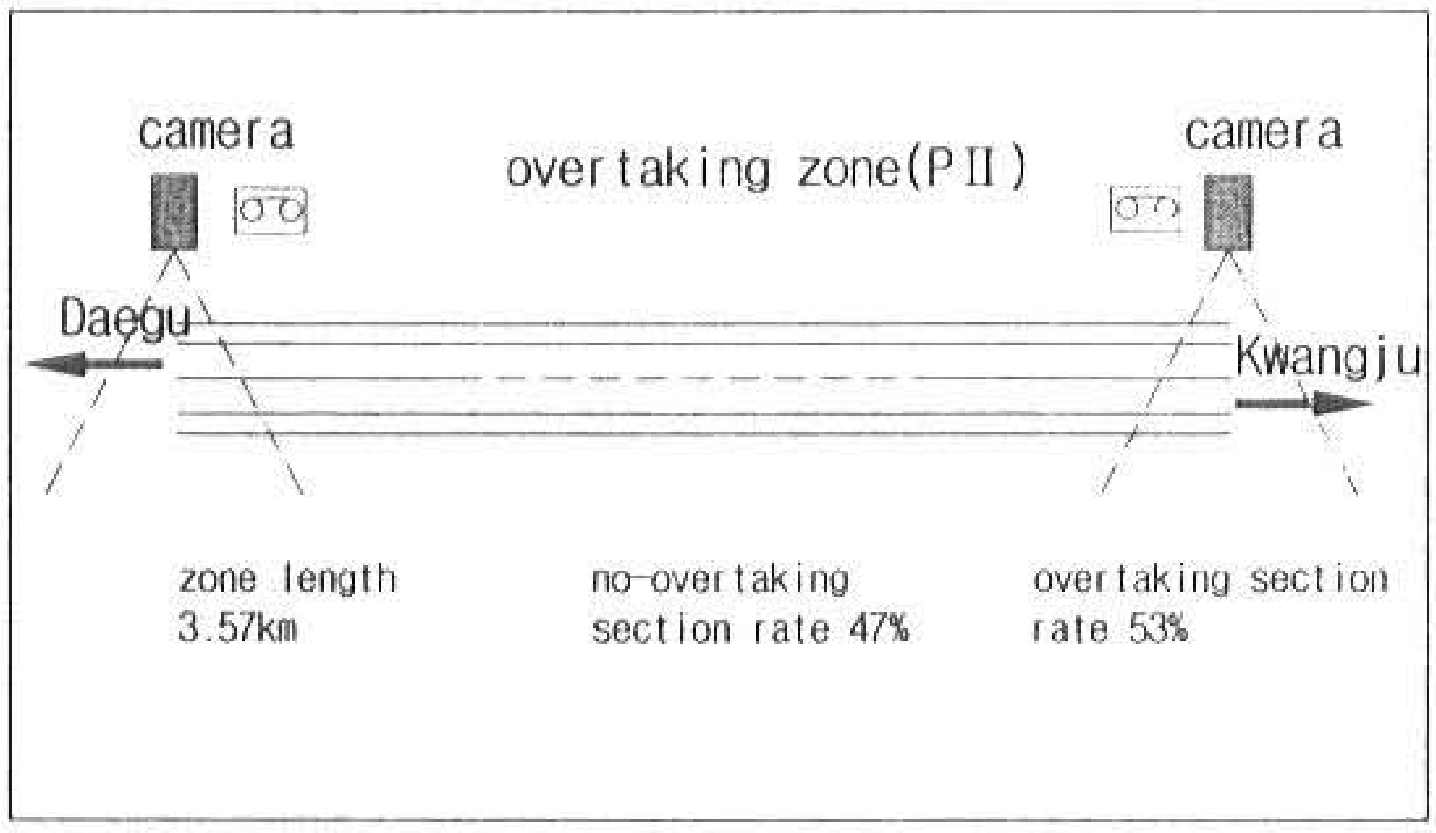

Fig.3 overtaking-zone (PII)

