Vehicle Emissions and Level of Service Standards: Exploratory Analysis of the Effects of Traffic Flow on Vehicle Greenhouse Gas Emissions

IN THIS FEATURE, WHICH ORIGINALLY APPEARED IN THE TRANSPORTATION RESEARCH BOARD'S 88TH ANNUAL MEETING COMPENDIUM OF PAPERS, A TRAVEL DEMAND FORECASTING MODEL SIMULATED BUILDOUT CONDITIONS WITH OPERATIONAL DEFICIENCIES IN CRITCAL AREAS. CHANGES TO ROADWAY LANE CONFIGURATIONS WERE THEN MADE TO ACHIEVE LOS THRESHOLDS OF E THROUGH A.

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ABSTRACT

Many local jurisdictions seek to preserve adequate infrastructure by enacting level of service (LOS) policies for proposed new development. Understanding the relationship between roadway LOS policies and greenhouse gas emissions is an important step toward reducing the emissions related to global climate change. By influencing the evolution of urban infrastructure, these LOS standards can have a significant impact on the type and character of vehicle trips made and the subsequent emissions released. Currently, most jurisdictions establish LOS threshold policies based solely on operational standards and rarely consider the impacts of greenhouse gas emissions.

Using a travel demand forecasting model for Grover Beach, CA, buildout conditions were simulated to make the network have operational deficiencies in critical areas, ultimately operating at a LOS F. Changes to roadway lane configurations were then made to achieve LOS thresholds of LOS E through LOS A. The resulting speed and flow data were analyzed in emission models to determine the relationship between the target LOS thresholds and emissions produced. The network was modeled for both roadway link LOS and intersection LOS conditions.

For roadway links, overall, the lowest amounts of emissions were released at the LOS B threshold and the greatest incremental decrease in emissions occurred between LOS D and C. At intersections, the lowest emissions point was LOS A and the largest incremental decrease occurred between LOS D and C. When considering the feasibility of implementation of LOS thresholds, LOS C was determined to be the most effective operating point for emissions.

INTRODUCTION

The use of personal vehicles is considered to be one of the leading contributors of pollution believed to be causing global climate change, including greenhouse gases. Land use and transportation policy decisions greatly affect the number and character of personal vehicle trips made. Some jurisdictions manage roadways by setting policies that establish one or more minimally acceptable thresholds for levels of service (LOS) for their roadways and intersections.

These policies vary by jurisdiction with some requiring minimal delay and congestion, which results in wider roadways and higher capacity intersections. Other jurisdictions allow more delay and congestion, generally implying development of narrower roadways. These policies directly impact vehicle operations, such as starts, percentage of stop-and-go traffic, travel speeds and overall travel demand on the roadway network. Currently, most jurisdictions establish LOS policies based solely on operational standards and do not consider the potential impacts on emissions. The purpose of this research is to explore the relationship between LOS policies and emissions and determine if there is a most effective operating policy. For the purpose of comparison, this investigation considered Carbon Monoxide, Organic Compounds and Sulfur Dioxide emissions as well as the greenhouse gases Carbon Dioxide and Nitrogen Oxides.[1]

To determine the relationship between LOS and emissions, a travel demand forecasting model developed by Fehr & Peers Transportation Consultants (F&P) for the San Luis Obispo Council of Governments (SLOCOG) was utilized.[2] Within the county-wide model, the study area selected for this research was the city of Grover Beach, CA, shown in Figure 1.

