VARIABLE TRAFFIC OPERATIONAL GUIDELINE FOR DYNAMIC LANE ALLOCATION; FOCUSING ON TEMPORARY CLOSURE OF CLIMBING LANE

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ABSTRACT

Interest in dynamic lane allocation is recently increasing as a way of resolving traffic congestion and preventing traffic accidents in advance through efficient use of the roads. This study tried to establish variable traffic operational guideline suitable for traffic characteristic and to analyze its effects with the example of climbing lane.
By selecting climbing section of Nakdong junction (for Masan), VISSIM-microscopic traffic simulation-analysis was conducted with the traffic operational variables such as v/c, heavy vehicle ratio. As the result of simulation, it was analyzed that the operation of climbing lane will have bigger operational effect in general traffic situation with no congestion, but the closure of climbing lane will be effective in traffic operation in case v/c and heavy vehicle ratio increase. As the result, in consideration of simulation analysis result, expressway operability, and drivers' perceptibility, average travel speed of 50km/h in climbing section was selected as operational standard (critical travel speed) which can determine the operation or closure of climbing lanes.
We established a variable traffic operational guideline base on critical travel speed with flexible management process for dynamic lane allocation on climbing lane. We conducted a dynamic lane allocation based on collected traffic data as a guideline, limited the minimum cycle of change in order to prevent driver's confusion, and suggested system configuration for that.

1. INTRODUCTION

The phenomenon of traffic congestion is repeatedly taking place in spite of continuous construction of expressways. To resolve the congestion, method of lane capacity increase such as lane expansion and construction of new lanes has been mainly used but this method has a disadvantage of inevitable continuance of traffic congestion for a considerable period of time because it takes long time to plan, design, and construct the lanes. At this point of time when interest in eco-friendliness of the roads is ever increasing, the efficient use of road facilities is very important and necessary for relief of the congestion, and temporally and spatially customized traffic operational management skills such as ramp metering and lane control system (LCS) are highlighted as new alternatives to resolve the congestion.

Temporally and spatially customized traffic operational management is based on the characteristics of temporal change of traffic stream such as v/c and v/c rate by vehicle type and on spatial characteristics of geometrical structure of the roads such as lane width, lane shoulder width, longitudinal slope, and cross-sectional slope, which means dynamic lane allocation. In other words, dynamic lane allocation means the dynamic management of the lanes suitable for the characteristics of traffic stream to maximize the use efficiency of the roads. This includes, on a large scale, the operation of variable lanes additionally added to middle direction in case characteristics of middle direction exist in peak time period or the provision of additional capacity to the roads by operating lane shoulder, and on a small scale, includes the attempt for maximization of lane capacity in consideration of traffic characteristics of each vehicle type such as operation of exclusive bus lanes to discourage people from using their cars and to encourage them to change the traffic means to buses in daytime with much car traffic or operation of exclusive truck lanes in night-time with much truck traffic.
The advantage of temporally and spatially customized traffic operational management is that we can find out the important variables for efficient operation of the roads when the characteristics of geometrical structure of the roads such as the number of lanes, lane width, speed limit, longitudinal slope, and cross-sectional slope are combined with the change of traffic volume by vehicle type and traffic hours and with the characteristics of each vehicle type (max/min. adjustable speed, average travel speed), which is implemented through dynamic lane allocation. In short, like the lowest point of water pail becomes the critical point when filling the water in the pail, the efficiency of the lanes can be maximized by dividing the lane in need of additional capacity and the lane in excess of its capacity and by distributing the capacity of the lanes as suitable for temporal and spatial traffic characteristics.
This study tried to understand the necessity and process of variable traffic operational guideline for dynamic lane allocation, to establish variable traffic operational guideline suitable for traffic characteristics with the example of climbing lane, and to analyze its effects.

2. THEORETICAL STUDY

Existing studies related to dynamic lane allocation are mostly for variable speed limit (VSL). This study conducted literature study on VSL system by dividing it into study on improvement of driving safety and study on minimization of driving time and optimization of traffic operation.

2.1. Existing Literature Study

2.1.1 Study on Improvement of Driving Safety

Peter Allaby. et. al. (2007) analyzed and evaluated the effects of VSL on urban highways by use of PARAMICS, a microscopic traffic simulation program. The result showed that the driving time increased and the driving safety was generally improved when VSL was applied but the driving safety decreased in non-peak time period.
Mohamed Abdel-Aty. et. al. (2006) conducted the analysis of VSL effect for improvement of road safety by use of CORSIM in non-congested section with high-speed vehicles and congested section with low-speed vehicles by utilizing a model for potential accident rate calculation progressed in previous studies (Abdel-Aty. et. al., 2005). The analysis result showed significant improvement of safety in non-congested section when VSL was applied, but showed no significant safety improvement in congested section, and suggested followings when VSL is to be applied.
· Progressive change of speed limit (5mph/10minutes)

- The change of speed limit should be posted at the same time (not to be differently posted according to distances)
- It is desirable to reduce the speed in upper part and to increase the speed in lower part.
- Even the short distances of upper and lower part are sufficient enough (2miles, respectively)

Chris Lee (2004) analyzed the driving time and potential accident rate when VSL is applied to 2.5km of highway sections including access ramp by use of PARAMICS, and the analysis result showed that the potential accident rate greatly decreased when low threshold was applied and the short VSL cycle increased potential accident rate. Potential accident rate showed low result in low speed limit section but the driving time appeared to have increased, and the section where potential accidents rate decreased the most greatly when VSL was applied was the upper part of the ramp with the greatest traffic congestion.
Kang et. al. (2004) suggested VSL Control Model in workzone and operational algorithm. The result of CORSIM simulation showed the greatest effects of increase of passing traffic volume and decrease of average traffic delay when VSL was applied in normal traffic condition.
Ali S. Al-Ghamdi (2007) studied on the operational evaluation of warning information system in case of foggy situation. The study result showed that the movement of drivers is greatly influenced by visual distances secured, and 6.5kph of deceleration effect was shown when deceleration message was posted, and the dispersion between the vehicles did not increase in deceleration. Fog warning information system can be considered as contributing to traffic calming which decreases the speed of high-speed vehicles and decreases the dispersion of speeds between the vehicles.

