MOVES-BASED NO_x ANALYSES FOR URBAN CASE STUDIES IN TEXAS

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1. INTRODUCTION

Emissions inventories are an important component of air quality planning and a key input to photochemical grid models used to support air quality assessments. Recent studies suggest that emissions of nitrogen oxides (NO_x, the total of nitrogen monoxide, NO, and nitrogen dioxide, NO_2) may be overestimated in the Environmental Protection Agency (EPA) National Emissions Inventory (NEI), by as much as a factor of two. This overestimate has generally been attributed to the mobile source sector, for which emission estimates are prepared using EPA's Motor Vehicle Emission Simulator (MOVES) model (Fujita et al., 2012; Anderson et al., 2014; Canty et al., 2015). A number of potential issues have been identified with MOVES and MOVES modeling, including reliance on the model's default input data rather than more representative local inputs (Koupal et al., 2014; Warila et al., 2017).

A method typically used to identify inaccuracies in an emissions inventory is comparing emissions and ambient concentration data, often referred to as "emissions reconciliation." Because ambient pollutant concentrations are not fully representative of emitted quantities (due to chemical transformations and atmospheric transport), the ambient data used to perform the reconciliation must be carefully selected. In this study, near-road ambient air pollutant data was used to examine MOVES emissions estimates for NO_x at three urban sites in Texas. The input parameters that have the greatest influence on MOVES-based NO_x emissions estimates were then identified. This emissions reconciliation and sensitivity analysis will help planning agencies in Texas assess the accuracy of current on-road mobile source emissions estimates of NO_x from MOVES and identify which local MOVES input parameters should be prioritized for data collection and quality assurance efforts for future MOVES-based emissions inventory development.

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2. EMISSIONS RECONCILIATION ANALYSIS

2.1 Data Selection and Methods

An emissions reconciliation analysis of NO_x was performed at three sites in Texas: El Paso (EP), Houston (HT), and Fort Worth (FW) (Table 1). These sites are located in three different counties (Harris, Tarrant, and El Paso county, respectively). The HT and FW sites are part of the EPA's near-road monitoring network, which requires that NO_2 monitors be located no more than 50 m from major roadways in areas with high population and/or traffic (Watkins and Baldauf, 2012). The HT and FW site are located 15 m from I-610 and I-20, respectively. No official near-road monitors are located in El Paso; a monitoring site located 125 m from Loop 375 was selected for this analysis.

Table 1. Site locations in Texas, including site abbreviation, Air Quality System (AQS) identification code, longitude (λ, positive East), latitude (ϕ, positive North), target (adjacent) road, and distance to target road (*d*).

Site	City	AQS ID	λ	ϕ	Road	*d* (m)
EP	El Paso	481410055	-106.40	31.75	L375	125
HT	Houston	482011052	-95.39	29.81	I-610	15
FW	Fort Worth	484391053	-97.34	32.66	I-20	15

For each monitoring site, hourly CO, NO_x, and wind speed and direction from January 1, 2015, to December 31, 2015, were acquired from EPA's Air Quality System (AQS). Additional quality assurance was applied to the CO and NO_x such that (a) hourly NO_x was invalidated if NO_x < NO, (b) hourly CO was invalidated if CO < 0 ppb, and (c) periods with perceivable baseline drift were removed. In general, the mean diurnal profile at all three sites exhibited a morning (6:00-9:00 LST) and early evening (17:00-20:00 LST) peak in CO and NO_x mixing ratios, which were approximately coincident with peak vehicle miles travelled (VMT) on the adjacent roadways (e.g., Fig. 1).

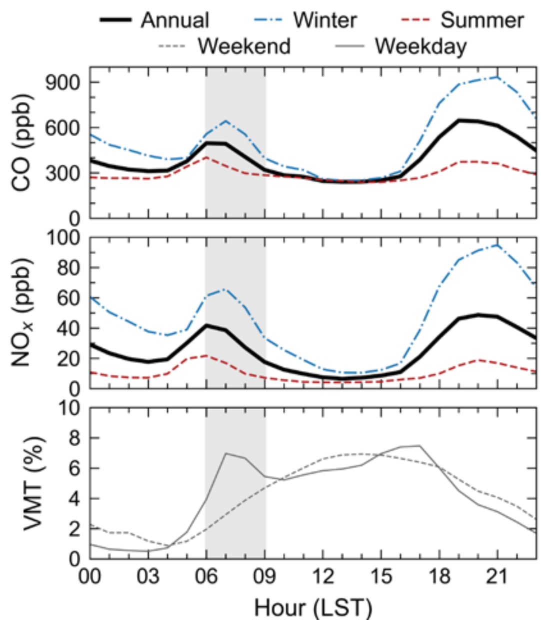

Fig 1. Mean diurnal profile of ambient CO, NO_x, and VMT for passenger cars on urban freeways at EP in 2015. VMT data provided by Texas Commission of Environmental Quality (TCEQ). Shaded background indicates the range of data used in this study.