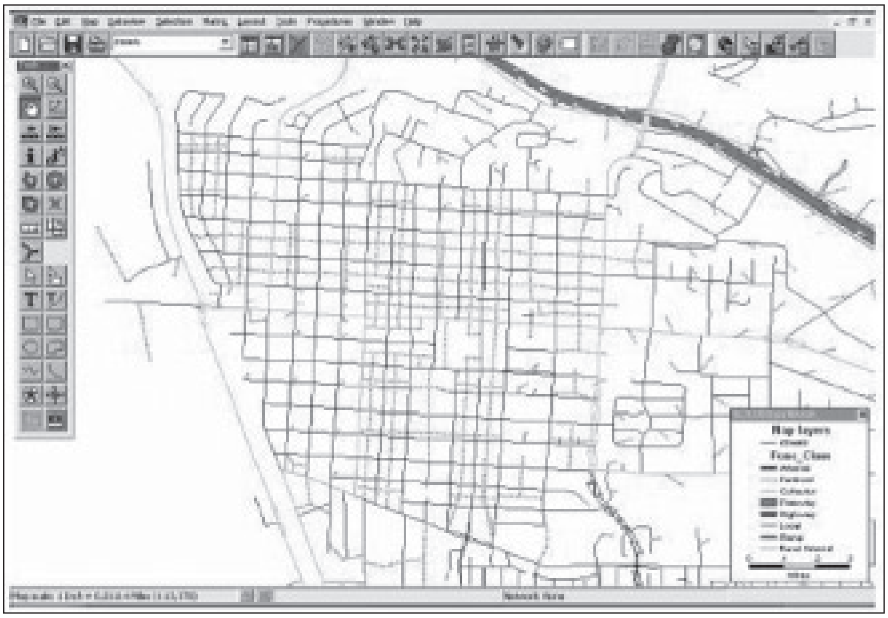

Figure 1. Screenshot of TransCAD showing the Grover Beach road network.

Table 1. Level of service methodologies utilized.

LOS	ICU
ICU 2003 Criteria for LOS at Signalized Intersection	
F	ICU > 1
E	0.90 < ICU ≤ 1.00
D	0.80 < ICU ≤ 0.90
C	0.70 < ICU ≤ 0.80
B	0.60 < ICU ≤ 0.70
A	ICU ≤ 0.60
HCM 2000 Criteria for Unsignalized Intersection	
LOS	**Delay (seconds)**
F	> 50
E	> 35–50
D	> 25–35
C	> 15–25
B	> 10–15
A	< 10
HCM 1985 Criteria for Roadway Links	
LOS	**V/C**
F	V/C > 1
E	0.90 < V/C ≤ 1.00
D	0.80 < V/C ≤ 0.90
C	0.70 < V/C ≤ 0.80
B	0.60 < V/C ≤ 0.70
A	V/C ≤ 0.60

Grover Beach was chosen largely for convenience and practicality—the city contains a fairly homogenous grid pattern of arterials and local streets without internal freeways, and is modeled by a comparatively fine-grained and regular system of traffic analysis zones.

The methodologies used to determine the LOS were the Intersection Capacity Utilization (ICU) 2003 Method for signalized intersections,[3] the *Highway Capacity Manual* (HCM) 2000 Method for unsignalized intersections[4] and the HCM 1985 Method for roadway links.[5] As shown in Table 1, ICU 2003 bases the results on an ICU ratio, which incorporates volume and capacity; HCM 2000 bases the results on average delay; HCM 1985 bases the results on the V/C ratios of the link.

LITERATURE REVIEW

There is an extensive and growing body of literature on the impacts of transportation improvements to traffic flow and demand.[6–15] However most of the literature does not evaluate these impacts on emissions.[16] There are nevertheless a few studies that address the link between transportation and emissions.[16–19] These existing studies do not directly address the link between operating level of service and emissions as explored in this paper. This gap may be explained by the fact that the differing operating standards associated with various levels of service can result in travel behaviors that may either increase or reduce emissions. Dowling et al. explain in NCHRP 535 (2005) that current modeling techniques generally account for the immediate impact on emissions as a result of a modification to a transportation facility; however, these modeling techniques fail to consider secondary and tertiary impacts caused by changes in drivers' behaviors as a result of more or less favorable driving conditions.

Literature on the effects of traffic flow on vehicle greenhouse gas emissions is broad and varied. There is substantial literature on the development of accurate models to predict vehicle emissions under different driving conditions, while there is also a multitude of literature addressing the issue from a policy point of view. These two different approaches ultimately aim for the same goal, to achieve a reduction in vehicle emissions.

In order to fully understand the effects of traffic flow on vehicle greenhouse emissions, a model must first be developed and validated. Vehicle emissions and fuel consumption models have evolved through decades of research. A paper by Cappiello et al.[20] suggests that many vehicle emissions models are overly simple, in particular the speed dependent models like MOBILE6 that are widely used, while others are too complicated, requiring excessive inputs and calculations, which ultimately slow down computational time. Those authors developed and implemented EMIssions from Traffic (EMIT), a statistical model of emissions (CO_2, CO, HC, and NOx) and fuel consumption for light-duty vehicles, which has been simplified from the physical load-based approach that was gaining popularity. The model is calibrated for a set of vehicles driven on standard and aggressive driving cycles. Preliminary results have indicated that the model gives reasonable results compared to actual measurements as well as to results obtained with CMEM. In particular, the model gives good accuracy for fuel consumption and carbon dioxide, carbon monoxide and nitrogen gases.