2.1.2 Study for Reduction of Driving Time

Paying attention to the fact that the drivers and LCS interact with each other, L. Schaefer (1998) analyzed the operational effects according to LCS compliance of the drivers. He classified traffic conditions into Light (300vphpl), Medium (900vphpl), and Heavy (1,550vphpl) condition, and organized the scenarios by giving compliance change (30%, 70%) to each traffic condition. Accident duration time and compliance delay in 1,300vphpl condition which shows LCS effect showed the effect of decrease of delay as the compliance increased regardless of accident duration time. Further, it appeared that the longer the accident duration time, the more the delay decreased, which showed us that the more serious the delay, the greater the LCS effect
Mithilesh Jha (1999) calculated change rate of driving time and delay according to LCS control length and coercive measures, assuming the considerations for LCS control as the length of LCS axis, traffic volume and lane use pattern, and compliance of the drivers. Experiments were conducted on the accidents in weaving section and ramp upper part of highway, classifying LCS control length and coercive measures into 3 LCS designs. In case of accident in weaving section, control effect in long control section length decreased by approximately 10~20% compared to short control section length, and it was observed that control effect is variable according to compliance.
Kang et. al. (2009) verified the control effect by variably changing the merging location of vehicles according to passing traffic volume in case of lane drop in main lane of highway. In other words, he concluded that, in light traffic demand situation, SEM (static early merge) method which encourages the merging of vehicles in advance at the upper part of accident spot is more advantageous, while SLM (static late merge) which encourages the merging of the vehicles when they approach accident spot is more advantageous in congested condition.

2.1.3 Conclusion

Previous researches on VSL were focused on the study for decrease of possibility of traffic accident according to road environmental conditions (such as fog, etc) and study on possibility of traffic accident and driving time according to traffic conditions. VSL application by use of simulation showed the effects of decreasing the possibility of traffic accident and increase or decrease of driving time according to study sections. But previous studies are mostly focused on decrease of traffic accidents, which makes it necessary to study on dynamic lane allocation which reflects environmental elements and traffic conditions of the roads as temporally and spatially customized traffic operational guideline.

2.2. Study on Application of Lane Control System

<Table 1> Status of LCS Operation

Division	Status of Operation
South Korea	• LCS lanes are being operated 15 sections (79.7km) and 15 lanes
Sweden	• VSL system is used by utilizing real-time speed-traffic volume data
Germany	•Dynamic lane control based on traffic volume of each merging direction is being implemented in the upper part of merging section in case the number of lanes in lower part which is operated with reduced number of lanes is less than the total number of lanes in upper part of merging section
England	•Balance between demand and capacity of each direction is maintained by installing LCS in 7-lane roads with no median barrier
The USA	•Traffic information is expressed mostly by use of variable information signal and sentence signal, where arrow signal symbol that expresses lane access restriction information has been developed

<Table 2> Status of Special Lane Operation

Division	Status of Operation
Emergency Lane Use on A48 Highway (France)	•Changing the shoulder lane to special shared lane through road marking for emergencies and operation of safety zone •special lane can be used by emergency vehicles, licensed regular buses and patrol vehicles in peak time period in the morning
MnPASS System in Minnesota (The USA)	• In order to guarantee smooth travel speed (50~55mph) for all MnPASS users, toll fees are adjusted in real time from a perspective of managing MnPASS demand
Zipper Lane System (USA)	• A method for using middle lanes by lifting median barrier and moving it to back right side by use of Zipper Machine, is being operated as an alternative to relieve traffic congestion in peak-time periods

In case of lane control system (LCS) which is being operated, clear standard or process has not been yet established, but traffic facilities are installed and statically operated to enhance the traffic capacity or safety of relevant section in the site-focused perspective.

Accordingly, for efficient and dynamic lane management, this study will analyze the traffic stream and spatial characteristics of geometrical structure of the roads in relevant section, and will try to establish variable traffic operational guideline on climbing lanes on the basis of dynamic lane management process such as operation of 'Right of Way' system imposed on specific vehicle types to improve the traffic capacity of the section.

3. ESTABLISHMENT OF DYNAMIC LANE ALLOCATION PROCESS OF CLIMBING LANE

Roads are generally designed as suitable for target service planned for their service lives, but this is just a service based on average traffic volume, so it can not actually reflect the changes of detailed traffic characteristics for a day. For example, when the traffic volume of buses is concentrated in specific time of rush hours, it is more efficient to operate temporary exclusive bus lanes, for which traffic operational guideline needs to be established.
Variable traffic operational guideline process for dynamic lane allocation of climbing lanes is as follows;

<Figure 1> Dynamic Lane Management Process of Climbing lane

4. ESTABLISHMENT OF VARIABLE TRAFFIC OPERATIONAL GUIDELINE FOR DYNAMIC LANE ALLOCATION OF CLIMBING LANE

4.1. Necessity of Traffic Operational Guideline of Climbing Lane

Climbing lanes are established to separate low-speed vehicles from high-speed vehicles and to enable the large trucks to drive on more than the minimum speed allowed to them, when significant decrease of traffic capacity is expected due to increase of mix ratio of large trucks which greatly lose their speed in climbing lanes or when lane selection and structural appearance of the road does not have economic feasibility or is not reasonable. Climbing lanes are established because large trucks can affect the overall traffic stream with their low speed in climbing sections while stable traffic flow can be maintained in flat part section with no big speed difference between the vehicles regardless of their types.

