Title
Impacts of Left Lane Truck Restriction on Urban Freeways

Authors
Yang, Choon-Heon
Regan, A C

Publication Date
2007-07-30

Impacts of Left Lane Truck Restriction on Urban Freeways

Choon-Heon Yang

Department of Civil & Environmental Engineering

Institute of Transportation Studies

University of California, Irvine

Irvine, CA 92697-3600

Phone: (949) 824-5623 / Fax: (949) 824-8385

E-mail: chyang@uci.edu

Amelia C. Regan

Department of Computer Science and

Department of Civil & Environmental Engineering

University of California, Irvine

Irvine, CA 92697-3600

Phone: (949) 824-1074 / Fax: (949)-824-8385

E-mail: aregan@uci.edu

Word Count: 7226

Table, Figure, Photo: 250*10=2500

Submission date: July, 30, 2007

Submitted in the 2nd National Urban Freight Conference (also submitted to the 2008 TRB meeting)

ABSTRACT

This paper examines the impacts of truck lane restriction on urban freeways using traffic simulation models. The study includes three main parts: Part (1) provides insights into conditions under which truck lane restrictions would work well; Part (2) identifies the best number of lanes to restrict and shows that this is an important factor in the success of lane restriction; Part (3) investigates potential impacts of truck lane restriction through a case study using a region with some of the highest truck volumes in the U.S., the I-710 corridor in Los Angeles County, California. The study begins by examining the potential impacts of truck lane restrictions using two representative hypothetical freeways. This is because the impacts of truck lane restrictions will vary with differing traffic and geometric conditions. Results suggest that truck lane restriction could work well when the rate of flow is more than 1300 vehicles per hour per lane and where trucks make up at least 10 percent of the total traffic. Three scenarios are developed. These are do-nothing (no strategy implemented), alternative I (the one leftmost lane restricted from trucks), and alternative II (the two leftmost lanes restricted from trucks). These are examined in a pair-wise manner. Results show that determining the best number of restricted lanes is very important. Through the I-710 case study we find that alternative II would have the most positive effects on traffic congestion and travel time variance. Based on these results, we conclude that truck lane restriction strategies, which are very simple and cost-effective to implement, may contribute to improved traffic flow on urban freeways.

BACKGROUND

Demand for trucking services continues to increase. According to the latest statistics available from the Bureau of Transportation Statistics (BTS) trucking accounts for an estimated 70% of the total value, 60% of the weight, and 34% of the ton-miles of freight moved in the U.S (Bureau of Transportation Statistics, 2006). In addition, between 1980 and 2020, truck travel is predicted to increase by over 90% while lane-miles of public roads will increase by only 5% (FHWA, 2006).

This increase will have significant negative influences on traffic congestion and safety. A truck lane restriction strategy is one of the truck management strategies available to address some of these impacts. An earlier study by Garber and Gadiraju examined a total of ten truck management alternatives combining differential speed limits and truck right lane restriction using a simulation approach (Garber and Gadiragu, 1990). They investigated traffic elements such as traffic flow, speeds, headways, and accident patterns. That study concluded that particularly on highways with high truck annual average daily traffic rates, implementation of differential speed limits and right lane restrictions would lead to an increase, rather than a reduction, in accident rates. Comprehensive truck restrictions were reviewed by Mannering, Koehne, and Arauto (Mannering et.al, 1993). That study performed three types of analysis. First, the researchers investigated how truck restriction could influence operational, safety, and economic impacts. Through a comparison between the study site, the Puget Sound Region, and others, they examined the feasibility of this strategy for other locations. Finally, a survey analysis was performed in order to obtain opinions from truckers, agencies, and general travelers. Their case study showed that there was no evidence to support improved traffic operation, safety or pavement maintenance. However, critical findings were that the impacts of truck lane restrictions were very dependent upon truck proportion of the total traffic. The proportion in the study site was approximately 5 percent, not high enough to demonstrate potential benefits of this strategy. Nonetheless, their study concluded that the impacts of truck lane restrictions could be a promising way to manage truck traffic. That study also concluded that the redistribution of truck traffic could reduce overall pavement deterioration. Various truck lane management strategies were examined for Interstate 81 in Virginia using the INTEGRATION traffic simulation model (Rahka et.al, 2005). Several alternatives related to the management of truck lanes, including extra lanes, managed lanes, truck-only lanes, physical separation of trucks and non-trucks, and the addition of climbing lanes were developed. The main objective of that study was to quantify benefits related to the efficiency, energy, environmental, and safety impacts of different alternatives. The researchers found that the maximum benefits were obtained in the case of a physical separation of trucks from other traffic. In addition, restricting trucks from the use of the leftmost lane also provided promising results regarding efficiency, energy, and environmental impacts on the study site.