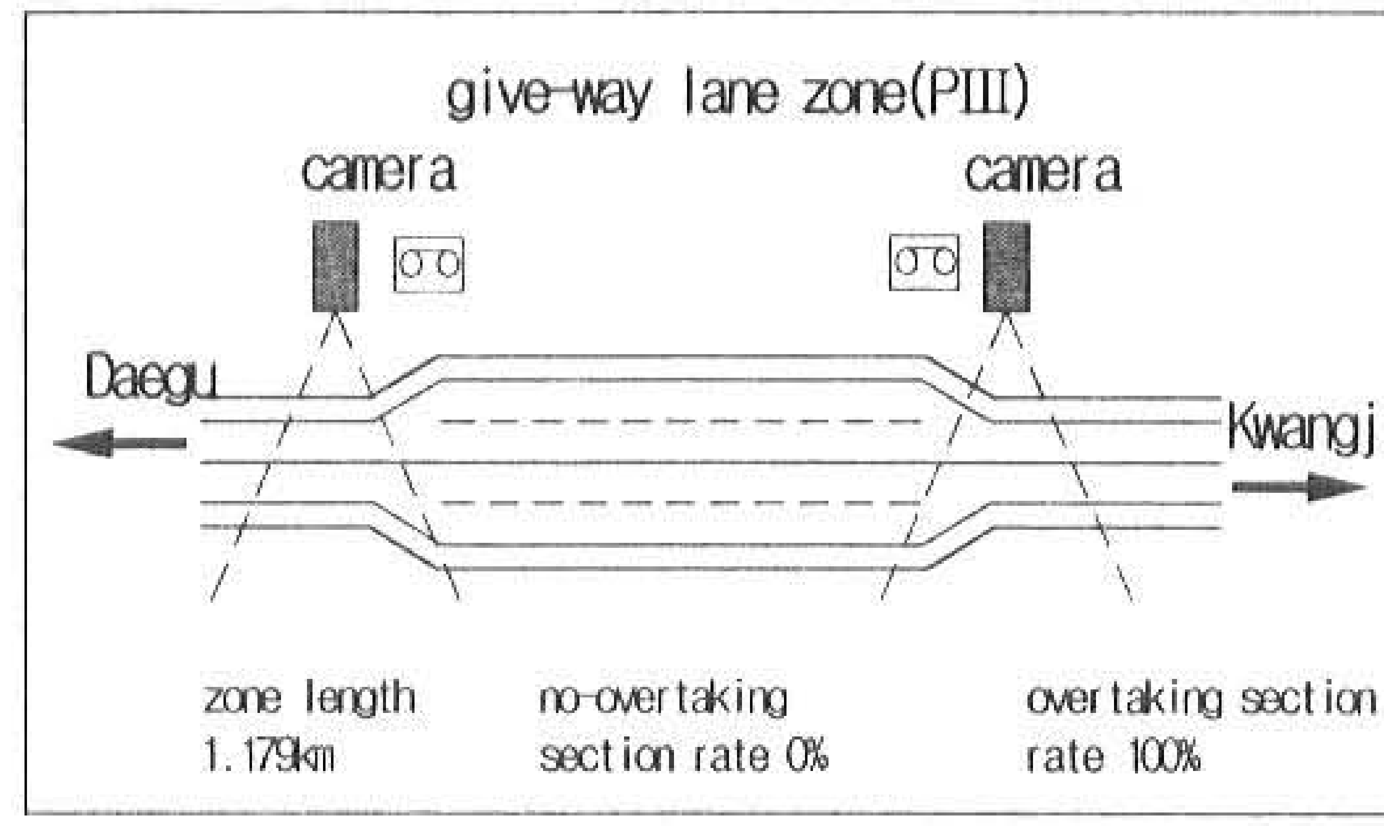

Fig. 4 Give-way lane zone (PIII)