Grant et al.[21] identify and discuss the various analysis tools available for assessment of greenhouse gas emissions from vehicles. Among the tools considered, the Emissions Factor (EMFAC) software was noted to consider the speed of vehicles when calculating CO_2 emissions; however, the paper notes that EMFAC uses

Table 2. Length of network in compliance with LOS threshold.

Scenario	% Compliance of LOS Threshold
LOS E	96.76%
LOS D	97.64%
LOS C	95.56%
LOS B	96.53%
LOS A	95.60%

Table 3. Speed bin output for 2004 existing conditions in the AB direction.

2004 Existing PM Peak Link Volumes AB Direction				
Speed Bin (mph)	**Length (miles)**	**% of total length**	**Total VMT**	**Speed Bin %**
0–4.99	0.78	1.61%	0.00	0.00%
5–9.99	0.00	0.00%	0.00	0.00%
10–14.99	0.00	0.00%	0.00	0.00%
15–19.99	0.00	0.00%	0.00	0.00%
20–24.99	1.84	3.80%	140.95	6.10%
25–29.99	38.72	80.00%	225.39	9.76%
30–34.99	6.31	13.04%	1918.71	83.09%
35–39.99	0.75	1.55%	24.14	1.05%
40–44.99	0.00	0.00%	0.00	0.00%
45–49.99	0.00	0.00%	0.00	0.00%
50–54.99	0.00	0.00%	0.00	0.00%
55–59.99	0.00	0.00%	0.00	0.00%
60–64.99	0.00	0.00%	0.00	0.00%
65–69.99	0.00	0.00%	0.00	0.00%
Totals	**48.40**	**100%**	**2309.19**	**100%**

data from 1985 for diesel vehicles, which is a point of concern for the authors.

The literature acknowledges that mobility and emissions models have been developed independently without the express objective of providing data to each other.[19, 22, 23] That explains why assortments of models were applied in this exploration of the relationship between levels of service and emissions.

METHODOLOGY

To achieve the objective of this study and to obtain the optimum LOS threshold, a number of software programs were used in this study. Brief descriptions of the programs along with their usage in this study are described in the following sections.

TransCAD

TransCAD, a travel demand forecasting software package, was utilized to obtain traffic information for the study area used for predicting emission. The data for San Luis Obispo County provided by F&P include three model years which are 2004, based on existing traffic data, 2015 and 2030, which are based upon forecasting. Initially, the 2004 model was run to obtain existing conditions.

In order to analyze all LOS threshold scenarios between LOS A and F, a buildout scenario was needed where a dramatic increase in traffic flow occurred. Using the 2030 model as a base, the land use data for Grover Beach were artificially increased. This increase in land use was spread out through the network in an attempt to create an even network loading. For the buildout scenario, which was LOS F, the major streets in the network operated with a consistent V/C of at least 1.0 with as many minor streets as possible above or near a V/C of 1.0.

Once the buildout condition was simulated, the results were compared to the existing condition to confirm that land use changes indeed result in an increase in traffic flow. The road network was then adjusted by increasing the number of lanes on congested segment with the intent of generally bringing the V/C below the threshold for LOS E. In some locations, lane configurations were allowed to remain unchanged even though the V/C threshold was exceeded by a minor amount because adding a lane created too large of a jump in V/C and, hence, LOS. As shown in Table 2, at least 95% of the total network length was operating within the target LOS threshold for all scenarios.

Once the LOS E threshold was achieved, this process was repeated for each of the other LOS thresholds, LOS D through LOS A. For each such scenario, all TransCAD parameters except for lane configuration remained constant to ensure that any changes in network loading were attributed to the change in lane configurations alone.

After each scenario was complete, the speed data were extracted from TransCAD. In order to generate the output for each scenario, both TransCAD and ArcGIS were utilized. In ArcGIS, the data from the roadway network were organized into speed categories referred to as speed bins, which is the percent of vehicle miles traveled within each speed category in 5 mph increments. TransCAD considers flow in each direction separately and identifies them as AB or BA; because of this, the directional data were organized separately and then combined for the purpose of emissions analysis. An example of the speed bin output is found in Table 3.

