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Operational Merits on Dividing a Multi-Lane Highway

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Abstract

Compared to a typical one-way multi-lane highway, a one-way divided highway operated, for instance, in the form of two two-lanes instead of four lanes may have an advantage on safety more than operation. In congested traffic conditions, drivers would change lanes into less heavy lanes. Frequent lane changes cause unstable traffic flows, reduce capacity and increase accident possibility. The purpose of this study is to observe an impact of one-way divided highway scheme on traffic operation compared to the conventional undivided. Average travel time and travel time variance are observed for traffic operation performance and travel time variability in the environment of computer simulation. In results, an undivided highway showed better performance than a divided highway in all cases. For travel time variability, no significant difference between an undivided highway and a divided highway was with small on-ramp demands. The large inflow from on-ramps, however, increased more travel time variability in a divided highway system.

Keywords: *One-way divided highway, Travel time reliability, Travel time variability*

1. Introduction

From the demand to figure out the growth in traffic with limited infrastructure investment, Intelligent Transportation Systems (ITS) has arisen. Since the advent of ITS, traffic information has settled down as valuable driving necessaries easy to obtain from not only a Variable Message Sign (VMS) but also a navigator, a smart phone, and so on. Travel time is one of traffic information that drivers most want to know in order to determine their routes [1]. In fact, it is important to traffic monitoring centers as well as drivers. Levinson and Lomax [2] mentioned that travel time best explained traffic condition as a congestion index.

What kind of paths will a driver choose if he or she has information enough to decide? A car navigator might show the best way with respect to time, price or distance, which could be a target to minimize in order to find an optimal solution. Unfortunately, uncertainty may not be considered in aggregate travel time [3]. According to Chen, et. al., [4], travelers are interested not only in travel time saving but also in travel time reliability. Nobody may want to be in large variation of travel time [5].

Abdel-Aty et. al., [6] found that travel time variability is one of the important factors in route choice decisions. Noland and Polak [7] explained travel time variability as uncertainty for travelers such that they do not know exactly when they will arrive at a destination. Travel time variability is, in fact, not issued in light traffic conditions in which the traffic flow is much less than the capacity and the density is low. On the other hand, individual travel time may be various in congested conditions where the traffic flow is around the capacity. In stop-and-go situations, some drivers often change lanes in order to find less congested lanes. Frequent lane changes are expected to cause unstable traffic state, which means decreasing capacity and increasing travel time variability [8, 9].

Operational ideas to keep traffic stability may be applied to highway design. It may, for example, help keep a traffic condition if a one-way four-lane highway is operated in the form of two divided two-lane highways in order to separate long-distance traffics from local traffics. Of course, this kind of experimental scheme might be studied at the viewpoint on operational performance such as efficiency as well as reliability. The purpose of this study is to observe an impact of one-way divided highway scheme on traffic operation compared to the conventional undivided. For operational efficiency and travel time reliability, average travel time and travel time variability are surveyed in the environment of computer simulation. In a broader sense, this study also aims to contribute to enhancing highway operation.

This paper is organized as follows. In section II, we introduce one-way divided highway scheme. Section III describes the design of our simulation experiment. Section IV discusses the results of the simulation experiment. In section V, we conclude this study.

2. One-way Divided Highway Scheme

A four-lane highway could be operated in the form of two divided two-lanes as well as one undivided four-lane. Decorla-Souza proposed separated operation at the viewpoint of road pricing: Very HOT lanes and FAIR (Fast and Intertwined Regular) lanes [10]. The former charges only for added express lanes, which can also be used for free by high-occupancy vehicles, and the latter combines regular, uncharged lanes and charged lanes with subsidies and quotas to avoid penalizing low-income drivers. However in several cases, the one-way divided scheme was applied to keep traffic stability as the result to separate long-distance traffics from local traffics. Figure 1 is the case that has applied the one-way divided highway scheme in Seoul, South Korea.

