Life-cycle Benefit-Cost Analysis of Alternatives for Accommodating Heavy Truck Traffic in the Las Vegas Roadway Network

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ABSTRACT

This research evaluates the network-level performance of several alternatives designed to mitigate the adverse effects of heavy truck traffic in the Las Vegas roadway network. A simulation-based dynamic traffic assignment framework used to analyze the performance of truck restriction lanes, truck-only lanes, truck-only toll lanes, and truck by-pass facilities. A life-cycle benefit-cost analysis was conducted to determine the best alternative based on multiple effects, including travel time savings, emissions reduction, fuel consumption, and safety considerations. Experiments were conducted, and policy and planning recommendations are provided.

1. INTRODUCTION

The Las Vegas Metropolitan region, which covers nearly 600 square miles, has experienced a significant and steady increase in population over the past two decades. As a consequence, the demand for transportation and goods also has increased significantly, creating congestion problems on the existing roadway system. The increased demand for goods has resulted in an increase of heavy truck traffic and its associated congestion. Based on a study conducted by the American Trucking Association*(1)*in 2008, the truck traffic operating on the freeways in the Las Vegas region in 1998 was 5,000 – 10,000 trucks; this traffic is estimated to increase to 10,000 – 20,000 trucks by 2017.

Truck traffic is one of the most important modes of freight movement in the Las Vegas Metropolitan region and as such, has adverse impacts on traffic flow and safety due to the large size of trucks. According to the National Highway Traffic Safety Administration, in the State of Nevada, almost 50% of fatal crashes involve trucks *(2)*. Truck crashes typically are a consequence of negligence on behalf of the truck driver, such as unsafe driving, driving under influence, and driver fatigue. Crashes involving heavy trucks are costly and also are likely to be severe and deadly due to their great mass. In addition, crashes involving heavy trucks create worse congestion problems than other types of vehicles.

Currently, the operational strategy in the Las Vegas Metropolitan region allows mixed traffic on all freeway lanes. This strategy raises such issues as congestion and crashes as well as discomfort to the roadway users. These issues are likely to be exacerbated in the near future if they are not addressed promptly. Multiple traffic projects and alternatives can be proposed to handle heavy truck traffic and mitigate its adverse effects. Considering that potential alternatives could have broad effects and also could be very costly, a system-wide analysis framework coupled with a life-cycle benefit-cost analysis is proposed here.

The following alternatives are evaluated in this study:

- Base (Do-nothing approach): This represents the existing real-world conditions of the Las Vegas roadway network.
- Truck-Restriction Lane (TR): This alternative implies the restriction of trucks to using only the left-most or right-most lane on freeways.
- Truck-Only Lane (TOL): With this alternative, a lane is designated exclusively for trucks. The objective is to separate trucks from other mixed-flow traffic to enhance traffic safety and flow.
- Truck-Only Toll Lane (TOT): This alternative requires a limited access toll lane or lanes available only for trucks. Trucks must pay a toll to use an exclusive truck lane.
- Truck Bypass A: This alternative involves the construction of a new freeway around the east side of the Las Vegas Metropolitan region. This alternative will enable the complete diversion of through traffic whose origin or destination is not Las Vegas, for example, traffic from Los Angeles or Phoenix to Utah and vice versa. Passenger cars and trucks are allowed to use all lanes.
- Truck Bypass A1: This alternative is the same as Bypass A but only trucks are allowed to use the bypass.
- Truck Bypass B: This scenario upgrades key existing roadway segments into a freeway facility for the diversion of traffic. Passenger cars and trucks and are allowed to use all lanes.

This paper is organized as follows. Section 2 describes some important aspects about the data required to conduct the analysis, the modeling, and the analysis methodology. Section 3 presents results and their analyses. Finally, Section 4 summarizes and provides recommendations.

2. METHODOLOGY

This section describes the data as well as the modeling framework used in this study. A simulation-based dynamic traffic assignment framework is used to estimate the performance of the different alternatives. A life-cycle benefit-cost analysis is conducted to rank the different alternatives.