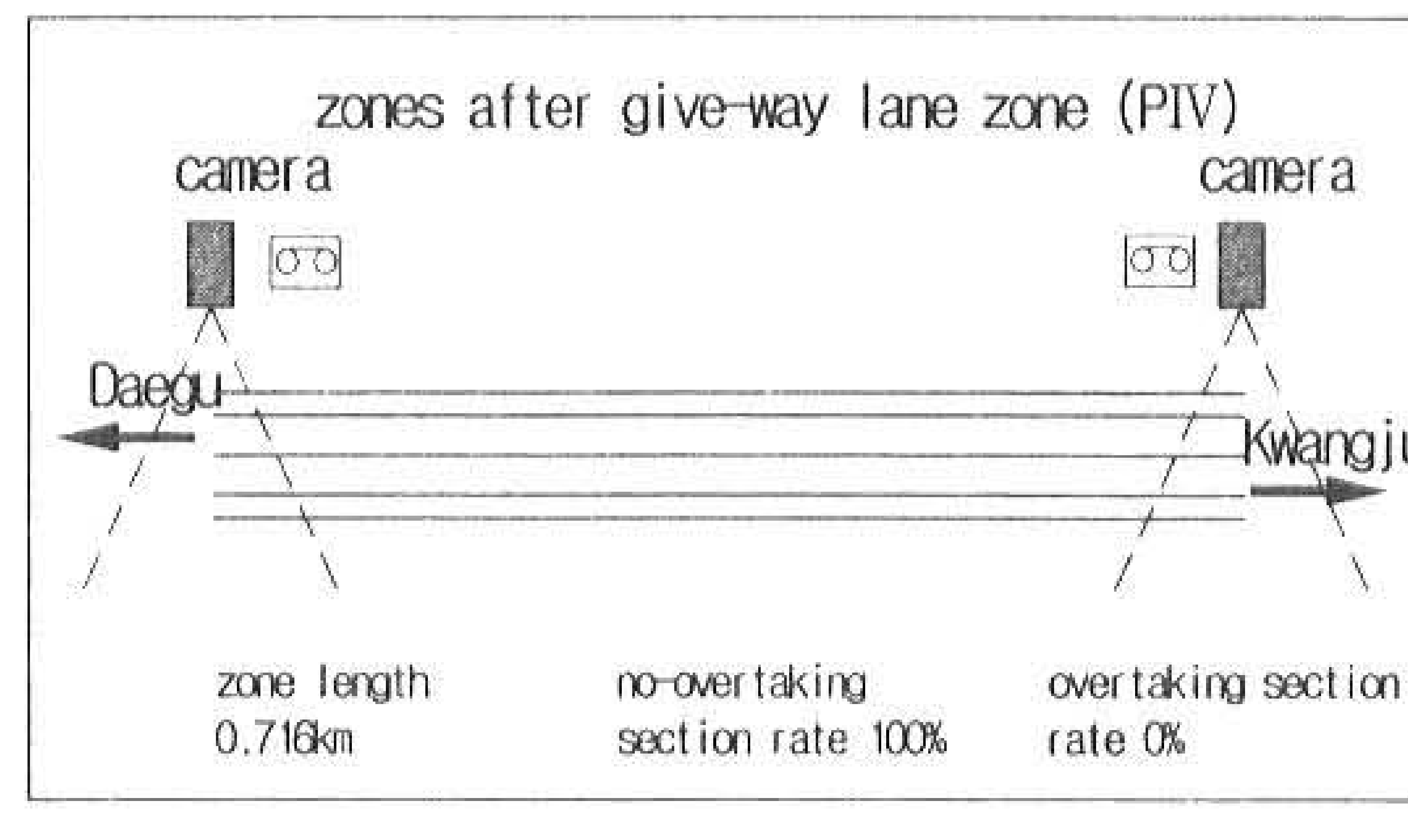

Fig 5 Zone after a give-way lane zone (PIV)

The investigation methods employed were video recoding and number plate investigation by sound recording.