EMFAC Model

EMFAC 2007 is an emissions model developed by the California Air Resources Board.[23, 24] It performs emissions analysis based upon several different options. The first option is to select the geographic area, where analysis can be completed for the entire state, an air basin, a state air control district or a county. All of these geographic divisions are larger than the study area, so the smallest one was used, which is the County of San Luis Obispo. The next option is the year and month or season of analysis. To ensure a constant comparison point, the EMFAC model was run for 2004 on an annual basis to average out any seasonal differences.

For the output, EMFAC offers three different output modes:

- Burden Area Planning Inventory
- EMFAC Area Fleet Average Emissions
- Calimfac Detailed Vehicle Data

For this research, the EMFAC Area Fleet Average mode was used. This mode allows for customization of the various inputs and provides raw emissions data that can be used for further calculations. These data show emissions produced per mile traveled at a certain speed for each pollutant at a specific atmospheric temperature and humidity. The temperature was set at 60°F and the humidity was set to 75%. Speed bins were set at 5 mph increments and Detailed Impact Reports (RTL) were generated. All other inputs remained as the default values.

The speed bins that were obtained from TransCAD analysis were used with the emissions data from the RTL to create a Microsoft Excel file that calculates the total emissions produced based on the VMT amounts at each speed increment.

Synchro

In addition to coupling TransCAD with EMFAC, Synchro was used as a second source of emissions estimates for comparison purposes. Synchro is a transportation operational analysis program that generates both intersection LOS reports and emissions data for carbon monoxide (CO), nitrogen oxides (NOx) and volatile organic compounds (VOC). This emissions model is based upon fuel consumption which is calculated using the following formulas from the Synchro 7 User's Guide:[25]

F = TotalTravel * k1—TotalDelay * k2 + Stops * k3

k1 = 0.075283—0.0015892 * Speed + 0.000015066 * Speed^2
k2 = 0.7329
k3 = .0000061411 * speed^2
F = fuel consumed in gallons
Speed = cruise speed in mph
Total travel = vehicle miles traveled
Total delay = total signal delay in hours
Stops = total stops in vehicles per hour

With the fuel consumption known, the emissions produced are determined using the following formulas:

CO = F * 69.9 g/gal = Carbon Monoxide Emissions (grams)

NOx = F * 13.6 g/gal = Nitrogen Oxides Emissions (grams)

VOC = F * 16.2 g/gal = Volatile Oxygen Compounds Emissions (grams)

F = Fuel Consumption (gallon)

To create a Synchro model for Grover Beach, 20 representative intersections within the study area were chosen. The 20 intersections represented the entire area with respect to geometry, control and volume. The intersections chosen not only represented typical intersections in Grover Beach, but they were also geographically spread out. Current lane configurations and control types were programmed into the model. For consistent signal phasing, the Synchro optimized phasing option was used.

Existing PM peak turning volumes were taken directly from the TransCAD SLOCOG model using the 2004 files and settings. Reports were then generated for each intersection that reported the intersection LOS and the emissions at each intersection. As stated previously, LOS was determined for signalized intersections based on the ICU 2000 methodology, and for unsignalized intersections using the HCM 2000 methodology.

Upon completing the existing condition scenario, the buildout condition scenario was examined. The turning movements from the buildout conditions in TransCAD were imported into the Synchro network. All other factors were kept constant, with turning volumes being the only variable. Like before, reports were generated for the buildout condition that provided LOS and emissions data for each intersection. After finishing the buildout condition, the turning movements and volumes were held constant while the LOS thresholds were applied to the network for LOS E, D, C, B and A. LOS threshold compliance was accomplished by altering the lane configurations and control type of the intersections that did not meet the target LOS threshold. For each LOS scenario in Synchro, all intersections operated at the desired LOS or better. Reports for LOS and emissions at each LOS threshold scenario were generated.