Several studies have addressed truck lane restriction strategies, but they usually focused on limited impacts resulting from the implementation. Our study investigates many different potential impacts of truck lane restriction strategies for urban freeways in order to determine conditions under which restrictions are promising. PARAMICS simulation is used as a main tool to examine scenario implementation strategies and to estimate for each performance measure using statistical techniques.

STUDY DESIGN

Hypothetical Cases

The study begins by examining the potential impacts of truck lane restriction using two representative hypothetical cases. This is because the impacts of truck lane restriction will vary with differing traffic and geometric conditions. Three feasible scenarios are developed. These are 1) Existing conditions: no strategy implemented 2) Alternative I: trucks restricted from the one left most lane and 3) Alternative II: trucks are restricted from the two left most lanes. The study is performed on an approximately 5-mile one-way section with five through lanes in case A and four through lanes in case B, including a single on and off ramp. Figure 1 shows hypothetical network designs for cases A and B, respectively.

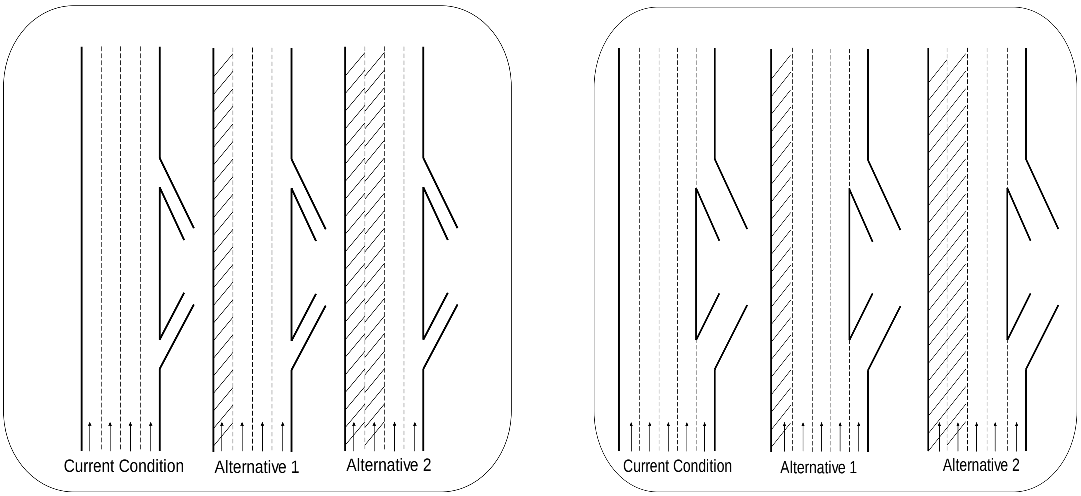


FIGURE 1 Hypothetical network designs for case A and case B

For the analysis, different levels of traffic conditions are examined using the level of service criteria for multilane highways suggested by the US Highway Capacity Manual (US-HCM, 2000), and the truck proportion is assumed to range from 5 percent to 20 percent for each flow rate according to the level of service. Flow rates are selected based on the fact that most speed limits on urban highways are 60 or 65 mph. The rate of flow at the on and off ramps was fixed at 500 vehicles per hour. Therefore, a total of 48 combinations of traffic volume and truck percent are developed.

TABLE 1 LOS Criteria for Multilane Highways

LOS	Density (pc/mi/ln)	60 mph Design speed		
		Speed	V/C	MSF*
B	≤20	≥48	0.5	1000
C	≤30	≥44	0.65	1300
D	≤42	≥40	0.80	1600
E	≤67	≥30	1.00	2000

***Maximum rate of flow (vphpl)**

Traffic Flow Components

Average speed or average travel time can be used as a measure of freeway service quality. Gan and Jo found that increase in average speed tends to appear under low truck volume, and low ramp volume, while average speed is insignificantly decreased under high truck percentages (approximately 25%) of total traffic or high ramp volumes (Gan and Jo, 2003). They found that reduction in average speeds resulting from truck lane restriction would be insignificant except when most lanes are restricted (three out of four lanes, for example). In our study, changes in average speed across scenarios are examined in order to identify whether or not truck lane restrictions lead to beneficial impacts in terms of the improvement of traffic flow efficiency.