4. Traffic flow analyzing by field investigation data

4.1 Overtaking rate analysis

The overtaking rate was calculated based on data by zones collected from the field investigation. Results is shown in Table 1.

Table. 1 Overtaking rate by zones

Zone	P_{I}	P_{II}	P_{III}	P_{IV}
Overtaking rate	0.43%	1.80%	24.30%	0.79%

Although P_{I} and P_{IV} were no-overtaking zones, illegal overtaking occasionally happened. The overtaking rate of P_{IV} was significantly higher than other zones. As for overtaking zones, overtaking was limited by the traffic of the opposite lane. Therefore, it is considered desirable to build give-way lanes rather than to have overtaking zones for easing traffic jams caused by low-speed vehicles and efficient road operation.

4.2 Desire speed calculation

This study used Nomann's free traffic flow classification criteria to calculate a desire speed. The desire speed was set to be 85% of cumulative distribution of free vehicles selected according to Nomann's classification criteria.

speed distribution figure to calculate a desire speed is as shown in Figure 6.

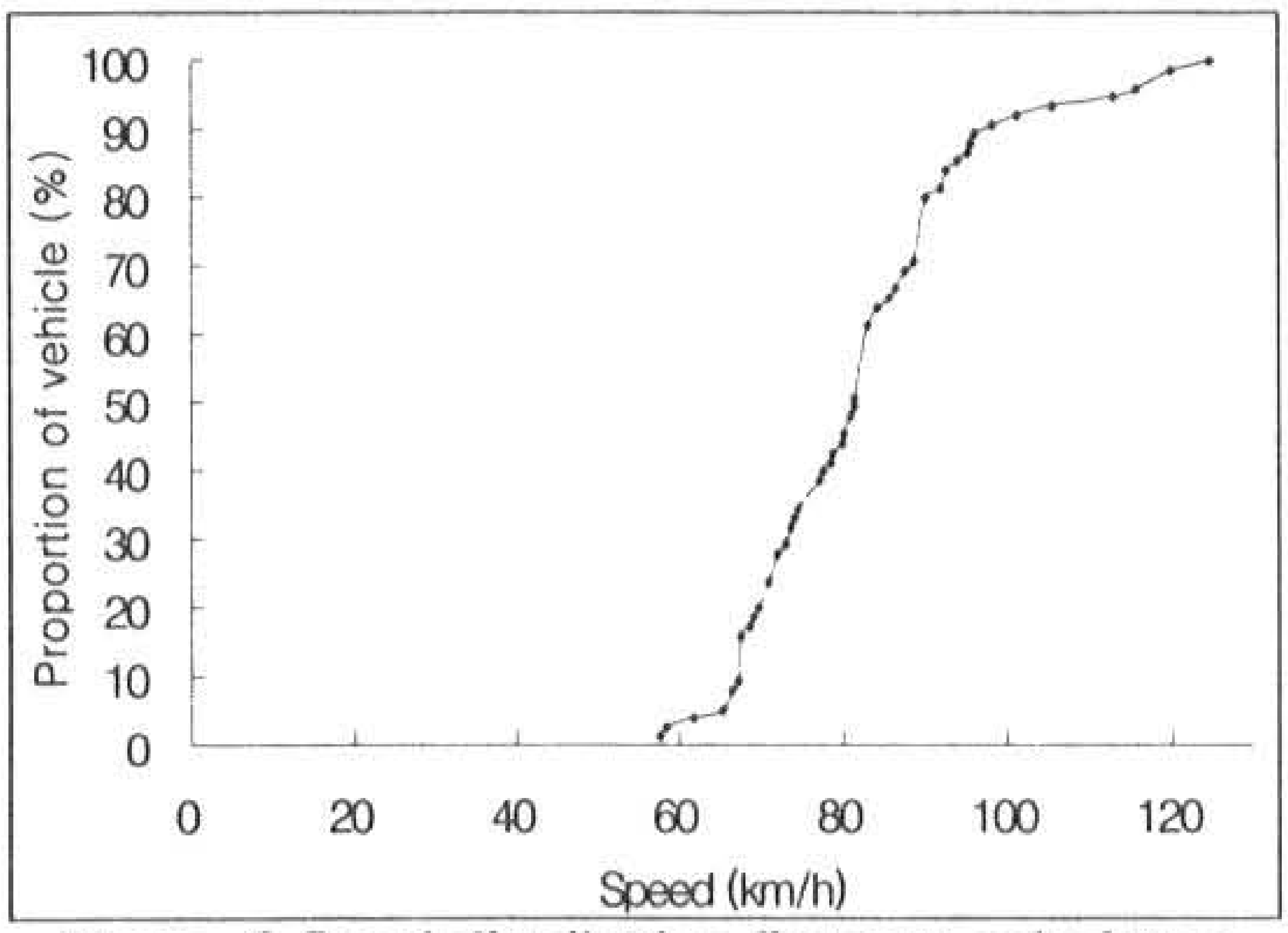

Figure. 6 Speed distribution figure to calculate a desire speed

The obtained desire speed was 93.57km/h. Using the speed this study calculated the total delay rate.

5. LOS analysis for each zone

5.1 LOS analysis by PTD

To examine changes in space headway, this study calculated the delayed vehicle rate using 4 seconds, which is the HCM standard, and 5 seconds, which is the Korean standard, and applied it as a substitute scale for PTD.

Results of LOS analysis is as in Table 2.

Table. 2 Results of LOS analysis of each zone according to the PTD

Zone	PⅠ	PⅡ	PⅢ	PⅣ
P T D(4sec)	83.71	84.45	69.29	70.74
P T D(5sec)	90.76	91.59	79.31	78.35