To compare ambient-based and model-based data in this reconciliation analysis, the ratio of CO-to-NO_x (CO/NO_x) was used rather than NO_x mixing ratios alone; this accounts for any daily changes in meteorological or traffic conditions. Ambient mixing ratios should be most representative of mobile source emissions since the three study sites are located next to major roadways. To further minimize the impacts of confounding factors such as photochemistry, transport, and vertical mixing through the boundary layer (e.g., Chinkin et al., 2005), only ambient data from the morning commute period (6:00-9:00 LST) was used. The data were further restricted to hours when the site was downwind of the adjacent roadway.

Ambient-based CO/NO_x ratios were determined using regression techniques similar to those employed by Parrish et al. (2002) and Luke et al. (2010). In this approach, it is assumed that CO mixing ratios are heavily influenced by regional CO levels. Thus, the slope of the fit between CO and NO_x mixing ratios indicates the ratio of these emissions, and the intercept approximates the regional CO level. A total linear least-squares regression was applied to the annual, summer (JJA), and winter (DJF) data at each site, where weekend and weekday CO/NO_x ratios were computed separately by season.

The EPA MOVES2014a model was then used at county scale to develop on-road mobile source CO and NO_x emissions on an annual and seasonal basis using national defaults (the "Default" scenario) and the county-level best available local (BAL) data inputs (the "Base" scenario), which were obtained from local planning agencies. Fleet mix (VMT by vehicle class) was adjusted using the Texas Department of Transportation 2015 Roadway Inventory to better reflect traffic on the adjacent roadways. Only running exhaust and crankcase running exhaust emissions of CO, NO, and NO_2 were modeled for urban restricted-access roads, since it is assumed that there is minimal idling or cold starts on urban freeways. Only emissions from 6:00-9:00 LST were modeled. All species were converted from a mass to molar basis, and molar NO and NO_2 were summed to obtain molar NO_x.

Finally, from the regression analysis, the intercept was subtracted from all CO mixing ratios to obtain ΔCO values, which effectively separates the influence of regional CO levels from on-road vehicle emissions. The arithmetic mean ambient $\Delta CO/NO_x$ ratio is most comparable to MOVES-based CO/NO_x ratios since MOVES results account only for on-road emissions averaged over the entire fleet and modeling period.

2.2 Results

The ambient-based annual CO/NO_x ratios near roadways during morning hours were calculated as 7.76 ± 0.10 at EP, 8.56 ± 0.17 at HT, and 7.04 ± 0.19 at FW (Table 2). These ratios are comparable to those found in previous studies (e.g., Luke et al., 2010). In comparison, the mean annual $\Delta CO/NO_x$ ratios were higher: 8.6 at EP, 10.6 at HT, and 8.2 at FW.

For all cases, CO/NO_x ratios based on MOVES Default estimates were much lower than ambient-based ratios, ranging from 2.7 (Houston winter weekday) to 4.7 (FW summer weekday). The largest difference was between the annual mean $\Delta CO/NO_x$ ratio (10.6) and annual MOVES default CO/NOx ratio (3.3) at HT. Overall, using default inputs in MOVES consistently resulted in underestimation of ambient CO/NO_x ratios. This implies that, based on MOVES default input data, emissions estimates for CO, NO_x, or both pollutants, are not properly represented and may not reasonably represent on-road mobile sources in the emissions inventory. This finding aligns with inventory evaluations discussed elsewhere (e.g., Fujita et al., 2012).

Table 2. Regression analysis results between CO and NO_x mixing ratios from 6:00-9:00 LST when the monitoring site was downwind of the adjacent roadway. Slopes and intercepts are expressed as the estimated value and standard error of the value, and *n* is the number of samples used. The mean is the mean $\Delta CO/NO_x$ ratio determined from the regression analysis, where n_m is the number of samples used. MOVES values are CO/NO_x ratios based on molar mass. A hyphen indicates that modeling results were unavailable (due to missing input data).