Data

The system-wide analysis proposed in this study requires regional-level data, including link attributes; time-dependent, origin-destination (OD) demand; and traffic signal settings. The link attributes and the time-dependent OD demand were obtained from the existing regional Travel Demand Model (TDM), provided by Regional Transportation Commission of Southern Nevada (RTC-SN).The TDM has projected travel demand for years 2013, 2020, and 2030, based on the current and estimated socio-economic characteristics in the region. The projected demand was used to evaluate the alternatives under future conditions.

Network modeling

Considering the level of resolution used to represent traffic flows along transportation networks, modeling approaches can be classified as macroscopic, microscopic, or mesoscopic. Typically, macroscopic approaches involve static traffic assignment models that enable the estimation of flow patterns on a regional scale but without any temporal resolution. These types of models use macroscopic traffic flow relationships, such as the Greenshield’s model, to determine link travel times based on link flows. Analysis tools within this category include TDM models used by transportation engineers and planners, assuming that no microscopic considerations are required for long-term planning.

In order to estimate the traffic flow pattern, the TDM provided by the RTC-SN uses a traditional four-step travel demand modeling procedure. One of its key modeling characteristics is that before the traffic assignment step, the OD matrices are aggregated across all modes. As a result, the model cannot differentiate between truck and car assignments. This precludes the evaluation of scenarios that require the simultaneous routing of different vehicle classes, such as trucks, cars, specially equipped vehicles, and recreational vehicles. Considering that this study requires the routing of trucks along particular facilities based on different traffic management strategies, the existing TDM cannot be directly used to conduct the desired analysis.

An alternative to TDM models are microscopic traffic flow and assignment models. Microscopic models enable the explicit modeling of individual vehicles as well as temporal variations in traffic flow in the order of 0.1 to 1.0 seconds. Microscopic models enable the representation of detailed traffic characteristics, such as lane changing behavior, acceleration/deceleration, and queuing related phenomena like spillback/spillover. These modeling capabilities imply a need for considerable computational analysis and data collection; as a result, microscopic models are difficult and expensive to develop for large-scale modeling efforts.

Although macroscopic and microscopic models are widely used, many emerging planning methods, such as congestion pricing, and operational concepts deployment of information, require modeling approaches that enable a greater level of detail than macroscopic models and with a much larger geographical scope than microscopic models. On the other hand, mesoscopic models incorporate many time-dependent traffic flow characteristics, such as spillback/spillover on a regional-level scale, for instance, a large urban transportation network with thousands of links, nodes, ODs, and vehicles. Hence, mesoscopic models combine most of both macroscopic and microscopic modeling capabilities.

Considering the broad impact of the alternatives under evaluation and the need to model and reroute individual vehicles, this study developed a mesoscopic Dynamic Traffic Assignment (DTA) model based on the existing regional TDM. DTA*(3)*is a methodology that enables the representation of time-dependent network states based on travelers' behavior regarding route choices as they travel from origin to destination. Most of the existing DTA models load individual vehicles into the network and solve a traffic assignment problem by considering each vehicle's operational characteristics.

DynusT is the DTA model used in this study*(4)*. A Graphical User Interface, NEXTA, was used to generate from the TDM most of the data required by DynusT. Input required by DynusT includes: network characteristics, origin and destination locations, signal control settings, and the time-dependent OD demand. The network characteristics include such data as the number of lanes, link length, saturation flow rates, and speed limits. The majority of this data was extracted from the existing TDM, although some data collection was required to ensure consistency and reflect existing network conditions. In each zone, there should be at least one generation link to generate traffic and one destination node to distribute traffic. To enhance modeling realism, freeway links cannot generate traffic, and freeway nodes cannot be assigned as destinations. Ideally, the actual signal settings on the field are used in the model. Signal settings for the existing conditions, representing the Base scenario, were provided by the Freeway and Arterial System of Transportation (FAST) of Las Vegas, Nevada. The signal settings for the remaining alternatives were estimated for present as well as future conditions. This estimation typically is expensive and time consuming; therefore, to simplify the process as well as represent likely future conditions, all intersections were modeled as actuated control with signal settings for the morning peak period. A total of 791 signalized intersections were modeled for Las Vegas roadway network.