Traffix

Traffix 7.9, an intersection operations analysis software package, was utilized in this research to determine the LOS for two intersections in the Grover Beach study area that could not be accurately modeled in Synchro due to the fact that ICU methodology cannot analyze intersections that are stop controlled and have multiple turn lanes, such as those in question here. While it is not realistic to have multiple turn lanes at a stop controlled intersection, they were used to maintain consistent intersection control for all scenarios. The two intersections were modeled in Traffix, with their respective lane configurations and control types. Existing traffic volumes were imported from TransCAD output to determine the existing LOS. Similarly, buildout volumes were imported into the model to determine buildout LOS. LOS threshold policies were then applied to create each LOS scenario and their respective data. The buildout traffic volumes were kept constant, with lane configuration and control type being the only variables changed to meet the desired LOS target. This process was conducted for all LOS scenarios, LOS F to A.

RESULTS

Evaluation Approach

Results from the various LOS scenarios were compared to determine the lowest point for emissions and the overall most effective LOS threshold for emissions. For each pollutant, two different metrics were used to determine the effect of LOS criteria on emissions: the total emissions produced at each LOS scenario, and the difference of emissions produced between adjacent LOS thresholds. When considering the incremental decrease in emissions, the identifying point was the better LOS standard; for example, if the pair was LOS D to C, the identifying point was LOS C. Depending on the pollutant, the point of lowest emissions and the location of greatest incremental decrease in emissions did not always coincide. For this reason, a simple algorithm was established to determine the most effective operating point that incorporates feasibility of implementation, as follows:

- If LOS A was shown to produce the lowest amount of emissions, it was disregarded because for the most part implementing a LOS A policy threshold is not feasible for a jurisdiction since it requires an unrealistic amount of infrastructure to be built.

- The point at which the lowest amount of emissions was produced was compared with the point where the greatest incremental decrease in emissions occurred. Two scenarios could occur:
  a. If these points matched, then this point was considered the most effective LOS threshold.
  b. If these points did not match, then the point that was the most feasible to implement was considered the most effective LOS threshold—this would be the poorer LOS threshold.

The purpose of the analysis is to quantify the relationship between LOS policy thresholds and pollution emissions. This information is intended to assist transportation professionals to fully inform and educate decision makers about the consequences of their policy choices with respect to both LOS and air quality.

Table 4. EMFAC emissions network totals.

	Emissions (kg)				
Scenario	**CO**	**TOG**	**SO_2 (g)**	**NOx**	**CO_2**
Existing	33.00	2.00	0.040	5.00	1973
Buildout	157.62	13.10	0.189	24.30	10143
LOS E	154.06	11.33	0.185	23.80	9623
LOS D	152.07	10.71	0.183	23.65	9402
LOS C	148.90	10.19	0.178	23.35	9005
LOS B	143.94	9.47	0.174	23.41	8744
LOS A	144.22	9.47	0.175	23.49	8757

Table 5. EMFAC emissions decrease from previous scenario.

	Emissions (kg)				
Scenario	**CO**	**TOG**	**SO_2 (g)**	**NOx**	**CO_2**
Buildout to E	3.56	1.77	3.32	0.50	519.35
LOS E to D	1.99	0.62	2.47	0.15	221.09
LOS D to C	3.17	0.52	4.79	0.30	397.54
LOS C to B	4.96	0.72	3.60	-0.06	260.38
LOS B to A	-0.28	0.00	-0.39	-0.08	-12.72