Korea has many mountainous terrains with high rate of heavy vehicles, so the effect of low-speed vehicle can be considered great in climbing sections. When climbing lanes are established, low-speed vehicles are separated from high-speed vehicles, which can increase the traffic capacity by decreasing traffic delay caused by low-speed vehicles, and at the same time, climbing lanes have the traffic operational effects of decreasing the passing of the vehicles which can happen as the speed difference increases between high-speed and low-speed vehicles.
However, climbing lane can sometimes act as an element of congestion in the perspective of traffic operation when v/c and the heavy vehicle ratio increase. Traffic conditions seem to temporarily have improved on access point and climbing section of the lane because climbing lane can have the effect of adding one lane to existing lanes, but around exit and merging point of climbing lane, 1 lane actually disappears, which can decrease the capacity of driving lanes due to bottleneck phenomenon caused by low-speed vehicles trying too much to join the main lane. In addition, low-speed vehicle drivers are reluctant to use climbing lane (low-speed lane), which sometimes makes the high-speed vehicle drivers attempt the passing by use of climbing lane, resulting in forceful closure of the climbing lane, but the clear operational guideline on this problem is nowhere to be found.

4.2. Literature Study related to Climbing Lane

4.2.1 Design Standard of Climbing Lane

Article 26 of <Rules for standard of structure and facilities of the road> stipulates that climbing lane can be established, when considered necessary, in the section with more than 5% (3% in case of expressway) of longitudinal slope, but climbing lane may not be established when design speed falls below 40km/h.
Standard for establishment of climbing lane in USA stipulates that climbing lane should be established in the section where standard truck speed decreases by more than 15km/h than other vehicles or when level of service falls between D~F in climbing slope (but climbing lane shall not be established when the traffic volume is less than 1,000 vehicles/lane on 4-lane roads regardless of truck ratio).
In Germany, start point of climbing lane shall be a place where travel speed of truck becomes 70km/h in the section with more than 100km/h of design speed, or a place where travel speed of truck becomes 60km/h in the section with more than 80km/h of design speed, and the place where travel speed of truck returns to 60km/h shall be designed as exit point.
In Japan, it is stipulated that climbing lane shall be established in the roads with more than 5% of longitudinal slope (more than 3% in case of expressway or design speed of more than 100km/h), as same as domestic standard.

4.2.2 Study on Previous Researches

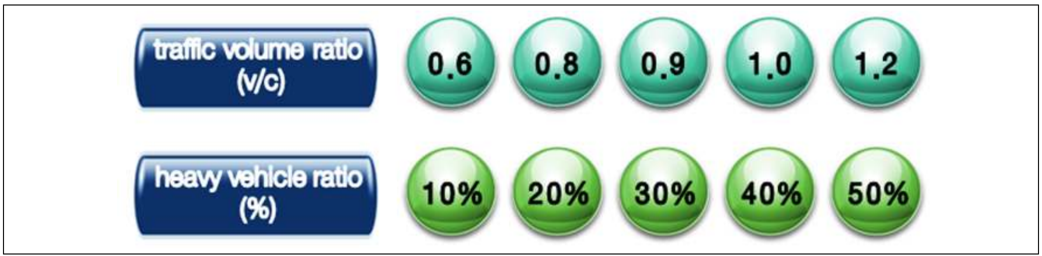
Previous researches related to climbing lane were mainly focused on design standard of climbing lane. Kim. et al (1998) carried out the research on design standard speed of climbing lane and Kwon. et al (1999) suggested design standard of exit point of climbing lane. Kim. et al (2006) suggested calibration standard of start and exit point of climbing lane, and Jang. (2008) suggested calculation standard for climbing lane length. In the mean time, Kim. (2003) suggested new standard for establishment of climbing lane, and Lee. et al (2010) even suggested a method of connecting outer lane with driving lane. However, previous researches were focused on design and establishment standard of climbing lane such as selection of climbing lane section, location of start and exit point, and method of establishment, and research on variable traffic operation of climbing lane has not been sufficiently conducted.

4.3. Setting up Research Methodology

4.3.1 Setting up Simulated Traffic Operation Variables

The most important thing in establishing flexible traffic operational guideline is to set up proper traffic operation variables, because only when they are properly set up, can establishment and closure effects of climbing lane be exactly identified, through which flexible traffic operational guideline can be established.

As previously studied, the result of research on standards (regulations, guidelines) for climbing lane establishment show that traffic condition of climbing lane is influenced by various elements such as traffic volume (v/c), heavy vehicle ratio, longitudinal slope, climbing lane extension, travel speed of each vehicle, and horse power of heavy vehicles. Accordingly, this study set up simulated traffic operation variables by applying the standard for establishment of climbing lane suggested in ‘Rules for standard of structure and facilities of the roads’ (hereinafter referred to as Rules). According to this ‘Rules’, establishment of climbing lane is decided depending on traffic volume and heavy vehicle ratio as suitable for size and length of longitudinal slope, so v/c and heavy vehicle ratio were selected as simulated traffic operation variables. The v/c was made to vary from 0.6 to 1.2, and heavy vehicle ratio n was made to vary from 10% up to 50% as general heavy vehicle ratio. Total 25 cases were analyzed through the combination of v/c and heavy vehicle ratio.



<Figure 2> Simulation Analysis Case

4.3.2 Selection of Evaluation Methodology

In order to study on traffic operational effect of climbing lane, travel speed was selected as MOE (Measure of Effectiveness), because climbing lane is established for the purpose of improving traffic conditions by separating low-speed vehicles from high-speed vehicles. Considering that the target place is on the expressway, 15 minutes of time interval was applied to travel speed for evaluation of the effects of climbing lane closure or maintenance, and spatial average speed was selected for each analysis section.

4.4. Selection of Target Section

It is well known that climbing lane has the effect of capacity increase resulting from the separation of low and high-speed traffic streams in uncongested situation, but it can become an important bottleneck point in case v/c increases. Accordingly, this study selected, as target sections, the places where there is not much traffic in normal period but the traffic rapidly increases in special period like consecutive holidays.

Selected target place was the climbing lane around Nakdong junction (139.2K) on Jungbunaerook Expressway, established with 3.7% of longitudinal slope in the 3.6km section from 136.9K to 133.3K for Masan. In this section, there was no congestion on weekdays or weekends, but there was some traffic delay in special transportation period such as 2008 Chuseok (Thanksgiving Day) and 2009 New Year’s Day, which lasted for max. 26 hours.