The frequency of lane changes is used as a measure of safety impacts. Intuitively, as the frequency of lane changes increases, the likelihood of a collision increases (Garber and Gardiraju, 1990). This measure can be obtained from the total lane changes divided by the total traffic volume. The study of Hoel and Peek found that the implementation of truck lane restrictions lead to an increase in the frequency of lane changes in the level sections and reduce those in the steep grade (Hoel and Peek, 1999). They recommended that a truck climbing lane is preferable to truck lane restriction when the grade exceeds 4%. Since this measure can be used to determine the consistency of traffic flow, by examining difference in the frequency of lane changes across scenarios, the impact of truck lane restriction on safety can be investigated.

A change in traffic volume may result from truck lane restriction because other vehicles can occupy the vacated capacity on the restricted lanes. Namely, the implementation of truck lane restriction may result in throughput improvement on that facility. The study of Gan and Jo demonstrated that a relatively small number of restricted lanes, for example one out of three lanes or one or two out of four and five lanes generally provide a higher capacity (up to 25%) than no restriction on lanes (Gan and Jo, 2003). Increase in throughput may be considered an important operational benefit.

Statistical Analysis

One-way ANOVA tests are used to produce a one-way analysis of variance for the quantitative traffic flow components. The P-value represents the difference in variances of the various components across scenarios. The null hypothesis is that the means across each pair of scenarios is the same regardless of maximum rate of flow and truck percentage of total traffic. All statistical tests were conducted using a 95% confidence interval. The three columns represent, from left to right, the average speed, the frequency of lane changes and the total volume.

TABLE 2 P-value Results for Case A

	Truck Percent											
MSF	5%			10%			15%			20%		
1000	0.028	0.000	1.000	0.000	0.000	1.000	0.001	0.000	1.000	0.000	0.000	1.000
1300	0.000	0.000	1.000	0.000	0.000	0.748	0.000	0.000	0.414	**0.000**	**0.000**	**0.028**
1600	0.000	0.000	0.035	0.000	0.001	0.074	**0.000**	**0.000**	**0.002**	**0.000**	**0.000**	**0.021**
2000	0.002	0.219	0.070	0.000	0.153	0.019	**0.001**	**0.000**	**0.008**	**0.000**	**0.001**	**0.015**

From left to right, average speed, the frequency of lane changes, and total volume

All P-values related to average speed reject the null hypothesis because they are smaller than significance level (0.05), implying that they are obvious differences across scenarios. These may result from an increase in speed on restricted lanes from trucks due to the absence of trucks, and thus average speed increases. For the frequency of lane changes, likewise, most P-values reject the null hypotheses except at 5% and 10% of truck proportion at 2000 vphpl. The difference in traffic volume across scenarios appears when maximum rate of flow is relatively high and truck proportion is equal to or more than 10%. On the other hand, under LOS B, low traffic conditions, there are no significant differences among scenarios in terms of traffic volume in the range of defined truck percent. All traffic flow components may change when traffic goes to 1300 vphpl and 15 percent truck traffic. The bold values in the table above show the conditions under which all three components change.

TABLE 3 P-values Results for Case B

	Truck Percent											
MSF	5%			10%			15%			20%		
1000	0.000	0.001	1.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	1.000
1300	0.000	0.519	1.000	0.000	0.000	0.963	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
1600	0.000	0.000	0.961	**0.000**	**0.000**	**0.007**	0.000	0.000	0.897	0.000	0.000	0.839
2000	0.000	0.003	0.247	**0.000**	**0.000**	**0.004**	**0.000**	**0.000**	**0.001**	**0.000**	**0.000**	**0.000**

From the leftmost column, average speed, the frequency of lane changes, and total volume in order

Table 3 provides the results of P-values for three traffic flow components under case B.

Average speeds across scenarios are significantly different under the same null hypothesis as in case A. For the frequency of lane changes, unlike case A, only one condition, when truck traffic was 5 percent and 1300vphpl, the P-value does not reject the null hypothesis. All traffic flow components simultaneously change when the maximum rate of flow is more than 1300 vphpl and trucks are more than 10 percent of the traffic. Results for case B is rather different those of case A. This suggests that the impacts of truck lane restrictions are dependent upon geometric conditions.