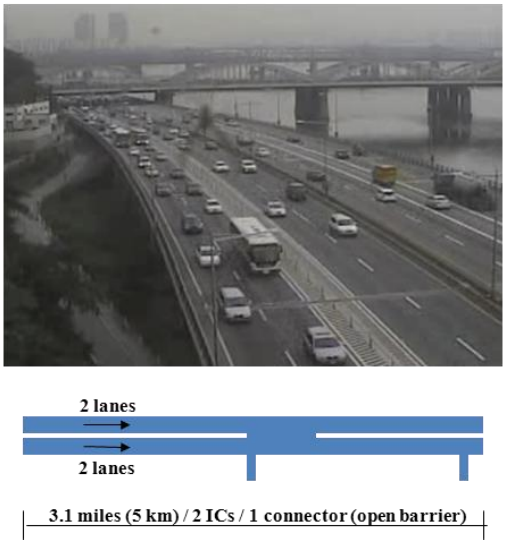

Figure 1. 88 Olympic Expressway in Seoul, Korea (www.smartway.seoul.kr)

As shown in Figure 1, 3.1 miles of 88 Olympic expressway is operated to two two-lane highways for operation and safety performance. Since frequent lane-change on a bridge section such as Figure 1 may cause severe accidents on unstable traffic conditions, these lanes were separated by a barrier. The local traffics on the outer highway can enter and exit through two interchanges. The barrier is open at a certain section to connect the inner highway with the outer highway. Figure 2 shows the case that 7.2 miles of interstate highway 270 is operated to four and two lanes in the United States.

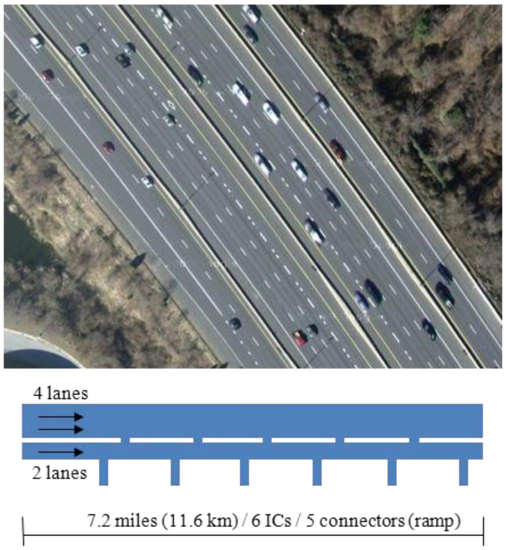

Figure 2. I-270 in Maryland, US (maps.google.com)

As shown in Figure 2, the inner highway is a four-lane expressway for long-distance traffics and the outer one is a two-lane local way for local traffics. A total of six interchanges links the outer highway to local areas. The inner highway is connected with the outer one by ramps located next to each interchange. Figure 3 is the other case operated without any connector between inner and outer highways in Korea.

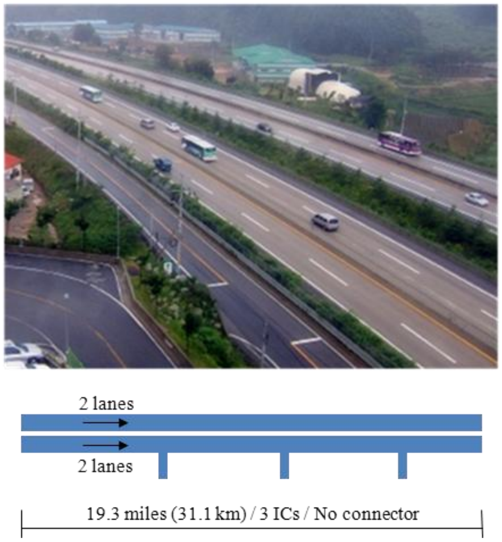

Figure 3. Jungbu expressway in Korea (www.naver.com)

In Figure 3, the whole section of the divided highway was totally separated; vehicles in the inner highway cannot get out to local areas until they arrive at the end point. The traffic monitoring center managing this highway provides drivers with information such as no interchanges and traffic conditions through fixed signs and VMSs prior to the departure point. In this case, the center controls traffic demands for inner and outer highways based on ITS. Traffics on the outer highway are able to access to local areas through three interchanges.