Two separate OD demand matrices were imported from the TDM, one for passenger cars and one for trucks. The Las Vegas TDM roadway network includes a total of 1,646 Traffic Analysis Zones. The morning peak-period (7 AM to 9 AM) was modeled using the corresponding two-hour demand. The demand was distributed for every 15 minute time interval within the morning-peak period. Hence, a total of eight demand matrices were used to dynamically load the vehicles into the network. The region-wide demand distribution over two-hour peak period was acquired from traffic counts distribution over the same two-hour peak period. Considering the demand profile, it was determined that aggregation of demand was feasible and convenient for computational performance. After aggregation, the number of zones was reduced from 1646 to 696 and the entire model was consistently updated to reflect zoning changes. Once all the input files were generated, the model was used to determine the network traffic flow pattern, including the vehicular routes as well as the corresponding link travel times and flows. To assess the difference between the model results and the real-world, simulated link counts were compared to actual link counts collected from FAST. Ideally, there should not be any difference between simulated and actual counts. However, considering the complexities involved in network traffic flow models, a 15% error range was allowed between simulated and actual counts. Initially, only 36% of the counts were within the 15% error range.

To reduce the significant difference between simulated and actual link counts, calibration efforts were conducted. These calibration efforts focused on the enhancement of parameters related to traffic flow and the time-varying OD matrices. The calibration of the OD matrices involved an optimization procedure *(5)* that minimizes the absolute deviation between simulated and actual link counts. Several iterations of calibration were conducted until at least 85% of the link counts were within 15% error region, as specified by the Federal Highway Administration Primer Volume III*(6)*. In this study, 87% of the calibrated counts were within 15% error region.

Measures of effectiveness

This study adopts an economic perspective to evaluate the different alternatives, which includes monetized costs and benefits associated with each of the alternatives. There are several economic efficiency criteria upon which decisions can be made regarding implementation of an alternative or selection of a specific project *(7)*. In this study, the best alternative is chosen based on a Present Worth Costs through a Life-cycle Benefit-Cost analysis. The various types of costs that are considered include agency and user costs. Agency costs include the construction costs of each of the alternative. User costs include travel time costs, safety costs, vehicle operating costs, fuel consumption, and emission costs. Ideally, one would like to include all possible costs; however, this would be limited by such factors as data availability, the resources required to estimate the different costs, and model capabilities.

Travel time costs

Network travel time is the time that all vehicles spend in the system. Results obtained from the network modeling only include the morning peak-period. To estimate the network travel time for the entire day, the peak-hour travel time is considered to be eight percent of the daily travel time.

Therefore, daily travel time is computed using a factor equal to 12.5 (100/8); the annual network travel time is computed considering 365 days in a calendar year. Network travel time cost is calculated using on-the-clock and off-the-clock travel time cost factors. Travel time cost by vehicle class for year 2005*(7)* is converted to year 2007 using an appropriate inflation rate. The inflation rate is computed using Equation 1. Construction Price Index for the years 2005 and 2007 are obtained from Bureau of Labor Studies.

$$InflationRate = \frac{CPI(2007) - CPI(2005)}{CPI(2005)} = \frac{207.3 - 195.3}{195.3} = 0.06 \qquad (1)$$

Crash costs

In this study, safety estimations are computed using the Deployment Analysis Systems (IDAS) methodology, developed by the Intelligent Transportation Systems (ITS) Joint Program Office of the U.S. Department of Transportation. This methodology relates volume-capacity ratios to average crash rates. The average ratios are updated to reflect the characteristics of the Las Vegas roadway network. Data for the year 2008 is used to conduct the update *(8)*. IDAS default crash rates are updated using factor (F), calculated using the Equation2.

$$F = \frac{NevadaCrashRate}{NationalCrashRate} \qquad (2)$$

IDAS default rates are multiplied by F to estimate safety impacts. Peak-hourly volume is obtained from the network modeling where capacity is defined as multiplication of the saturation flow rate and the number of lanes. Hence, volume to capacity (v/c) ratios can be computed to determine the appropriate crash rates. Crashes are classified mainly into three categories: fatal crashes, injury crashes, and property damage only (PDO) crashes. The input data required for crash computations is discussed below. The number of crashes in the entire network for a year is given by the Equation3:

$$Crashes = \frac{(R * L * V) * 365}{1{,}000{,}000} \qquad (3)$$

where,
R = Crash rates for fatal, injury, and PDO,
L = Link length in miles, and
V = Daily volume computed from peak-hour traffic volume.