In the section between Nakdong junction (139.2K) and Gimcheon junction (114.4K) of Jungbunaerook Expressway, traffic volume is continuously increasing due to the opening (Nov.28.2007) of Cheongwon~Sangju section of Dangjin-Gimcheon Expressway, and particularly, the increase of heavy vehicle volume is remarkable (Ratio of heavy vehicle volume in 2008: 64.9%). This increase may have been caused by increase of heavy vehicle volume of Dangjin-Sangju Expressway, and the ratio of actual heavy vehicle volume out of total traffic volume of the section between Cheongwon~Nakdong is 50%.

<Figure 3> Target Place Selection

4.5. Simulation Analysis and Calculation

4.5.1 Summary of Simulation Analysis

(1) Simulation Tool Selection

As this study is in need of simulation which can describe the change of traffic stream resulting from various traffic variables such as climbing lane length, slope, traffic volume, and heavy vehicle ratio in actual traffic condition, this study selected VISSIM as simulation tool which can simulate the congestion caused by merging of the vehicles at the exit point of climbing lanes, and can individually realize geometrical structure of actual expressways and performance of the vehicles.

VISSIM, a microscopic simulation experiment model based on behaviour, can identify various vehicle types, input traffic volume of each vehicle type, distinguish drivers' patterns, and organize vehicle type and class you want, with the advantage of being able to analyze detailed items such as speed on each place, speed on each lane, speed and driving time on each section, and analysis of congested traffic stream.

(2) Simulation Network Organization

Geometrical structure of the roads around Nakdong junction including climbing lane of target section was organized with simulation network. Distance from Nakdong junction to climbing lane, classification variable section in climbing section, climbing lane section, merging variable section in climbing section, and approximately 14.5km to Seonsan Service Area were selected as simulation networks. The change of lanes and distance of each section are as follows;

○ Simulation Network

- Lane change: 2 lanes → 3 lanes → 2 lanes
- 2 lanes (3km) + variable section (400m) + 3 lanes (climbing lane 3.6km) + variable section (500m) + 2 lanes (7km)

(3) Division of Vehicle Type

This study divided simulation vehicle types into cars and heavy vehicles, and applied 100km/h of travel speed to cars and 60km/h to heavy vehicles, because the result of site survey showed that the travel speed of heavy vehicles in climbing lanes was approximately 60km/h, different from travel speed of common vehicles. In order to exactly realize climbing lanes operated in reality on VISSIM, climbing lane closure function was installed for all other vehicles except heavy vehicles.

(4) Other Input Variables

Common simulation values were applied to all other variables except simulated traffic operational variables for establishment of climbing lane traffic operational guideline. Particularly, in case of microscopic simulation model like VISSIM, it is important to decide on the parameters of drivers' behaviours about the vehicle following and lane selection. To decide on the parameters of drivers' behaviours necessary for driver VISSIM model, simulation was conducted by use of default values (but with change of traffic variables such as traffic volume and vehicle type ratio as suitable for relevant sections) provided from VISSIM.

In VISSIM model, the speed of each vehicle type can be changed depending on the slope, so this study also applied it as it was and examined whether the change of travel speed according to the slope in simulation was reflected as similar with actual target sections through simulation calculation process, and also confirmed its statistical significance.

4.5.2 Simulation Controlled Variables Establishment

(1) Performance of Truck

Considering that analysis target section is expressway which is now being operated, 200lb/hp of climbing performance was applied to truck (heavy vehicle).

(2) Warm-up Time Decision

Before the result of simulation is analyzed, warm-up time should be decided in advance. The result obtained from the situation where the flow of input traffic volume has not been stabilized can not reflect the characteristics of actual road conditions and may be inappropriate.

Generally, there exist 2 methods of deciding warm-up time, a method of designating certain time and initializing it, and a method of initializing specific indexes until they are satisfied, and this study adopted the former method. In other words, VISSIM simulation was conducted for 7,200 seconds, warm-up time for the first 3,600 seconds, and simulation analysis was conducted for the remaining 3,600 seconds (3,600~7,200 seconds), according to climbing lane closure or operation.

(3) Random Seed Application

In order to enhance the reliability of simulation result and for objective evaluation of travel speed difference according to climbing lane closure or operation, this study generated each different random seed value in each different scenario for 3 times and conducted total 6 times of analysis, each 2 times respectively, and compared the average values of the result.

4.5.3 Simulation Calibration

Prior to conducting actual simulation (VISSIM), it is important to check how much exactly the organized simulation networks and input variables simulate the traffic condition of actual target section. In this study, simulation accuracy was calibrated for actual traffic data (speed) of target section on the basis of travel speed.

(1) Study on Truck Performance

① Truck Performance Analysis

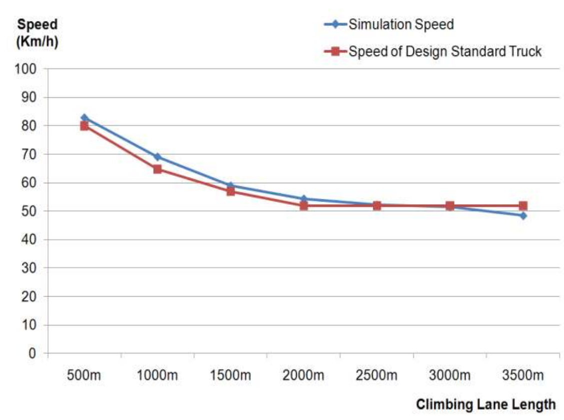
Calibration of driving performance of trucks is very important and necessary in calculation of simulation. For this, statistical calibration was conducted to check whether driving performance of trucks applied in simulation was the same as performance function (200lb/hp) of standard trucks stipulated in 'Rules for standard of structure and facilities of the roads'.

Vehicle variable of simulation model was put in as the same specific property with design standard truck (min. 180lb/hp, max. 220lb/hp, average 200lb/hp), and the result of simulating it in geometrical structure (climbing slope 3.7%, section length 3.6km) of target section of the analysis showed the distribution as shown in Table 3.