Though all of those three cases are a one-way divided highway, they include somewhat different factors which are able to influence operational performance. As mentioned above, the number of lanes and interchanges, connecting types between inner and outer highways, connecting intervals and so on are the factors relevant to road design. Of course, traffic demands may be the most influential factor. Table 1 is to summarize key factors described in those three cases.

Table 1. Key Factors on a One-way Divided Highway

Traffic demand	• Long distance • Local - Interchange density
Road design	• Lane assignment • Connecting type - Ramp - Open barrier • Connecting interval

In Table 1, traffic demand consists of long distance and local traffics. It may directly influence highway performance. To evaluate the operational performance, traffic flowing under a variety of traffic demands should be examined. *Average travel time* could be an MOE (Measure OF Effectiveness) for flowing efficiency. The road design factors may influence traffic flow stability. Since variable stability increases variability of travel time, those factors may affect reliability of travel time. *Travel time variance* could be an MOE for the reliability of road designs.

3. Experiments

The one-way divided scheme is not a common design since its efficiency has not been confirmed at various angles. This study chose a computer simulation experiment in order to control variables able to influence results. The simulation design on road networks, scenarios and simulation parameters are described in this chapter.

3.1. Road Networks

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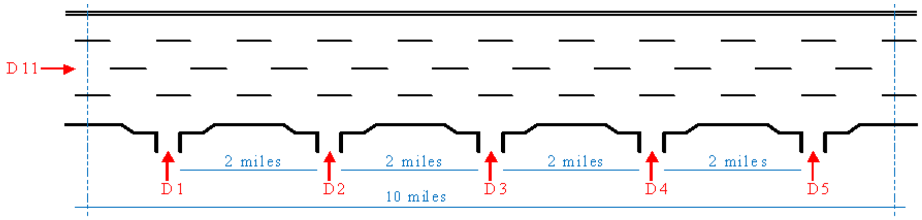
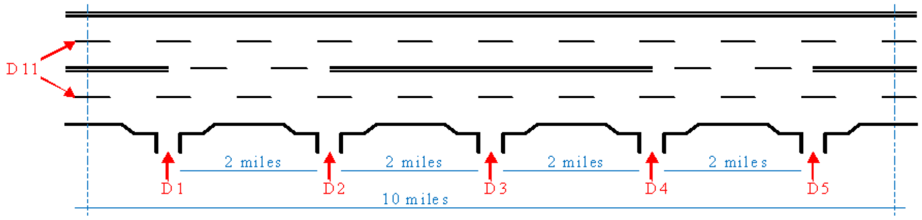
In this study, two road networks are designed for simulation: a one-way undivided four-lane highway and a one-way divided four-lane highway. Figure 4 shows the two types of networks: Networks 1 and 2.



(a) Network 1: One-way undivided four-lane highway



(b)) Network 2: One-way divided four-lane highway

Figure 4. Simulation Network Design

As shown in Figure 4, the Network 1 is an undivided four-lane highway on one way, whereas the Network 2 consists of two two-lane highways which are intertwined on one way. These networks are exactly same but the divided. Due to the dividers to play a role to prohibit lane changes, long-run vehicles would travel on the left side highway of the divider, the inner highway, and short-run vehicles would run on the right side highway of the divider, the outer highway. These dividers are opened twice for lane changes of long-run travelers.

Input demands consist of D11 from the departure point of the route, and D1, D2, D3, D4 and D5 from five interchanges, on-ramps. Several scenario sets with demands close to capacity and even over are provided.

3.2. Traffic conditions

In order to compare and analyze two networks, various traffic demand conditions were decided as input data for traffic conditions. Traffic demands for a departure point and five on-ramps were represented to several scenarios. Traffic demands from the departure point, D11, were assumed to increase 1,000 vehicles from 2,000 veh/hr to 10,000 veh/hr. Demands from five on-ramps, D1, D2, D3, D4 and D5, were built to four types of scenarios: two same demand patterns and two different demand patterns. Table 2 contains demands for each scenario as input data assumed.