Comparison between estimated and actual crashes *(9)* suggested that actual fatal crashes were almost 87 percent higher than the estimated values. Similarly, injury and PDO crashes were 50-60 percent higher than the estimated values. Hence, calibration factors were used to estimate adequately future crashes. To estimate the cost corresponding to crashes, the number of crashes in each type is multiplied by the corresponding cost factors *(10, 11)*.

Emission costs

Emissions play a very important role in the evaluation of transportation alternatives because they are directly related to human health and the environment. Billions of dollars are lost due to health and environmental effects associated with vehicular emissions. Major pollutants from vehicles include carbon monoxide, volatile organic compounds, oxides of nitrogen, oxides of sulfur, carbon dioxide and particulate matter (PM_{10}). This study uses the following data:

a) Emission rates (R) (in gm/mile), provided by the California Air Resource Board (CARB)*(12)* and based on the EMFAC 2007 model. These rates are a function of link speeds that are obtained for each alternative, using the network modeling methodology described earlier.
b) Link Length (L) (in miles).
c) Daily volume (V) estimates, based on peak-hour volume. It is assumed that the peak-hour traffic is eight percent of the Average Daily Traffic (ADT).

Daily emissions for each link in the network are given by the Equation 4.The emissions cost for each of the pollutants is obtained using Benefit/Cost models (Cal B/C models) developed by the California Department of Transportation, as shown in Equation 5. It is assumed that the emissions cost in the Las Vegas Valley is the same as the cost in the Los Angeles/South Coast region. The monetary value of emissions (dollar/ton) for the year 2007 is based on the Cal B/C models *(13)*.

$$Emissions(E) = \frac{(R * L * V)}{1{,}000{,}000} \qquad (4)$$

$$EmissionsCost = E(ton) * Cost\left(\frac{\$}{ton}\right) \qquad (5)$$

Fuel consumption costs

Fuel consumption plays a vital role in the evaluation of investment of transportation projects because they are directly related to the energy consumption and the environment. Millions of dollars can be saved in fuel consumption cost if appropriate transportation investments are chosen. In this study, the estimation of fuel consumption uses the following data:

a) Fuel Consumption rates (FC) (in gallons/mile), provided by the IDAS methodology. These rates are a function of link speeds that are obtained for each alternative from the output of network model.
b) Link length (L) in miles.
c) Daily volume (V) estimates, based on peak-hour volume.

Daily Fuel Consumption for each link in the network is given by Equation 6, and the annual fuel consumption cost is computed using Equation 7.

$$DailyFuelConsumption(F) = FC * L * V \qquad (6)$$

$$AnnualFuelConsumptionCost = F(gallons) * FuelCost\left(\frac{\$}{gallon}\right) * 365 \qquad (7)$$

Vehicle operating costs

Vehicle operating costs (VOC), which are costs that fluctuate with vehicle usage, are normally expressed in cents per vehicle mile. Components that constitute vehicle operating costs include fuel, tires, maintenance, repairs, and mileage-dependent depreciation *(11)*. In this study, medium auto and truck costs were used to estimate the vehicle operating costs using Equation 8.

$$VOC = \frac{Volume\left({}^{veh}/_{hr}\right) * length(miles) * \%\, VehicleType * AvgVOC\ Cost}{1000000} \quad (8)$$

Construction Costs

This analysis includes the overlay cost, the construction cost per lane mile, and the construction cost for new interchanges. The corresponding unit construction costs are obtained from an NDOT report *(14)* for the State of Nevada. The 2007 overlay cost is $1.9 M, new construction cost is $5.0 M per lane mile, and the interchange costs are approximately $20 M for small interchange and $25 M for large interchange.