Results Summary

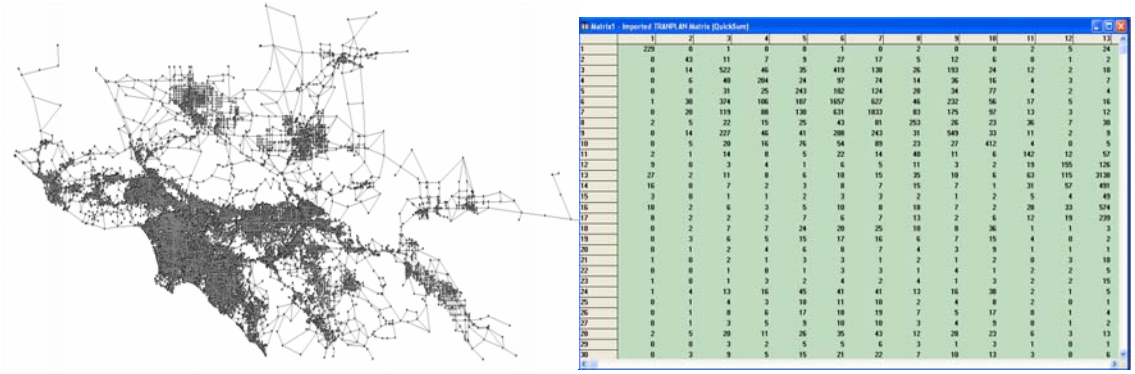
Alternatives I and II both appear to lead to increased average speeds. In addition, the average speed under alternative II (two leftmost lanes restricted) is higher than under alternative I (single leftmost lane restricted). The frequency of lane changes may also vary according to geometric conditions (e.g. number of lanes and physical configuration of on and off ramps). Other studies have shown that truck lane restriction would provide improved safety due to a reduction in lane changes (Vargas, 1992) but this study found that these results vary according to geometric conditions. When truck lane restriction is implemented, traffic throughput is likely to increase. This is because space in the restricted lanes is available to passenger cars which can travel with higher speeds. These results would suggest that truck lane restriction could work well when the rate of flow is more than 1300vphpl and trucks are at least 10% of the total traffic. These results are also consistent with the previous study of Grezeback et al which found that “Truck traffic makes a relatively small contribution to freeway congestion except on those few highly congested freeways where truck volumes exceed 10 percent of total vehicles” (Garezeback, 1990). In addition, each alternative-pair (existing condition and alternative I, existing condition and alternative II and alternative I and II) shows statistically different results. Therefore, the number of restricted lanes can be considered as a very important factor to consider.

CASE STUDY

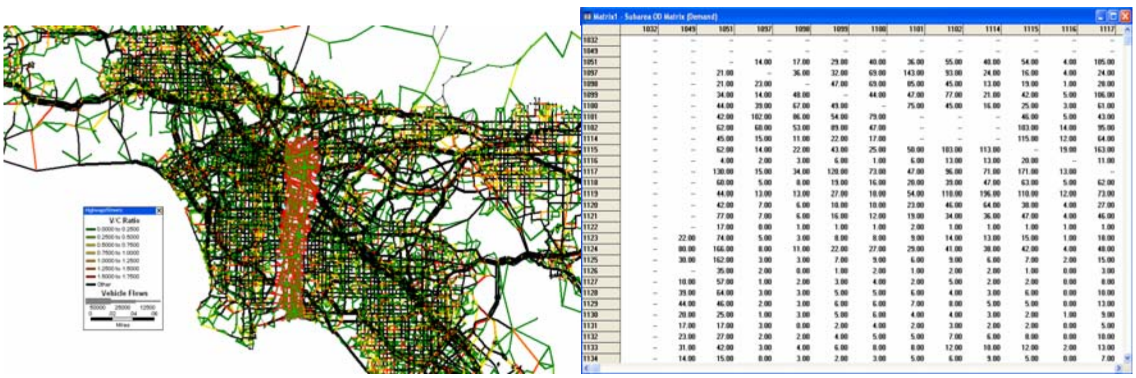
The research now turns to a specific case study with. The I-710 corridor in Los Angeles County California was chosen as a study site because it has one of the highest truck volumes in the U.S., reaching as high as 21% to 25% in some locations (Caltrans, 2006). This corridor has been a candidate for various truck management strategies including truck-only lanes and sophisticated weigh-in-motion station implementations. However, due to space restrictions, both of these candidate strategies were rejected. Our study is performed on an approximately 10-mile section from Del Amo to Firestone of the northbound side of I-710. The midday peak time for truck volumes is chosen for analysis. Traffic conditions for this time period in 2005 involved approximately 1300 to 1500 veh/hr/lane with 13% truck traffic based on information provided by the Freeway Performance Measurement System (PeMS) developed by the University of California, Berkeley researchers in cooperation with various state and local agencies (PeMS, 2003). In order to obtain OD demands for the study site, a traffic planning model is used because input demands are necessary for the PARAMICS simulation and these are not otherwise available.