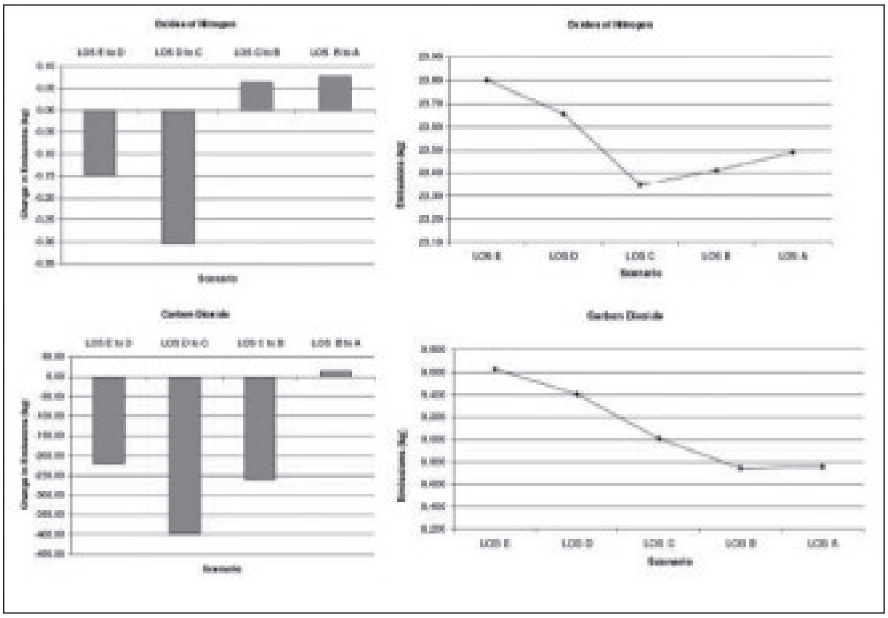

Figure 2. Emissions produced at each LOS threshold and change in emission between each LOS threshold for oxides of nitrogen and carbon dioxide.

Roadway Link Emissions

TransCAD and EMFAC produced emissions data for Carbon Monoxide (CO), Total Organic Gases (TOG), Sulfur Dioxide (SO_2), Oxides of Nitrogen (NOx) and Carbon Dioxide (CO_2). Summarized in Table 4 are the total emissions produced for each scenario.

Of the five pollutants examined, CO and TOG reported a most effective operating point of LOS B with the remaining three pollutants reporting a most effective operating point of LOS C, as shown in Table 5. This creates a very close comparison between LOS C and B. From strictly an emissions point of view, LOS B is the most effective threshold. However, when feasibility is considered, LOS C is the overall most effective point. Figure 2 shows emissions produced at each LOS threshold and change in emission between each LOS threshold for Oxides of Nitrogen and Carbon Dioxide, the other pollutants experienced trends similar to that of Carbon Dioxide.

Intersection Emissions

Upon running all of the scenarios in Synchro, LOS results and emissions data for Carbon Monoxide (CO), Nitrogen Oxides (NOx), and Volatile Organic Compounds (VOC) were produced. The LOS scenarios were compared using the criteria above. Table 6 shows the emissions produced at each LOS scenario.

After analyzing the three pollutants from the Synchro output, LOS A showed the overall lowest amount of emissions; however, when considering feasibility as previously discussed, LOS A was disregarded. With LOS A removed, the next lowest total emissions occurred at LOS B for all of the pollutants; however, upon further analysis, the incremental decrease in emissions from LOS C to B was found to be small in comparison to the incremental decrease in emissions from LOS D to C. Therefore, LOS C was found to be the overall most effective LOS policy.

Table 6. Summary of emissions results.