The Base scenario and the alternatives for TR, TOL and TOT do not require new construction. Hence, the only costs associated with them are overlay costs. To obtain the total overlay costs, the unit overlay costs are multiplied by the length of the freeway segment (estimated to be 20 miles) and number of lanes (6 lanes in both directions). For Bypass A and Bypass A1, the costs include new construction of lanes and interchanges. As discussed earlier, Bypass A and Bypass A1 are new freeway facilities with 2 lanes in each direction, 3 large interchanges and a segment length of approximately 40 miles. Bypass B has new construction of approximately 5 miles (2 lanes in each direction) with 12 small interchanges and an overpass over the entire corridor.

Depreciation costs

The *Straight-Line method* is the simplest way to calculate annual depreciation, comparing the purchase price of the asset (C), its years of life (T), and its final salvage value. In this study, C is defined as the construction cost associated with any alternative, while T is analysis period, in this case, 23 years.

The *Interest Rate (i)* is the rate of interest an investor expects to receive after subtracting inflation. The "real interest rate" is approximately the nominal interest rate minus the inflation rate. This is based on a Real Interest Rate, which is the market rate less inflation, on 30-year treasury notes and bonds. The real interest rate for present worth analysis is calculated by subtracting the average of the nominal interest rate with the interest rate adjusted for inflation. The interest rate used in the analysis is 2.2825*(15)*. Finally, the annual depreciation cost is converted to present value in 2007 dollars.

Salvage value

The expected life of a new freeway facility is assumed to be 40 years, with an analysis period of 23 years, from 2007 to 2030. Hence, a capital value factor of 0.58*(16)* is used to calculate the salvage value. Finally, the salvage value is converted to present value in 2007 dollars. Table 1 shows the present value of annual depreciation costs and the salvage value of various alternatives, in billions of dollars.

3. RESULTS AND ANALYSIS

The results indicate that the alternatives -- truck-restriction lane, truck-only lane, and truck-only toll lane -- have higher costs for network travel times than the Bypass A and Bypass A1 alternatives. The lower costs associated with the bypass alternatives can be attributed to the corresponding increased capacity. The Bypass A1 scenario represents a 1.5% cost savings in network travel time when compared to the Base scenario. In contrast, the Bypass A scenario represents no savings relative to the Base scenario.

TABLE 1 Present Value of Annual Depreciation and Salvage Value of Various Alternatives

	Annual Depreciation (billions)	PV (2007) (billions)		Salvage Value (billions)	PV (2007) (billions)
Base Case	0.0000	0.0000	**Base Case**	0.0000	0.0000
TR	0.0010	0.0184	**TR**	0.0000	0.0000
TOL	0.0010	0.0184	**TOL**	0.0000	0.0000
TOT	0.0010	0.0184	**TOT**	0.0000	0.0000
Bypass A	0.0160	0.2835	**Bypass A**	0.5075	0.3022
Bypass A1	0.0160	0.2835	**Bypass A1**	0.5075	0.3022
Bypass B	0.0062	0.1102	**Bypass B**	0.1972	0.1174

Costs for crashes, emissions, fuel consumption, and volatile organic compounds (VOCs) were estimated for the entire Las Vegas roadway network. Crash costs for bypass scenarios are all less than the Base case scenario; this may be attributed to increased capacity and diversion of traffic. The TR, TOL and TOT cases seem to have more crashes than the Base case scenario. TR scenario represents the situation where there is increased interaction between the trucks and passenger cars, which may contribute to more crashes. The TOL and TOT presents a decrease in existing capacity, which may be a factor contributing to increase in crashes.

Total emissions for the alternatives increase over the years because of the expected increase in volume. Emissions for TR, TOL, and TOT, are lower than the Base case scenario and all Bypass alternatives. Although this is counterintuitive, average speeds of these three alternatives are slightly higher than the Bypass alternatives and the Base case scenario, but not so much higher that pollutant emissions would increase. Among all the alternatives, the TR alternative has lowest fuel consumption and vehicle operating costs during the entire analysis period. The Bypass alternatives had higher vehicle operating costs compared to the TR alternative; this may be because the former included longer distances traveled. Bypass A1 has lower VOC costs as compared to Bypass A due to free flow conditions.