Data

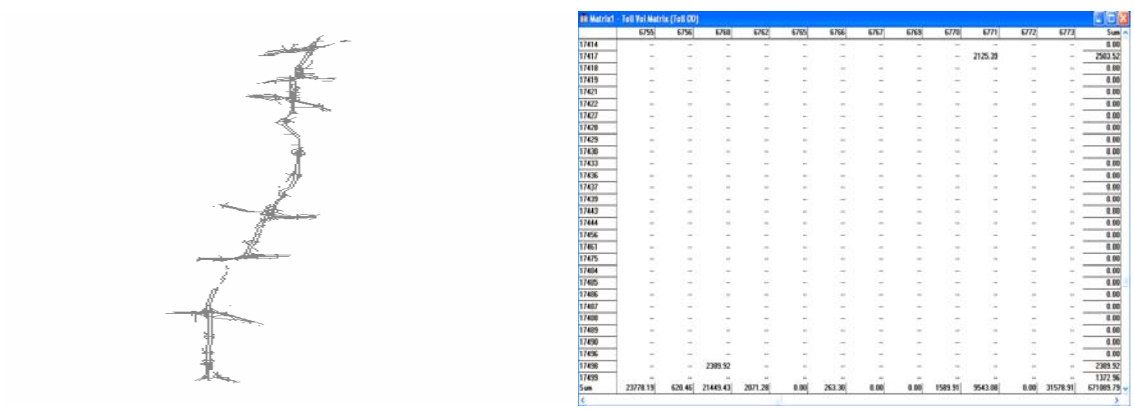
The Southern California network and its corresponding static demands in a TRANPLAN format were obtained from the Southern California Association of Government (SCAG) for the year 2000. Those data were transformed into the TransCAD format to facilitate the analysis and the data were updated based on year 2005 data. In addition, a physical examination of the facility and an independent count of truck frequency were performed in order to confirm the soundness of the data. The study site occupies a very small part of the entire network thus both the network of interest and its traffic demands must be extracted from the larger one. TransCAD is used to perform this task using sub-area analysis. Figure 2 shows input data used in the simulation.



Task 1: Original network and its corresponding demands in TransCAD format



Task 2: Traffic assignment and sub-area analysis



Task 3: I-710 network and its demands

FIGURE 2 Input data processing for simulation

Task 1 shows an original network and its OD demands. Task 2 performs traffic assignment, and then sub-area analysis can be done and finally the sub-area network and its corresponding OD demands are obtained. The extracted sub-network including local streets adjacent the highway was developed in task 3. Since the TransCAD network has a lot of attributes such as link type, number of lanes, speed, and capacity and so on, the relevant highway network can be easily extracted by selecting attributes of highways. The OD demands were modified and repeatedly run in PARAMICS simulation until the simulated traffic counts matched the known traffic counts obtained from PeMS for the year 2005.

ANALSYS IMPACTS OF TRUCK LANE RESTRICTION

Congestion and Reliability

Impacts on congestion and reliability of truck lane restriction scenarios are investigated by measuring total delay, average travel rate, truck travel time and travel time variance. Total delay, assuming that all the vehicles complete their trips, is expressed by the sum of time lost due to congestion. Congestion used here is when travel time or delay exceeds travel time at free-flow conditions (70mph). This measure is simply used to reflect the impact of any improvement from the implementation. Travel rate is the rate of motion for a specified roadway segment or vehicle trip and is also a basic measure for many analyses. Although it is not widely accepted for congestion measure, it is more likely to be used in travelers’ trip planning. Truck travel time can be considered a good measure of productivity of trucking because this is important for the private sector profitability. In practice, travel time reliability that has to be measured in the field over a number of days in order to capture the effects of incidents. However, as described earlier, this study is performed with traffic simulation based on a single demand for the study site. Therefore, travel time variance that resulted from using different seed number in simulations is used to specify which scenarios produce less variability under the same seed number conditions. Travel time variance is analogous to reliability in this study. The following table shows multiple comparisons across scenarios using the SPSS statistical software.