Site	Season	Day	*n*	Slope	Intercept	Mean	n_m	MOVES scenario	
								Default	Base
EP	Annual	All	566	7.76 ± 0.10	164.3 ± 6.8	8.6	547	3.3	6.4
	Summer	Weekday	60	8.64 ± 0.32	195.1 ± 10.2	8.8	60	4.0	7.9
		Weekend	30	11.65 ± 2.19	189.4 ± 22.1	13.9	30	-	-
	Winter	Weekday	109	7.01 ± 0.19	150.9 ± 20.2	8.7	106	3.1	5.5
		Weekend	46	9.24 ± 0.26	99.8 ± 26.5	12.5	45	-	-
HT	Annual	All	428	8.56 ± 0.17	204.2 ± 11.0	10.6	413	3.3	7.4
	Summer	Weekday	55	8.31 ± 0.58	211.7 ± 42.7	9.1	55	4.4	9.6
		Weekend	27	9.63 ± 0.69	287.5 ± 28.6	10.0	27	-	-
	Winter	Weekday	48	7.53 ± 0.23	167.7 ± 20.2	7.2	47	2.7	5.6
		Weekend	14	10.24 ± 1.34	56.3 ± 80.6	12.0	14	-	-
FW	Annual	All	520	7.04 ± 0.19	272.0 ± 7.2	8.2	515	3.5	10.2
	Summer	Weekday	173	9.17 ± 0.39	234.1 ± 11.0	9.4	173	4.7	15.2
		Weekend	53	12.06 ± 1.13	254.4 ± 19.0	12.8	53	-	-
	Winter	Weekday	42	7.76 ± 0.51	109.4 ± 42.2	8.3	42	3.0	8.0
		Weekend	12	4.98 ± 0.72	223.9 ± 24.4	5.4	12	-	-

When BAL data inputs were used in MOVES, the resulting CO/NO_x ratios were in much better agreement with ambient-based ratios. Both ambient- and emissions-based CO/NO_x ratios were higher in summer than in winter; this is expected given that near-road measurements indicate a larger increase in NO_x than in CO mixing ratios from summer to winter (Fig. 1). However, CO/NO_x ratios modeled in MOVES exhibit a larger seasonal variation than ambient-based ratios. The ambient-based ratios are comparable to the MOVES emissions-based ratios for the annual and winter weekdays when local data inputs were used (within the acceptable 25-50% range of agreement; California Air Resources Board, 1997): on average, the difference between ambient-based and MOVES-based ratios was within 24% at EP; similar mean results were shown at HT (within 19%) and FW (within 30%). This comparison indicates the importance of using BAL data inputs to generate more accurate emissions estimates. However, it is important to further examine the sensitivity of NO_x emissions estimates to various MOVES modeling parameters.

3. MOVES-BASED EMISSIONS SENSITIVITY ANALYSIS

3.1 Test Scenarios

For each of the three case study sites, the Base scenario results were compared to 18 sensitivity test scenarios developed to represent reasonable ranges of input parameters. Changes in NO_x emissions and CO/NO_x ratios were quantified with respect to changing fleet mix (using 0%, 5%, 10%, 20%, and 30% fleet truck percentage), vehicle speed (VMT by speed distribution, using a ‘low’, ‘medium’, and ‘high’ speed distributions), vehicle age (VMT by age distribution, using ‘new’, ‘medium’, and ‘old’ vehicle age distributions), and meteorology (using a 6-month, 3-month, and 1-month averaging period to derive temperature and relative humidity inputs). For each test parameter, all other parameters were modelled using BAL data inputs. A hybrid Base-Default reference scenario was also included, in which the test input parameter was set as the MOVES default value and the BAL data were used for all other inputs.

3.2 Results and Discussion

Within the range tested, there is a positive linear relationship between NO_x emissions and fleet average truck percentage (not shown). As a result, MOVES-based CO/NO_x ratios decrease with increasing truck percentage at all three sites (Fig. 2). The rate of decrease is larger when truck percentage is low, given that NO_x emissions are more sensitive than CO to truck percentage.

CO/NO_x ratios do not vary considerably with respect to speed on a fleet average basis (Fig. 2). At EP and HT, CO/NO_x ratios exhibit a slight decrease, then increase when fleet average speed changes from 40 mph to 70 mph; in contrast, CO/NO_x ratios at FW decrease over the entire range of fleet average speeds tested. CO/NO_x ratios modeled using a Base-Default configuration are much lower at all three sites than all test scenarios and Base scenario results.