PM Peak Hour Intersection Emissions – Grover Beach Study Intersections																						
Intersection	Control	Existing Emissions			Buildout Emissions			LOS E Emissions			LOS D Emissions			LOS C Emissions			LOS B Emissions			LOS A Emissions		
		PM Peak			PM Peak			PM Peak			PM Peak			PM Peak			PM Peak			PM Peak		
		CO	NOx	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx	VOC
Grover Beach Intersections																						
1 Grand Ave/ Pacific Blvd	Signalized	2.06	0.40	0.48	7.74	1.51	1.79	6.12	1.19	1.42	5.12	1.00	1.19	4.38	0.85	1.01	4.27	0.83	0.99	4.13	0.80	0.96
2 El Camino Real/ N 12th St	Side-Street Stop/ Signalized	0.30	0.06	0.07	55.87	10.87	12.95	8.45	1.64	1.96	8.45	1.64	1.96	4.65	0.91	1.08	3.94	0.77	0.91	2.49	0.48	0.58
3 Atlantic City Ave/ N 12th St	Side-Street Stop	0.07	0.01	0.02	0.75	0.15	0.17	0.75	0.15	0.17	0.75	0.15	0.17	0.75	0.15	0.17	0.75	0.15	0.17	0.75	0.15	0.17
4. Atlantic City Ave/ N Oak Park Blvd	Side-Street Stop/ Signalized	0.88	0.17	0.21	39.40	7.67	9.13	3.76	0.73	0.87	3.20	0.62	0.74	3.20	0.62	0.74	3.20	0.62	0.74	3.20	0.62	0.74
5 Atlantic City Ave/ N 8th St	Side-Street Stop	0.02	0.00	0.00	0.05	0.01	0.01	0.05	0.01	0.01	0.05	0.01	0.01	0.05	0.01	0.01	0.05	0.01	0.01	0.05	0.01	0.01
6 Newport Ave/ N 14th St	Side-Street Stop	0.03	0.01	0.01	0.33	0.06	0.08	0.33	0.06	0.06	0.33	0.06	0.08	0.33	0.06	0.08	0.33	0.06	0.08	0.33	0.06	0.08
7 Grand Ave/ S Oak Park Blvd	Signalized	3.84	0.75	0.89	9.40	1.83	2.18	9.40	1.83	2.18	9.40	1.83	2.18	9.40	1.83	2.18	9.40	1.83	2.18	7.03	1.37	1.63
8 Grand Ave/N 8th St	Signalized	1.59	0.31	0.37	8.06	1.57	1.87	6.12	1.19	1.42	6.88	1.34	1.59	4.65	0.90	1.08	4.06	0.79	0.94	3.96	0.77	0.92
9 Grand Ave/S 4th St	Signalized	1.07	0.21	0.25	2.89	0.56	0.67	2.89	0.56	0.67	2.89	0.56	0.67	2.89	0.56	0.67	2.89	0.56	0.67	2.90	0.56	0.67
10 Manhattan Ave/ N 8th St	All-Way Stop/Signalized	0.22	0.04	0.05	2.94	0.57	0.68	1.74	0.34	0.40	1.74	0.34	0.40	1.50	0.29	0.35	1.20	0.23	0.28	1.14	0.22	0.26
11 Manhattan Ave/ S 4th St	Side-Street Stop	0.07	0.01	0.02	0.34	0.07	0.08	0.34	0.07	0.08	0.34	0.07	0.08	0.34	0.07	0.08	0.34	0.07	0.08	0.34	0.07	0.08
12 Mentone Ave/ S 10th St	All-Way Stop	0.03	0.01	0.01	0.50	0.10	0.12	0.50	0.10	0.12	0.50	0.10	0.12	0.50	0.10	0.12	0.50	0.10	0.12	0.50	0.10	0.12
13 Farrol Ave/S 13th St	All-Way Stop	0.02	0.00	0.01	0.34	0.07	0.08	0.34	0.07	0.08	0.34	0.07	0.08	0.34	0.07	0.08	0.34	0.07	0.08	0.34	0.07	0.08
14 Farrol Ave/S 4th St	Side-Street Stop	0.07	0.01	0.02	0.65	0.13	0.15	0.65	0.13	0.15	0.65	0.13	0.15	0.65	0.13	0.15	0.65	0.13	0.15	0.65	0.13	0.15
15 Farrol Ave/S 8th St	Side-Street Stop	0.21	0.04	0.05	2.20	0.43	0.51	2.20	0.43	0.51	1.89	0.37	0.44	1.89	0.37	0.44	1.68	0.33	0.39	1.67	0.32	0.39
16 Ocean View Ave/ N 1st St	Side-Street Stop	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00
17 Ocean View Ave/ N 4th St	Side-Street Stop	0.52	0.10	0.12	1.07	0.21	0.25	1.07	0.21	0.25	1.07	0.21	0.25	1.07	0.21	0.25	1.07	0.21	0.25	1.07	0.21	0.25
18 Mentone Ave/ S Oak Park Blvd	All-Way Stop/Signalized	0.36	0.07	0.08	0.94	0.18	0.22	0.94	0.18	0.22	0.94	0.18	0.22	0.94	0.18	0.22	0.94	0.18	0.22	0.84	0.16	0.19
19 Seabright Ave/ S 14th St	Side-Street Stop	0.02	0.00	0.00	0.31	0.06	0.07	0.31	0.06	0.07	0.31	0.06	0.07	0.31	0.06	0.07	0.31	0.06	0.07	0.31	0.06	0.07
20 Newport Ave/ N 4th St	Side-Street Stop	0.44	0.08	0.10	1.06	0.21	0.25	1.06	0.21	0.25	1.06	0.21	0.25	1.06	0.21	0.25	1.06	0.21	0.25	1.06	0.21	0.25
Network Totals		11.84	2.28	2.76	134.86	26.26	31.26	47.04	9.16	10.89	45.93	8.95	10.65	38.92	7.58	9.03	37.00	7.21	8.58	32.78	6.37	7.60

Notes: 1. All emission values given in kg.