<Table 3> Comparison of Climbing Performance (Travel Speed) of Simulation and Design Standard Truck (200lb/hp)-Climbing Slope 3.7%

(unit : km/h)

Climbing Length	Simulation					Design Criteria
	15min	30min	45min	60min	average	
500m	83.16	82.12	83.22	82.74	82.81	80.0
1000m	69.12	69.07	69.65	68.51	69.09	64.8
1500m	59.98	58.25	59.04	58.50	58.94	57.0
2000m	55.56	53.44	54.17	54.33	54.38	51.9
2500m	52.91	51.66	51.69	52.76	52.26	51.9
3000m	50.3	51.5	51.69	52.85	51.59	51.9
3500m	47.5	48.82	47.65	49.96	48.48	51.9



Performance function of design standard truck showed the characteristic of rapid speed decrease up to 2.0km distance right after it entered climbing section, maintaining certain speed of approximately 52km/h after 2.0km distance, and it was analyzed that simulation model of this study has the similar climbing characteristics as design standard truck.

② Mann-Whitney Test

As a result of Mann-Whitney Test, speed group deducted from simulation trucks and speed group of design standard truck can be considered as having statistically same distribution, because approximate significance probability (both) for Z statistic is 0.706, bigger than risk ratio of 0.05. Accordingly, driving performance (200lb/hp) of simulation trucks and climbing performance characteristics of design standard trucks can be considered same in 95% confidence level.

<Table 4> Mann-Whitney Test Statistic

Division	Test Statistic
Mann-Whitney W	480.0
Wilcoxon W	1110.0
Z	-0.377
Approximate significance probability (both)	0.706

(2) Simulation Accuracy Test

Site data were collected from Freeway Traffic Management System (FTMS) where actual Vehicle Detection System were installed, and data of 17:30~18:30 of April 15, 2010 on 134.0K~137.0K of Jungbunaerook Expressway (for Masan) were compared in 5-minute intervals. For simulation accuracy test, t-test was conducted for travel speed difference between Freeway Traffic Management System and simulation. As shown on Table 5, average travel speed of Freeway Traffic Management System for target section showed the same simulation result in all sections except point 1. T-test also showed the statistically same travel speed of simulation and Freeway Traffic Management System in all sections, which means that simulation structure exactly reflects the real situations.

<Table 5> Simulation Calibration

Division	Average Travel Speed		Std. Dev. of Travel Speed		t-value	p-value
	FTMS*	Simulation	FTMS	Simulation		
All sections	83.73	83.61	5.14	5.53	0.11	0.912
Point 1 (134.0K)	88.33	92.18	4.91	1.39	-2.61	0.023*
Point 2 (135.3K)	82.92	82.21	4.67	2.23	0.49	0.632
Point 3 (136.3K)	82.22	80.88	4.32	2.11	1.47	0.163
Point 4 (137.0K)	80.75	79.17	3.93	2.79	1.14	0.270

Note) * FTMS : Freeway Traffic Management System

4.6. Establishment of Traffic Operational Guideline on Climbing Lane

4.6.1 Simulation Analysis Result

As the result of simulation analysis to understand the effect of climbing lane operation or closure on climbing section, it was analyzed that the operation of climbing lane will have bigger operational effect in general traffic situation with no congestion, but the closure of climbing lane will be effective in traffic operation in case v/c and heavy vehicle ratio increase, which means that flexible operation of climbing lane according to the change of traffic volume (v/c) and heavy vehicle ratio can determine the traffic situation of climbing section, which makes us confirm the necessity of establishment of flexible traffic operational guideline to relieve the congestion of climbing section.

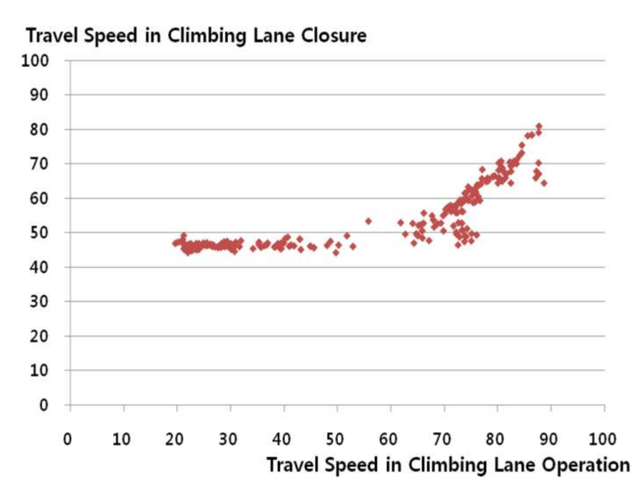
4.6.2 Establishment of Traffic Operational Guideline on Climbing Lane

(1) Establishment of Operational Guideline by use of Travel speed

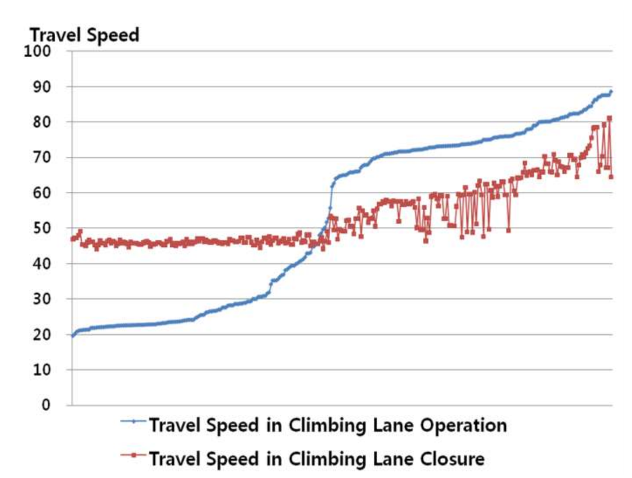
This study tried to establish operational guideline by use of travel speed, a traffic operational variable which can be collected in real-time. <Figure 4. a> is a graph which shows travel speed relationship between operation and closure of climbing lane in scatter diagram on the basis of simulation analysis result, and <Figure 4. b> is a graph which shows travel speed relationship between operation and closure of climbing lane on the basis of travel speed when climbing lane is operated.