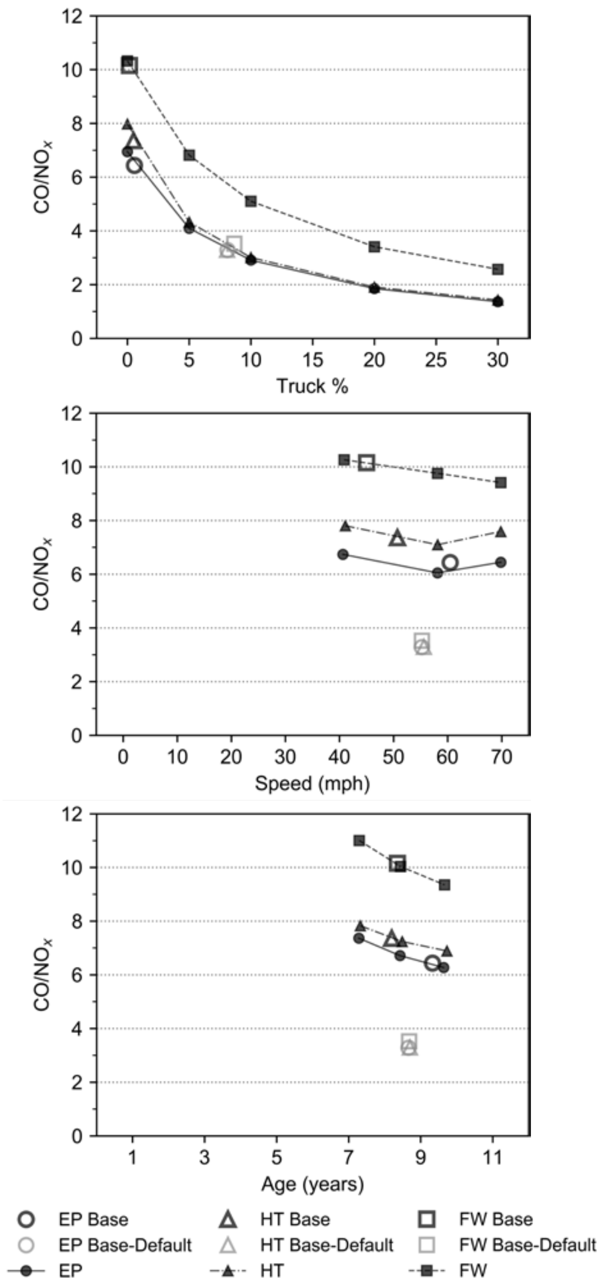

Fig. 2. Annual morning peak CO/NO_x ratios for (top) fleet mix scenarios by fleet average truck percentage, (center) vehicle speed scenarios by fleet average speed, and (bottom) vehicle age scenarios by fleet average age. Solid markers indicate the results for each sensitivity scenario using BAL data inputs for all other parameters examined.

The fleet average vehicle ages tested ranged from 7 to 10 years old. NO_x emissions increased nearly linearly with respect to fleet average vehicle age (not shown), though CO/NOx ratios decreased (Fig. 2).

Finally, using different averaging techniques to derive meteorological parameters (temperature and relative humidity) did not result in considerable changes in NO_x emissions or CO/NO_x ratios among test scenarios (not shown).

Overall, the EP, FW, and HT case studies in the emissions sensitivity analysis demonstrated the importance of replacing and improving MOVES default inputs with local data to allow a more robust assessment of on-road vehicle emissions. Among the MOVES input parameters tested in the sensitivity study, fleet mix and vehicle age distribution have larger effects than vehicle speed distribution and meteorological data on NO_x emissions estimates. Therefore, these input parameters should be of highest priority for data collection.

4. CONCLUSION

Based on 2015 ambient pollutant data and emissions estimates from MOVES, the results from this study suggest that, when appropriate local data are used, MOVES can reasonably reflect mobile source emissions. MOVES emissions-based ratios were comparable to the ratios derived from ambient measurements in reconciliation analyses. However, relying on MOVES default inputs can generate biased ratios and lead to incorrect emissions assessments and conclusions. The evaluation of the mobile source NO_x emissions inventory (e.g., the assessment of NEI in recent studies) should consider how MOVES default inputs are used and what their effect is on emissions estimates.

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