Table 2. Demand Patterns for each Scenario

Demands	Departure point	On-ramps (% for D11)				
	D11 [veh/hr]	D1	D2	D3	D4	D5
Scenario 1	2,000 –10,000	10%	10%	10%	10%	10%
Scenario 2	2,000 –10,000	20%	20%	20%	20%	20%
Scenario 3	2,000 –10,000	2%	4%	6%	8%	10%
Scenario 4	2,000 –10,000	5%	10%	15%	20%	25%

In Table 2, each on-ramp demand is decided in the form of percentage for departure point demands because departure point demands are changed every 1,000 from 2,000 veh/hr to 10,000 veh/hr. Scenarios 1 and 2 are to assume that same demands enter the highway from each on-ramp; each 10 % and 20% for departure point demands in Scenarios 1 and 2, respectively. Scenario 3 represents input values with small increment in different on-ramp demand situations. The demands for each on-ramp increased from the 1st on-ramp to the last on-ramp by small percentage in the Scenario 3: 2% of departure point demands for the 1st on-ramp, 4%, 6%, 8% and 10% for next on-ramps, respectively. Scenario 4 contains different demand situations with a large increment. Scenario 4 is same as Scenario 3 but the percentage. The percentages of Scenario 4 are 5%, 10%, 15%, 20% and 25%, respectively. It is assumed that traffics exit same as entering every interchange.

3.3. Simulation Environments

As a computer simulator, Corsim 5.1 was employed in this study. The time period of all simulations were set up to 60 minutes. For input parameters, truck percentages were decided to 10% at the departure point and 5% at each on-ramp since many trucks were assumed to move a long distance. In order to obtain many samples, every simulation was conducted 31 times with different random number seeds.

Table 3. Parameter Descriptions

Parameters	Values
Simulation time	60 minutes
Truck percentages	10% at the departure point and 5% at each on-ramp
Iteration	31 times

The simulator employed in this study excludes the results until the network reaches equilibrium at the beginning. This function is expected to make the confidence of results better. To prevent traffic jam from too many vehicles, inflow demands gradually increase; for example, D5 is the highest demands. More validation and calibration were not conducted in order to exclude other variables able to influence results.

4. Results

This study defines travel time variability as a degree of differences between travel times that could be obtained on a route. For two networks, the means and variances of travel times obtained as outputs of the simulations were compared according to different demand scenarios. At the first part, the system performance for two networks was compared according to each scenario. The impact of a divided highway on travel time variability was examined at the next part.

4.1. System Performance

In order to compare the system performance of two networks according to each traffic condition, simulation was implemented. As a Measure Of Effectiveness (MOE), travel time was chosen. Figures 5, 6, 7 and 8 compared 10-mile travel time data of the networks according to each scenario.