<Table 6> Simulation Result

Traffic Volume ratio (v/c)	Heavy Vehicle ratio (%)	Average travel speed		
		When climbing lane is operated (a)	When climbing lane is closed (b)	Speed difference (a-b)
0.6	10	86.7	79.3	7.5
	20	80.6	69.7	10.9
	30	76.0	63.0	13.1
	40	73.2	59.6	13.6
	50	70.4	57.8	12.6
0.8	10	81.8	70.3	11.5
	20	75.0	63.1	12.0
	30	71.2	57.1	14.1
	40	66.1	53.7	12.4
	50	39.8	47.3	-7.4
0.9	10	79.0	66.4	12.6
	20	72.5	53.5	19.1
	30	44.8	46.3	-1.5
	40	30.0	46.1	-16.1
	50	23.4	45.2	-21.9
1.0	10	72.6	49.2	23.3
	20	33.5	47.4	-13.9
	30	28.5	46.1	-17.6
	40	27.4	45.8	-18.4
	50	23.7	45.3	-21.7
1.2	10	61.0	49.4	11.5
	20	33.3	47.5	-14.2
	30	30.1	46.8	-16.7
	40	29.9	45.9	-16.0
	50	23.6	45.2	-21.7



(a) Scatter diagram of travel speed in operation and closure of climbing lane



(b) Travel speed graph in operation and closure of climbing lane

<Figure 4> Travel speed Distribution in Operation and Closure of Climbing Lane

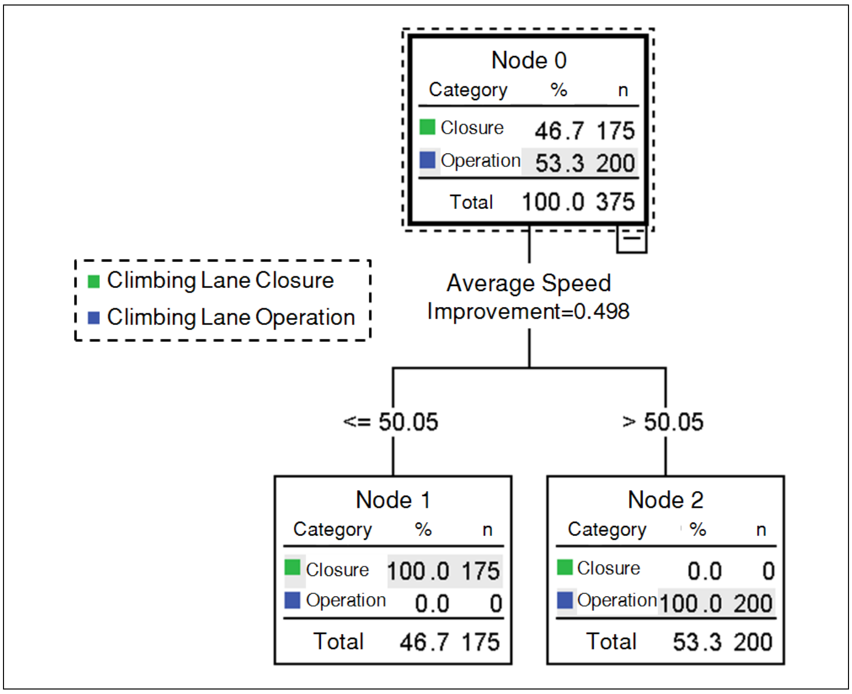
As the result of analysis of travel speed which is a standard of positive/negative crossing of travel speed difference when climbing lane is operated and closed, positive/negative of travel speed difference between climbing lane operation and closure changed based on approximately 50km/h.

(2) Establishment of Operational Guideline through CART Analysis

To find out the exact critical point which determines the operation of climbing lane, this study conducted CART analysis and defined the travel speed which can be a standard for classification of groups as “Critical Travel speed”, trying to use it as operational guideline of climbing lane.

The result of CART analysis showed that climbing lane operation group is distinguished from the closure group on the basis of 50.05km/h of travel speed. Group 1 was defined as ‘climbing lane operation group’ where travel speed in climbing lane operation is faster that

that in climbing lane closure, and Group 2 was defined as ‘climbing lane closure group’ where travel speed in climbing lane operation is slower than that in climbing lane closure.



<Figure 5> CART Analysis Result

Statistical test was conducted for the groups reclassified by travel speed by conducting t-test for the groups distinguished by CART analysis. p-value in Levene’s test showed 0.000 with the same homogeneity of distribution between the groups, and p-value in t-test showed 0.000, which can be considered as having significant difference between 2 groups in 95% confidence level.

<Table 7> T-test Result

Parents Node	Children Node	N	average	Standard deviation	Levene’s test		t-test	
					F	p-value	t-value	p-value
Node0	Node1	180	30.666	8.340	16.530	0.000	-55.608	0.000
	Node2	195	74.316	6.835				

(3) Summary of Analysis Result

On the basis of the result of VISSIM analysis, a microscopic simulation, this study tried to establish variable traffic operational guideline on climbing lane based on travel speed.

As the result of analysis of travel speed which is a standard of positive/negative crossing of travel speed difference when climbing lane is operated and closed, it was analyzed that positive/negative of travel speed difference started to change their signals in approximately 50km/h speed.

On the contrary, as the result of CART analysis to find exact critical point which can distinguish climbing lane operation and closure group, it was analyzed that the groups can be distinguished in 50.05km/h.

On the basis of above analysis result and in consideration of expressway administrator’s operability and drivers’ perceptibility, 50km of average speed in climbing section was selected as critical travel speed which decides on the operation of climbing lane.