TABLE 4 Statistical Results related to Congestion Measurements

Total Delay		Mean Difference	P-value	Significance
Existing Condition	Alternative I	4564.45	0.000	**Significant**
Existing Condition	Alternative II	7576.21	0.000	**Significant**
Alternative I	Alternative II	3012.80	0.000	**Significant**
Average Travel Rate		Mean Difference	P-value	Significance
Existing Condition	Alternative I	-5.8071	0.023	**Significant**
Existing Condition	Alternative II	-10.1214	0.000	**Significant**
Alternative I	Alternative II	-4.3143	0.113	Not significant
Truck Travel Time		Mean Difference	P-value	Significance
Existing Condition	Alternative I	-0.0321	0.574	Not significant
Existing Condition	Alternative II	-0.0911	0.014	**Significant**
Alternative I	Alternative II	-0.0589	0.158	Not significant
Travel Time Variance		Mean Difference	P-value	Significance
Existing Condition	Alternative I	0.0264	0.089	Not significant
Existing Condition	Alternative II	0.0403	0.012	**Significant**
Alternative I	Alternative II	0.0139	0.371	Not significant

Total delay in alternative I and II are lower than existing conditions under the given level of significant (0.05). Based on the results, congestion is reduced regardless of the number of restricted lanes. Results of average travel rate are the same as those of total delay, which implies truck lane restrictions may have positive impacts in a reduction in travel rates (which implies an increase in speed). In addition, average link speeds are also significantly different. The average link speeds of alternative II substantially increases (about 19%) relative to that of existing conditions and also 11%

relative to alternative I. Although truck travel time in alternative II increases and statistically different from that of existing conditions, travel time variance in alternative II is lower than under existing conditions. This result may be important to private sector trucking companies because reliability can influence a trucking operations schedule and “just-in-time” delivery.

Safety

Many previous studies have identified the relationship between frequency of lane changes and crashes (Garber and Gardiragu, 1990). They found that as the frequency of lane changes increase, the likelihood of crashes also may increase. Similarly, speed differential between trucks and non-trucks can be also used as a safety measure. Identifying these impacts is very important to establish causal factors for vehicular crashes and for strategy evaluations. The following table shows statistical results related to safety measures.

TABLE 5 Statistical Results related to Safety Measurements

Speed Differential		Mean Difference	P-value	Significance
Existing Condition	Alternative I	-0.4283	0.341	Not significant
Existing Condition	Alternative II	-0.3909	0.384	Not significant
Alternative I	Alternative II	0.0374	0.934	Not significant
Average frequency of lane changes		Mean Difference	P-value	Significance
Existing Condition	Alternative I	-110.3846	0.995	Not significant
Existing Condition	Alternative II	-55.6923	0.999	Not significant
Alternative I	Alternative II	54.6923	0.999	Not significant

It turns out that there is no obvious difference across all scenarios on both measurements. Some previous studies demonstrated that truck lane restriction may improve safety. This result may imply that impacts on safety of truck lane restriction that worked in one area may not work in another from a safety point of view. However, although the impact on safety does not appear to be clear for this case study, there are no obvious negative impacts of truck lane restrictions.

Air Quality

Typically, trucks use diesel engines. These internal combustion engines are a main contributor to air pollution, generating the following emissions. Hydrocarbons (HC) are partially burned fuel and also called volatile organic compounds (VOCs). Carbon monoxide (CO) is a product of an incomplete combustion of carbon. Nitrogen oxides (NOx) are the product of high-temperature combustion of nitrogen. Carbon dioxide (CO_2) is the complete combustion product of carbon in the fuel and so on. For air quality analysis in this study, five emissions such as CO, CO2, HC, NOx, and fuel consumption are examined using the Comprehensive Modal Emission Model (CMEM) developed by researchers led by Matthew Barth the University of California, Riverside (Barth, 2005).