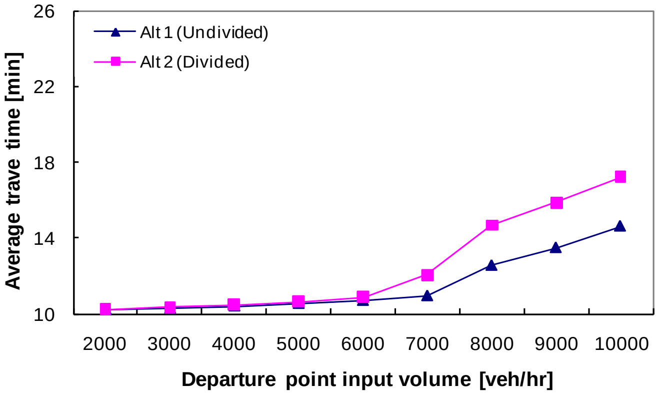


Figure 5. Travel Time Comparison on Scenario 1

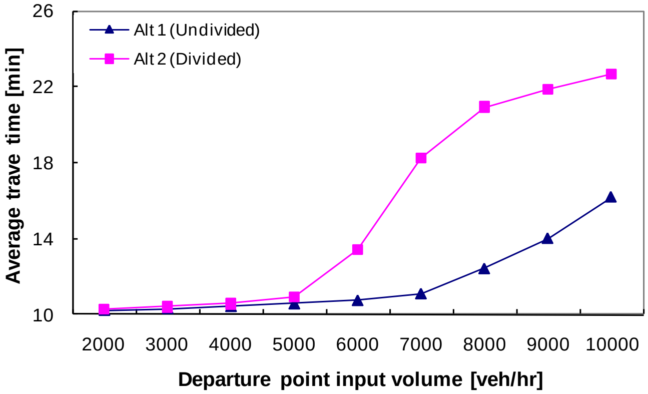


Figure 6. Travel Time Comparison on Scenario 2

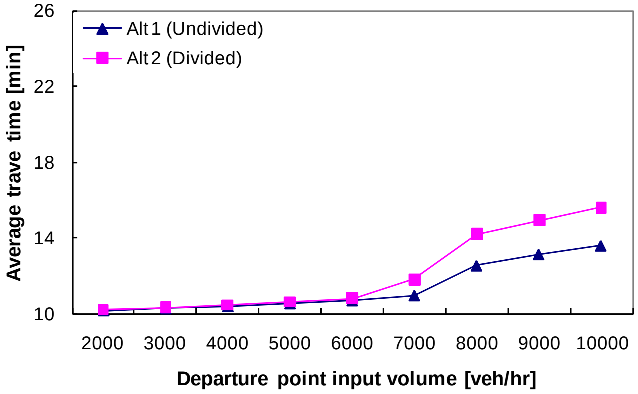


Figure 7. Travel Time Comparison on Scenario 3

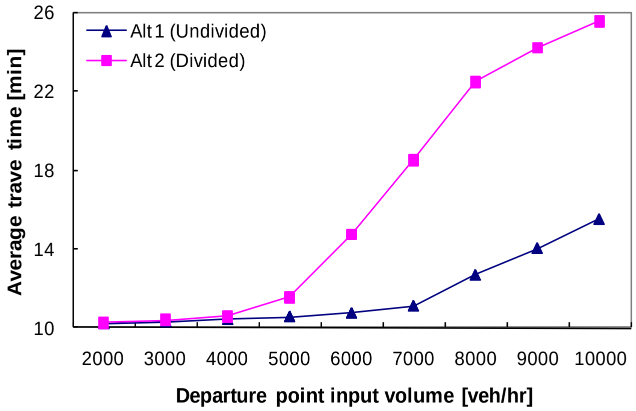


Figure 8. Travel Time Comparison on Scenario 4

In Figures 5, 6, 7 and 8, average travel time represents mean values of 31 travel time samples for the 10-mile simulation highway. As shown in Figures 5, 6, 7 and 8, travel time for Network 1 was lower than that for Network 2 in all scenarios. For departure point demands, travel time differences between Networks 1 and 2 were very small within 5,000 veh/hr in all scenarios. The inflow of large on-ramp demands such as Scenarios 2 and 4, however, caused the significant travel time differences between networks. In addition, specific patterns between same on-ramp demands, Scenarios 1 and 2, and different on-ramp demands, Scenarios 3 and 4, were not revealed.

4.2. Travel Time Variability

In this study, variance was applied as an evaluation measure to analyze travel time variability for the simulation route. The variance is for 31 travel time data obtained from different random number seeds. Figures 9, 10, 11 and 12 show the variance comparison of the networks according to each scenario.