Life-cycle benefit-cost analysis

The travel time costs, crash costs, emission costs, fuel consumption costs and vehicle operating costs were computed for the years 2008, 2013, 2020 and 2030. To perform a Life-cycle Benefit-cost analysis, costs are required for all the years between 2008 and 2030. This is obtained by linear interpolation of costs between years 2008-2013, 2013-2020, and 2020-2030. Finally, the costs for all the years are converted to present value in 2007 dollars. Construction costs, salvage value, and depreciation costs are converted to 2007 dollars, as discussed in the previous section. Figure 1(a) shows the analysis of benefits versus costs over the life cycle, and Figure 1(b) shows net benefits of the aforementioned performance measures, in millions of dollars.

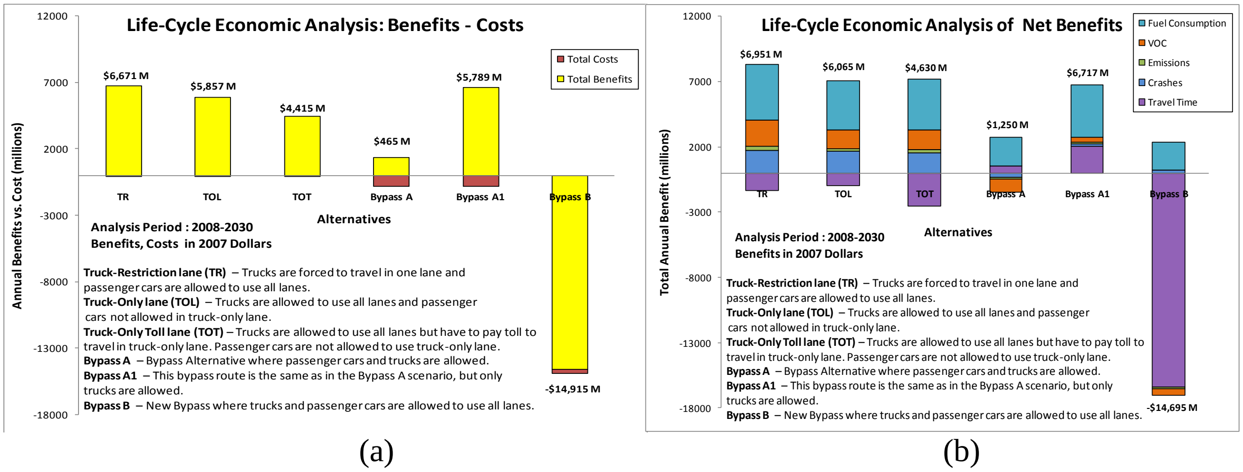

FIGURE 1 Life-Cycle Benefit-Cost Analysis: (a) Benefits vs. Costs and (b) Net Benefits.

Figure 1(a) shows that all the alternatives, except Bypass A and Bypass B, have less costs when compared to the Base case scenario. This can be attributed to the higher construction costs associated with the Bypass A alternative. Bypass B is the least preferred alternative due to higher congestion, resulting in higher travel time costs, crash costs, and emission costs. Figure 1(b) summarizes the net benefits by individual performance measures. It is evident that TR is the preferred alternative, followed by Bypass A1, when net benefits are considered for travel time, crash, emissions, fuel consumption, and vehicle operating costs.

4. CONCLUSIONS

In evaluating and ranking several alternatives proposed to accommodate truck traffic in the Las Vegas roadway network, this study considered various performance measures, including travel time, crashes, emissions, vehicle operating costs, fuel consumption, depreciation, salvage value, and construction costs. Based on Life-cycle Benefit-Cost analysis, and considering the performance measures used, the alternatives are ranked in the following order: Truck-Restriction Lane, Bypass A1, Truck-Only Lane, Truck-Only Toll, Bypass A, Base scenario, and Bypass B.

Detailed analysis indicates that travel time and crashes are the factors that contribute the most to the total cost. If individual performance measures are considered independently, the ranking might change. For example, if travel time is considered separately, then the Bypass A1 alternative is the best followed by the Truck Restriction Lane alternative. To enable a more comprehensive evaluation, it is recommended that careful consideration is taken by the decision makers to prioritize the performance measures such that the appropriate resources are allocated.

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