4.6.3 Establishment of Dynamic Lane Allocation of Climbing Lane

(1) Method of Dynamic Lane Allocation of Climbing Lane

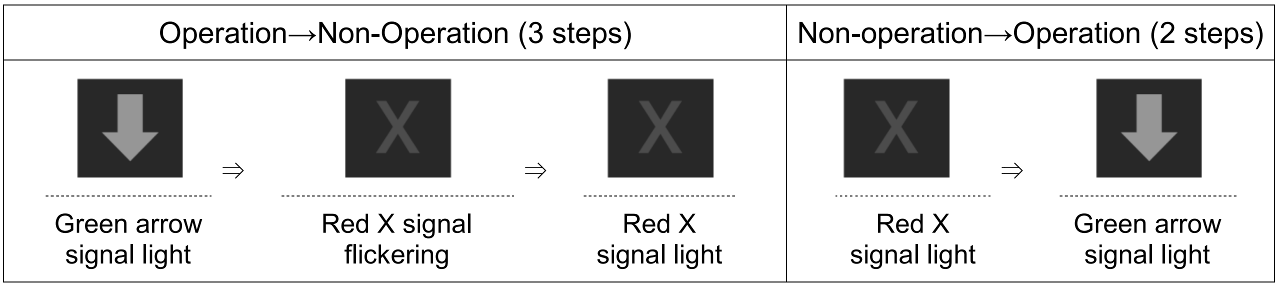
It is necessary to establish operational guideline for dynamic operation and control of climbing section on the basis of above simulation analysis result. In other words, climbing lane in climbing section is operated in normal times, but in case average travel speed of climbing section can't maintain travel speed (critical travel speed) of certain level, climbing lane shall be closed, when frequent revision of dynamic operation and control according to frequent change of speed shall be prevented by fixing minimum closure time. Accordingly, this study selected following operational guidelines;

- Minimum operation time (1 cycle) shall be 15 minutes in case of dynamic control of climbing section
- In case of less than 50km/h of average travel speed in climbing section, climbing section shall be closed
- In order to reduce the rate of mal-perception due to temporary breakdown of Vehicle Detection System, the change of operational guideline for climbing lane shall be decided by travel speed calculated through weighted value with travel speed of last cycle

(2) Designing Method of Traffic Facilities in Climbing Section

Efficient operation of climbing section shall be promoted by installing sentence-type VMS in access point of climbing section, lane control signal machine (500m interval), and red-light cameras. In addition, monitoring of climbing lane operation section shall be conducted through installation of CCTV.

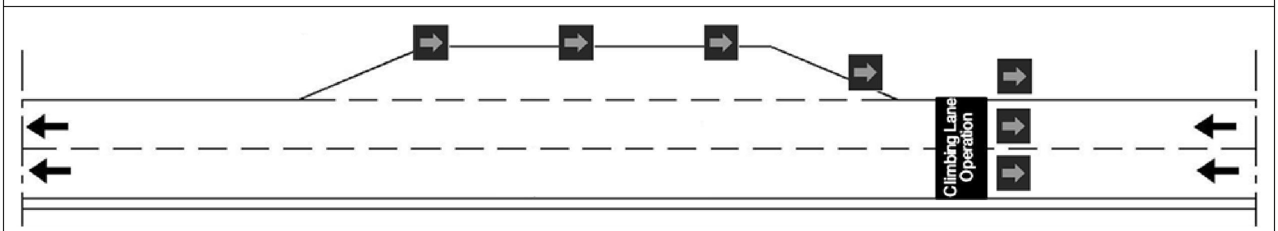
Risk of accidents due to drivers' confusion shall be reduced by differentiating signal change methodology according to climbing lane operation or closure. When climbing section is changed from operation to non-operation, climbing lane shall be closed after making drivers aware of signal change with 'Red X Signal' flickering lights. On the contrary, in case of change from non-operation to operation of climbing section, green arrow signal shall be immediately lighted without flickering lights in advance.



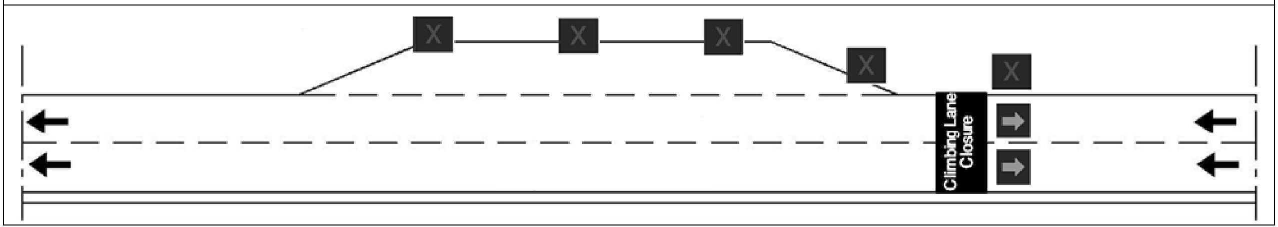
<Figure 6> Signal Change Methodology according to Climbing Lane Operation or Closure

Dynamic information of each road traffic condition shall be provided to drivers by establishing guidelines for VMS operation in access point and lane control system (LCS) operation in climbing section according to climbing section operation or closure.

○ In Operation



○ In Closure



<Figure 7> Installation of Signs in Lane Control System Operation Section of Climbing Section

5. CONCLUSION AND FUTURE RESEARCHES

5.1. Conclusion

The phenomenon of traffic congestion is repeatedly taking place in spite of continuous construction of expressways. At this point of time when interest in eco-friendliness of the roads is ever increasing, the efficient use of road facilities is very important and necessary for relief of the congestion, and temporally and spatially customized traffic operational management skills such as ramp metering and lane control system are highlighted as new alternatives to resolve the congestion. Temporally and spatially customized traffic operational management is based on the characteristics of temporal change of traffic stream and on spatial characteristics of geometrical structure of the roads, which means dynamic lane allocation. The advantage of these is that we can find out the important variables for efficient operation of the roads with the characteristics of geometrical structure of the roads and with the characteristics of each vehicle type.