LOS(4sec)	E	E	D	D
LOS(5sec)	E	E	E	E

5.2 LOS analysis by ATS

According to field investigation, the mixture rate of trucks was 0.035 and the calibration coefficients for trucks and buses were 1.1 and 1.0 respectively. The calibration coefficient for heavy vehicles obtained using the results were 0.996 and 1. In addition, Fnp is the calibration coefficient for the rate of no-overtaking zones, and the calibration coefficient for each zone is as in Table 3.

Table. 3 Calibration coefficient for each zone by field investigation

Zone	PⅠ	PⅡ	PⅢ	PⅣ
The rate of no-overtaking zones (%)	100	47	0	100
Calibration coefficient	2.4	1.7	0	2.4

The service level of each zone according to the average traffic speed obtained from the results of field investigation is as in Table 4.

Table. 4 Result of LOS analysis of each zone according to the ATS

Zone	PⅠ	PⅡ	PⅢ	PⅣ
ATS (km/h)	59.03	59.33	61.43	59.03
LOS	E	E	D	E

5.3 LOS analysis by PTSF

LOS analysis by PTSF was conducted using the results of field investigation.

The calibration value of each zone for the calibration against the rate of no-overtaking zone and the influence of the traffic flow of the opposite lane is as in Table 5, and the result of LOS analysis of each zone by PTSF is as in Table 6.

Table. 5 The calibration value of each zone for the calibration against the rate of no-overtaking zone and the influence of the traffic flow of the opposite lane

Zone	PⅠ	PⅡ	PⅢ	PⅣ
The rate of no-overtaking zone (%)	100	47	0	100
$f_{d/np}$	6.7	6.0	0	6.7

Table. 6 The result of LOS analysis of each zone by PTSF

Zone	PⅠ	PⅡ	PⅢ	PⅣ
PTSF(%)	83.9	83.2	77.2	83.9
LOS	E	E	D	E

5.4 LOS analysis by KHCM

KHCM calculates the total delay rate by road type using the total delay rate calculation formula under an ideal condition as follows.