DISCUSSION OF RESULTS AND RECOMMENDATIONS

The authors recognize there are some limitations in the methodology. These limitations are related to software and data that could not be modified under the constraints of this exploratory analysis. Because of this, we have the following recommendations for future research that we believe likely would refine and extend our present findings:

- Replicate the analysis using a model network that has a larger variety of road types, speed limits and land uses than Grover Beach provided. The main reason for this suggestion is that as the LOS criteria were modified, the highest speed achieved was 35mph because of the limited number of speed limits throughout the city. Table 7 shows a breakdown of the number of miles associated with each speed range. Since the EMFAC model shows an increase in emissions once a vehicle is driving faster than approximately 40–50 mph, it is likely that by allowing a wider range of speed conditions to exist, there would have been a shift in the emissions generated at each LOS scenario.
- The transferability of this research is limited to jurisdictions with similar characteristics to Grover Beach such as population, density, land uses and roadway facility types, lengths, speed limits and control. The greatest transferability would be achieved by matching the frequency of speed limits shown in Table 7. Similar roadway networks would be more likely to produce results similar to those found in this research. As deviation from this speed limit frequency increases, it is increasingly likely the results would be incompatible.
- Include idle time and vehicle starts in the emissions calculations. The TransCAD model does not provide such outputs and EMFAC offers limited input options. Idle time and vehicle starts can have a significant impact on the total emissions produced, especially under congested situations where vehicles may be sitting in stop-and-go traffic for a long period of time.
- Explore other sources of emissions data. EMFAC is designed to be used on a large scale basis such as an entire county or air basin and is not well sited for examining an area as small as Grover Beach. Because of this, the data produced by EMFAC may not be completely accurate. Future work should explore the implications of using a driving mode-based model such as CMEM.[26]
- Model entire network of intersections so that there is not only a representative sample of intersections, but all of the intersections. This would give much more accurate trends.
- There are inherent limitations in outputting turning movement volumes from a travel demand forecasting model, especially a regional model. Like this model, most models are developed and validated at a regional level. They are not intended to be used at such a microscopic level with intersection turning movements.
- In future modeling, isolate the study area to prevent external trips from being attracted to the network. While the total trips generated on the network for each LOS scenario remained constant, there was an increase in VMT for each step improvement in LOS, as shown in Table 8. This is because as the network became more appealing, external trips were assigned to the Grover Beach network as a cut-through instead of using alternate routes.
- For each LOS scenario, import the turning movements from TransCAD into Synchro. This allows for a direct comparison between route choice behavior and intersection LOS analysis and how it impacts emissions. In this research, the buildout turning movements were held constant while applying each LOS threshold policy by changing only the intersection geometry.
- The model did not consider induced trips. As the roadway network improves and it becomes more attractive to users, people are more likely to make more vehicle trips or choose routes that they would have not otherwise taken. These effects certainly could have had significant effects on estimated emissions.

Table 7. Lane miles at each speed limit.

Grover Beach Network Speed Limit Frequency		
Speed Limit (mph)	Length of Roads (miles)	% of entire network
25	41.19	85.10%
35	7.21	14.90%
total	48.40	100.00%

CONCLUSION

The purpose of this research was to conduct an exploratory investigation in order to quantify the relationship between LOS policies and their effect on emissions. The key findings and conclusions from this research can be summarized as follows:

- For roadway link analysis on the study network considered, the lowest amount of emissions occurred at LOS B; however, the greatest incremental decrease in emissions occurred between LOS D and C. When taking into account the feasibility of implementing and maintaining a LOS threshold, it was concluded that LOS C is the most effective operating point.
- For intersection analysis, the lowest amount of emissions occurred at LOS

Table 8. Increase in VMT for each LOS scenario.

	Vehicle Miles Traveled			Increase from Previous Scenario	% Increase from Previous Scenario
Scenario	AB	BA	Total		
LOS E	9157	8137	17294	–	–
LOS D	9467	8335	17802	508	2.940%
LOS C	9576	8485	18062	259	1.456%
LOS B	9729	8566	18295	234	1.293%
LOS A	9782	8590	18372	77	0.420%

A with the largest incremental decrease in emissions occurring between LOS D and C. As with roadway link analysis, when feasibility was considered, LOS C was found to be the most effective operating point.

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