This study tried to find out process of flexible traffic operational guidelines for dynamic lane management, to establish flexible traffic management guidelines suitable for traffic characteristics with the example of climbing lane. By selecting climbing section of Nakdong junction (for Masan), VISSIM-microscopic traffic simulation-analysis was conducted with the traffic operational variables. In order to check how much exactly the organized simulation networks and input variables simulate the traffic condition of actual target section, we verified simulation accuracy on actual traffic data with travel speed as a standard. Also, for verification on driving performance of truck on simulation, we verified if truck vehicle's driving performance applied to simulation is same as standard truck's performance function (200lb/hp).

As the result of simulation, it was analyzed that the operation of climbing lane will have operational effect in general traffic situation with no congestion, but the closure of climbing lane will be effective in traffic operation in case v/c and heavy vehicle ratio increase. And the result of analysis of travel speed which is a standard of positive/negative crossing of travel speed difference when climbing lane is operated and closed, it was analyzed that positive/negative of travel speed difference started to change their signals in approximately 50km/h speed. On the contrary, as the result of CART analysis, there was a distinction between uphill road management/shut down groups at 50.05km/h. As the result, in consideration of simulation analysis result, expressway operability, and drivers' perceptibility, average travel speed of 50km/h in climbing section was selected as critical speed which can determine the operation or closure of climbing lanes.

5.2. Future Researches

This study established flexible traffic operational guidelines for climbing lane by selecting specific target section, but it is necessary to establish traffic operational guidelines which can be generally used in the future, for which analysis needs to be conducted by applying more detailed simulation input variables (heavy vehicle acceleration performance, traffic volume (v/c), heavy vehicle ratio, longitudinal slope) for various target sections. Through this, flexible traffic operational guidelines which have generalized and objectified each type of characteristics of climbing lane can be suggested. Furthermore, the efforts to quantify the effect of temporary closure of climbing lane through continuous site inspection are also important. And empirical research for dynamic lane management is also necessary by use of various traffic operation methods such as operation of exclusive driving lane for specific traffic stream, operation of variable lane in consideration of middle direction, apart from climbing lane.

REFERENCES

1. Ministry of Land, Transport and Maritime Affairs (2004), Guide on Road Capacity, Korea
2. Ministry of Land, Transport and Maritime Affairs (2008), Rules for standard of structure and facilities of the road (explanation and guideline), Korea
3. Korea Expressway Corporation (2009), Guideline for Road Construction (Volume 1, Road plan and Geometrical structure)
4. Jing-Pyo Kim, Myeong-Soon Jang (1998), Study on standard of design speed of climbing lane by merging characteristic, Korean Society of Transportation Journal, Vol.16, No.2
5. L.Schaefer et al (1998), An Evaluation of Freeway Lane Control Signing Computer Simulation. Mathl, Computer Modeling Vol27, No 9-11
6. Oh-Cheol Kwon, Je-Mu Won, and Sang-Gu Kim (1999), Research on design standard of exit point of climbing lane, Korean Society of Transportation Journal, Vol. 17, No.1
7. Mithilesh Jha et al (1999), Evaluation of Freeway Lane Control for Incident Management. Journal of Transportation Engineering
8. Dong-Seok Kim (2003), Research on standard of new installation of climbing lane, Master's Degree Thesis, University of Seoul
9. K. P. Kang, P. W. Lin, and G.L. Chang (2004). Exploring the Effectiveness of Variable Speed Limit Controls on Highway Work-Zone Operations, Intelligent Transportation Systems, 8, pp. 1-14.
10. Chris Lee (2004), Proactive Vehicle Crash Prevention on Instrumented Freeways Using Real-Time Traffic Control, Ph.D. Thesis, University of Waterloo, Ontario, Canada
11. Heung-Woon Oh, Jeong-Gyu Kang (2005), Study on installation standard of climbing lane through study of capacity of each section of highway, Highway & Transportation Technology Institute, Korea Expressway Corporation
12. Mohamed Abdel-Aty, Rami Harb, Essam Radwan, and Xuedong Yan (2005) Light Truck Vehicles (LTVs) Contribution to Rear-end Collisions, Accepted for Presentation at the Annual TRB Meeting, January 2006 and inclusion in conference CD
13. Mohamed Abdel-Aty, Rami Harb, Essam Radwan, Xuedong Yan, and Anurag Pande (2005), Freeway Work-Zone Crash Analysis and Risk Identification Using Multiple and Conditional Logistic Regression. ASCE
14. Sang-Yoon Kim, Heung-Woon Oh (2006), Research on Calibration of access and exit point of climbing lane, Korean Society of Transportation Journal, Vol. 24, No.52
15. Heung-Woon Oh (2006), Study on Method of differential application of standard truck, Thesis Collection of Korean Society of Road Engineers, Vol.8, No.1
16. Peter Allaby, Bruce Hellinga, Mara Bullock (2007), Variable Speed Limits: Safety and Operational Impacts of a Candidate Control Strategy for Freeway Applications, IEEE Transactions on Intelligent Transportation Systems - TITS , vol. 8, no. 4, pp. 671-680
17. Ali S. Al-Ghamdi (2007), Experimental evaluation of fog warning system, Accident Analysis and Prevention 39, pp 1065–1072
18. Hoo-Bok Jang (2008), Study on appropriate climbing lane length calculation by use of driving speed, Master's Degree thesis, Hanyang University
19. Kyeong-Pyo Kang et al (2009), Lane Based Dynamic Merge Control Strategy Based on Optimal Thresholds for Highway Workzone Operation. Journal of Transportation Engineering
20. Ui-Joon Lee, Kwon-Je Park, Ki-Hwan Han, and Gyeong-Min Park (2010), Effect analysis according to improvement of driving method in climbing lane, Thesis collection of Korean Society of Road Engineers, Vol. 12, No. 2
21. Yoon-Hyuk Choi, Seung-Jun Lee, Young-Seok Bae, and Han-Geom Ko (2010), A Case Study on the Traffic Operational Guidance for Temporary Closure of Climbing Lane ; Focusing on Nakdong JC at Jungbunaeryuk Expressway, Korean Society of Road Engineers Journal, Vol. 12, No.4, pp. 17~28