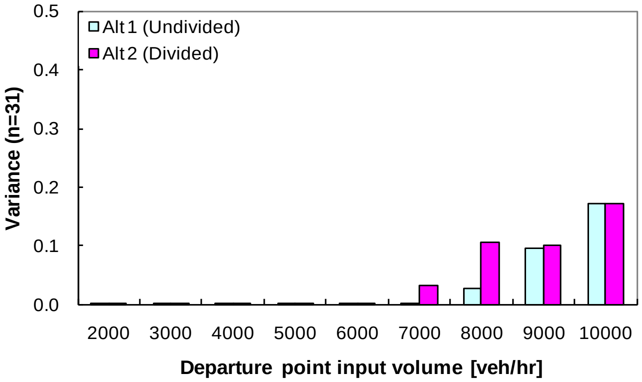


Figure 9. Variance Comparison on Scenario 1

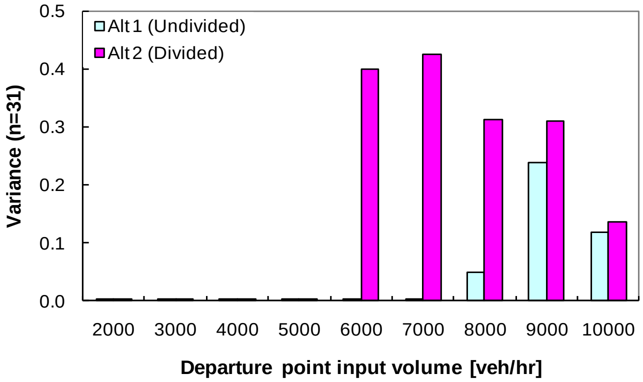


Figure 10. Variance Comparison on Scenario 2

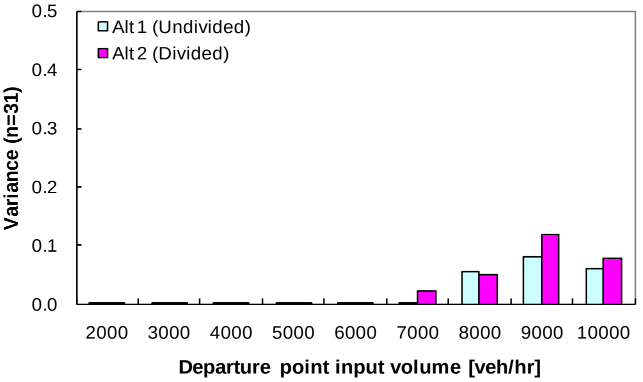


Figure 11. Variance Comparison on Scenario 3

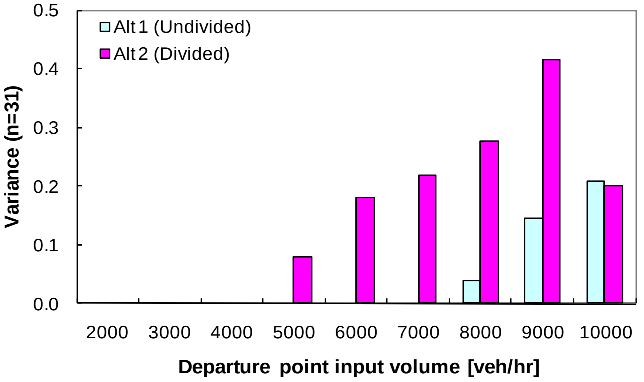


Figure 12. Variance Comparison on Scenario 4

As shown in Figures 9, 10, 11 and 12, the variances of Network 1 were, overall, smaller than those of Network 2. In Figures 7 and 9, the Scenarios 1 and 3 with small on-ramp demands showed low variances even in the high departure point demands in the both cases of networks. In Figures 10 and 12, large on-ramp demands influenced the lift-up of variances.

In Figure 10, same large on-ramp demands steeply raised the variance from the departure point demand 6,000 veh/hr in the Network 2. In Figure 12, different large on-ramp demands almost linearly increased the variance from 4,000 veh/hr to 9,000 veh/hr.

5. Conclusion

In order to observe an impact of one-way divided highway scheme on operational performance, average travel time and travel time variance. A computer simulation experiment was applied to a 10-mile virtual highway. For two structural networks, four on-ramp demand scenarios and nine demand levels for departure point were set up and simulated 31 times with different random number seeds.

For system performance, an undivided highway was better than a divided highway in all cases. More departure point demands and on-ramp demands increased performance differences between two types of highways. Compared to a divided highway system, an undivided highway system appears to be more structurally efficient on operation since the vehicles can change lanes between the 2nd lane and the 3rd lane.

For travel time variability, no significant difference between an undivided highway and a divided highway was with small on-ramp demands. The large inflow from on-ramps, however, increased more travel time variability in a divided highway system.

In this study, only mean and variance of travel time from 31iteration were used to compare network efficiency. For more details, each traffic flow condition on the inner lanes and the outer lanes, impact of large vehicles and so forth in the divided system should be studied. Authors would present such issues in the next paper.

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