TABLE 6 Amounts of Emission Sources (gram/veh)

Emission Sources	CO	CO2	HC	NOx	FC
Existing Condition	67.32	0.27	32.91	157.55	1.26
Alternative I	68.05	0.28	33.38	159.10	1.28
Alternative II	68.05	0.28	33.38	159.12	1.28

The results indicate that there are insignificant impacts across scenarios even if all emission sources are slightly increased in alternative 1 and 2 relative to existing conditions. Impact for air quality would be minor because that analysis area is very small. Another possible reason could be the analysis time period. Although this period had high truck volumes, it was not heavily congested (about 1300~1500 veh/hr/lane). In addition, average speeds were relatively constant and close to existing conditions (54.2mph), Alternative I (60.0mph), and Alternative II (64.3mph).

TABLE 7 Statistical Results related to Emission Sources

CO		Mean Difference	P-value	Significance
Existing Condition	Alternative I	-26.3183	0.948	Not significant
Existing Condition	Alternative II	-26.3183	0.948	Not significant
Alternative I	Alternative II	0.000	1.000	Not significant
CO2		Mean Difference	P-value	Significance
Existing Condition	Alternative I	-190.2110	0.959	Not significant
Existing Condition	Alternative II	-192.1294	0.959	Not significant
Alternative I	Alternative II	-1.9184	1.000	Not significant
HC		Mean Difference	P-value	Significance
Existing Condition	Alternative I	-1.0761	0.943	Not significant
Existing Condition	Alternative II	-1.0761	0.943	Not significant
Alternative I	Alternative II	0.000	1.000	Not significant
NOx		Mean Difference	P-value	Significance
Existing Condition	Alternative I	-0.1797	0.957	Not significant
Existing Condition	Alternative II	-0.1797	0.957	Not significant
Alternative I	Alternative II	0.0000	1.000	Not significant
Fuel Consumption		Mean Difference	P-value	Significance
Existing Condition	Alternative I	-41.3260	0.959	Not significant
Existing Condition	Alternative II	-40.9881	0.959	Not significant
Alternative I	Alternative II	0.3379	1.000	Not significant

Based on the multiple comparison results above, all emission sources in alternative I and II increased compared with existing conditions but not by a statistically significant amount. This is because total vehicle-miles traveled in alternative I and II was slightly increased relative to the existing condition.

Pavement Deterioration

Pavement deterioration is influenced by increases in axle load and thus increased truck volumes play a significant role in an increased rate of deterioration. Heavy vehicles impose more damage on pavements than other smaller vehicles. Since the Equivalent Single Axle Load (ESAL) is the most commonly used unit in expressing the degree of damage on pavement surface, these are considered as a main measure of pavement deterioration in this study. All ESAL results are based on the assumption that the compliance rate is 100%. In practice, truck violation rates range between 0% and 10 % (Fitzpatrick et al, 1992).