The design speed for the section investigated in this study is 80km/h, so the section belongs to Type I.

The rush hour-based traffic volume of the corresponding road is calculated. If the obtained volume exceeds the road capacity, LOS is decided to be F, and if not, the analysis process is continued.

According to the results of field investigation, the traffic volume was found not to exceed the capacity, and the calibration coefficient for heavy vehicles was calculated as 0.98, and PHF as 0.95. In addition, the total delay rate calibration coefficient according to the distribution by zones and directions and the percentage of no-overtaking zones appeared as in Table 7.

Table. 7 The total delay rate calibration coefficient according to the distribution by zones and directions and the percentage of no-overtaking zones

Zone	P I	P II	P III	P IV
The rate of no-overtaking zone (%)	100	47	0	100
f_{dD-P}	1.185	1.145	1.065	1.185

The results of LOS analysis using the field investigation results are as in Table 8.

Table. 8 The results of LOS analysis

Zone	P_{I}	P_{II}	P_{III}	P_{IV}
Total delay rate(%)	24.42	23.60	21.95	24.42
L O S	D	D	C	D

5.5 LOS analysis by the total delay rate calculation formula

The results of LOS analysis, which applied the field investigation results to the total delay rate calculation formula as Formula (1), are as in Table 9.

Table. 9 The results of LOS analysis

Zone	P_{I}	P_{II}	P_{III}	P_{IV}
Average travel speed (km/h)	65.79	72.64	76.23	87.30
Desire speed (km/h)	93.57	93.57	93.57	93.57
Total delay rate (%)	29.75	22.41	18.54	6.70
L O S	D	C	C	A

The reason that the total delay rate was small in P_{IV} is thought because of overtaking occurred in P_{III}. Thus, LOS in P_{IV} is considered to result from the characteristics of the traffic flow of P_{III}.

5.6 Comparison and examination of LOS analysis results

The present study analyzed LOS by geometric structure using PTD, ATS, PTSF and the service standard of total delay rate. The results appeared to vary according to LOS measure and LOS analysis standards. LOS comparison according to LOS measure is as in Table 10.

Table. 10 LOS comparison according to LOS measure

Zone		P_{I}	P_{II}	P_{III}	P_{IV}
HCM(1994)	PTD(5)	E	E	E	E
HCM(2000)	ATS	E	E	D	E
	PTSF	E	E	D	E
KHCM(2001)	Total delay rate (%)	D	D	C	D
LOS by the total delay rate calculation formula		D	C	C	A

As a whole, it was found that LOS in overtaking zones is not significantly different from that in no-overtaking zones, and LOS in give-way lanes is better than that of other types of zones.

6. Conclusion

In this study, the highway zones that have a overtaking lane or a concession lane out of annexed lanes to bi-directional two lane highway were investigated. Characteristics of the highways according to geometrical structure were analyzed and LOS analysis was performed for each zone.

The results are as follows;

1. When looking into the vehicle speed and time headway analysis, similar characteristics of traffic flow were shown in both No-overtaking Zone and overtaking Zone. In Concession Zone, remarkably better traffic characteristics were shown. This phenomenon is clearer when analyzing overtaking rate. When overtaking rate is analyzed, overtaking rate in No overtaking Zone was 0.43% that in overtaking Zone was 1.80% and that in Concession Zone was 24.30%. When looking into these results, overtaking rate cold change the traffic characteristics.

2. When an analysis by HCM, KHCM and total suspension calculation equation was performed in order to analyze the service level according to highway operation type,

concession highways showed better service level than No-overtaking Zone and overtaking Zone.

3. When summarizing those analysis results, in overtaking zone, it is very difficult to overtaking actually because of many restrictions such as securing enough distance and sight for outrunning and it becomes similar to No-overtaking Area. Therefore it is judged that concession areas should be established even partially to reduce the congestion of two-way two-lane roads.

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