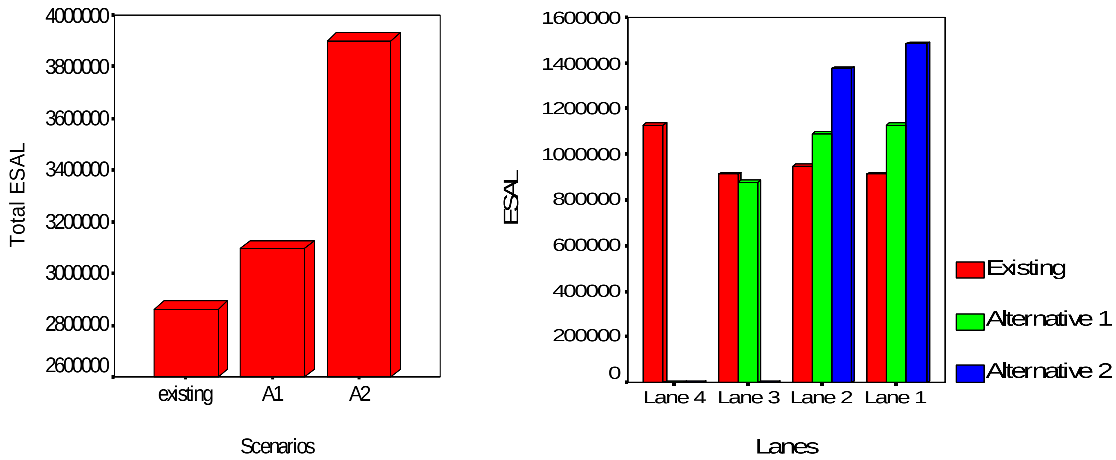


FIGURE 3 ESAL results for each lane and total across scenarios

ESAL for each lane is calculated using the standard equation suggested by AASHTO (AASHOTO, 1993). The ESAL value of existing conditions is relatively uniformly distributed. Since a restriction forces trucks to shift, the distribution of ESAL for each lane is likely to be uneven and thus deterioration differs across lanes. The sum of ESAL across all lanes showed clearer inference of pavement deterioration. Alternative II has larger total ESAL relative to others due to the redistribution of truck traffic. Our results suggest that the strategy may not provide promising results based on solely ESAL measurements.

CONCLUSION

This study was performed to develop insights into the effectiveness of truck lane restriction strategies using traffic simulation models. Through an experimental study, the geometric and traffic conditions under which truck lane restriction would be beneficial were examined. Previous studies have largely focused on traffic congestion and safety impacts. These impacts alone appear to be insufficient to support the implementation of this truck management strategy. Therefore in this study, broader impacts of truck lane restrictions including congestion, reliability, safety, air quality, and pavement deterioration were examined. Our simulation analysis suggests the following:

1) The maximum rate of flow should be more than 1300 vehicles per hour per lane (level of service C) and trucks should make up more than 10% of the traffic.
2) Removing trucks from one or more lane will increase the overall capacity of the corridor.
3) The results of the case study showed that alternative II, in which the two leftmost lanes are restricted, provides the greatest benefit for travel time reliability.
4) Truck lane restriction on our case study site does not appear to have positive or negative safety or air quality impacts.
5) The proper number of restricted lanes for trucks should be carefully determined since the results can be very different when either one or two lanes are restricted.

REFERENCES

1. Bureau of Transportation Statistics Homepage. Accessed June 15, 2007. http://www.bts.gov/programs/freight_transportation/html/trucking.html
2. *Freight in America*. Research and Innovative Technology Administration/Bureau of Transportation Studies, January 2006.
3. Garber, N.J., and R.Gadiraju (1990). Effects of Truck Strategies on Traffic Flow and Safety on Multilane Highways. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1256*, pp. 49-54.
4. Mannering, F.L., J.L. Koehne, and J. Arauto (1993). *Truck Restriction Evaluations: The Puget Sound Experience*. Washington State Transportation Center, University of Washington, Seattle.
5. Rakha, H., Flintsch, A, M., K, Ahn, I, El-Shawarby, and M, Arafeh (2005). Evaluating Alternative Truck Management Strategies along Interstate 81. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1925*, pp. 76-86.
6. Highway Capacity Manual Special Report 209 (2000). Transportation Research Board, National Research Council, Washington, D.C.
7. Gan, A and S, Jo (2003). *Operational Performance Models for Freeway Truck-Lane*

Restrictions. State of Florida Department of Transportation, Florida International University, Miami.

8. Hoel, L.A and J.L. Peek (1999). A Simulation Analysis of Traffic Flow Elements for Restricted Lanes on Interstate Highway in Virginia. Virginia Department of Transportation.
9. Vargas, F.A. Safety Effects of Freeway Truck Restrictions (1992). Compendium of Technical papers, Institute of Transportation Engineer, Washington, D.C.
10. Grenzeback, L, R., W. R., Reilly, P, O., Roberts, and J. R., Stowers (1990). Urban Freeway Gridlock Study: Decreasing the Effects of Large Trucks on Peak-Period Urban Freeway Congestion. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1256*, pp. 16-26.
11. California Department of Transportation. Truck DATA 2005. Accessed Jan. 3, 2007.
http://www.dot.ca.gov/hq/traffops/saferesr/trafdata/index.htm
12. Barth, M., G., Scora, and T., Younglove (2005). Modal Emissions Model for Heavy-Duty Diesel Vehicles. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1880*, pp. 10-20.
13. Fitzpatrick, K., D. Middleton, and D. Jasek (1992). Countermeasures for Truck Accidents on Urban Freeways: A Review of Experiences. In *Transportation Research Record: Journal of*

the Transportation Research Board, No. 1376, pp. 27-30.

14. *AASHTO Guide for Design of Pavement Structures* (1993). AASHTO, Washington, D.C.