

simulation as reference, the proposed emission estimation method was evaluated. It was found that it performs better than the current practice and is capable of estimating time-dependent emissions with the presence of traffic sensor data.

It is noted that micro-simulation models may not accurately model acceleration or deceleration when compared to actual on-road vehicle activities. Although this may be a restriction of the approach, it is the only standard approach that is feasible given the limitation on obtaining real-world data. Furthermore, a calibrated simulation model was applied.

While the proposed method underestimates total emissions, the model has the potential to be further improved. The model can incorporate other ESC variables, such as driver characteristics, weather and vehicle characteristics, some of which cannot be modeled and captured by micro-simulation. In addition, the relationship between speed and ESC can be further improved by using multivariate statistical analysis techniques, such as structural equation modeling, where linear relationships between a number of endogenous and exogenous variable (as well as latent variables) can be established.

Although this paper assumes the existence of good detectors in the target network for dynamic estimation of emissions, the developed intermediate model is actually flexible enough to work with different data sources, such as probe vehicle data, historical speed data, and the speed output from travel forecasting model. If the speed data from travel forecasting model are used, the proposed model will only be restricted to provide a static

emission estimate, which may still be a better estimate than from current practice due to the involvement of other ESC variables. When advanced traffic information systems are deployed, this methodology would be readily available to better estimate emissions. Two separate models could be calibrated: one for cases when sensor speed data (or other real data) are not available and another when they are available. Furthermore, this research can be developed to include the effect of different vehicle type mixes.

It is realize that, while a fundamental problem in the modeling of emissions and energy consumption in travel forecasting is examined, the most fundamentally detailed solution is not necessarily provided (such as utilizing dynamic models). The state of the art in this area is still several years away from any practical application, due primarily to the lack of route choice and other behavioral paradigms for the dynamic domain (as well as deeper questions as to what extent dynamic equilibrium exists in the real-world). Simulation-based non-equilibrium analysis to augment travel forecasting is one option, but again this is also not an option in which the planning community has sufficient level of comfort for practical use. The proposed scheme, however, attempts to bridge the gap in a practical way, with a good understanding of the underlying theoretical problems which point to network and traffic dynamics.

The proposed method provides traffic agencies and practitioners with a way to improve emission estimates based on available data sources. The calibration of the intermediate model would be required prior to adoption in other areas. In the future, the intermediate

model can be developed as a corrective model by collecting real-world data sets for more varied types of street characteristics and traffic conditions with large data sets.

ACKNOWLEDGEMENT

The authors would like to thank anonymous reviewers of the paper for their valuable comments. The first author would also like to thank the Ford Foundation International Fellowship Program that provided support to pursue doctoral study at the University of California, Irvine.

REFERENCES

1. Andre, M., Hammarstrom, U., 2000. Driving Speeds in Europe for Pollutant Emissions Estimation. *Transportation Research Part D Transport and Environment*, 5, 321-335.
2. Barth, M., An, F., Norbeck, J., Ross, M., 1996a. Modal Emissions Modeling: A Physical Approach. *Transportation Research Record*. TRB National Research Council, Washington, D.C., 1520, 81-88.
3. Barth, M. J., E. Johnston, Tadi R.R., 1996b. Using GPS Technology to Relate Macroscopic and Microscopic Traffic Parameters. *Transportation Research Record*. TRB National Research Council, Washington, D.C., 1520, 89-96.
4. Brundell-Freij, K., Ericsson, E., 2005. Influence of Street Characteristics, Driver Category and Car Performance on Urban Driving Patterns. *Transportation Research Part D: Transport and Environment*, 10(3), 213-229.
5. California Air Resources Board (CARB)., 2002. EMFAC 2002 On-Road Emissions Inventory Model, California Air Resources Board, Presented by Mobile Source Analysis Branch, Planning and Technical support Division, El Monte.
6. Chu, L., Liu X., Recker, W., 2004. Using Microscopic Simulation to Evaluate Potential Intelligent Transportation System Strategies under Nonrecurrent Congestion, *Transportation Research Record* 1886, Transportation Research Board, National Research Council, Washington, D.C., pp.76-84.

7. Deakin, E., Harvey, G., 1993. A manual of regional transportation modeling practice for air quality analysis, National Association of Regional Councils, Washington, D.C.
8. Dion, F., Rakha, H., 2003. Estimating Spatial Travel Time using Automatic Vehicle Identification Data, Presented at 82nd Annual Meeting Preprint CD-ROM, Transportation Research Board, Washington, D.C.
9. Dowling, R., Ireson, R., Skabardonis, A., Gillen, D., Stopher, P., 2005. Predicting Air Quality Effects of Traffic-Flow Improvements: Final Report and User's Guide. NCHRP Report 535, Transportation Research Board, Washington, D.C. 165pp.
10. Fitzpatrick, K., Carlson, P., Brewer, M., Wooldridge, M., 2001. Design Factors That Affect Driver Speed on Suburban Streets. Transportation Research Record (1751): 18-25.
11. Galin, D., 1981 Speeds on Two-Lane Rural Roads - A Multiple Regression Analysis. Traffic Engineering + Control, vol. 22, No. 8/9, pp. 453 - 463.
12. Guensler, R., Washington, S., Bachman, W., 1998. Overview of the MEASURE Modeling Framework; Presented at the 77th Annual Meeting of the Transportation Research Board, Washington D.C.
13. Guo, P., Poling, A.D., 1995. Geographic Information Systems/Global Positioning Systems Design for Network Travel Time Study. In Transportation Research Record, TRB National Research Council, Washington, D.C. 1497, 135-139.
14. Hallmark, S. L., Guensler, R., Fomunung, I., 2002. Characterizing On-Road Variables That Affect Passenger Vehicle Modal Operation. Transportation Research Part D: Transportation and Environment, 7, 81-98.

15. Joumard, R., Philippe, F., Vidon, R., 1999. Reliability of the Current Models of Instantaneous Pollutant Emissions. *The Science of the Total Environment*, vol. 235, 133-142.
16. Kean, A. J., Harley, R. A., Kendall, G.R., 2003. Effects of Vehicle Speed and Engine Load on Motor Vehicle Emissions. *Environmental Science & Technology*, vol. 37, No. 17, 3739-3746.
17. Kilpelaninen, M., Summala, H., 2004. Effects of weather and weather forecasts on driver behavior. 3rd International Conference on Traffic and Transport Psychology, Finland.
18. LeBlanc, D. C., Saunders, M., Meyer, M.D., Guensler, R., 1995. Driving Pattern Variability and Impacts On Vehicle Carbon Monoxide Emissions. *Transportation Research Record*, TRB National Research Council, Washington, D.C., 1472, 45-52.
19. McLean, J. 1981. Driver speed behaviour and rural road alignment design. *Traffic Engineering & Control* **22**(4): 208-212.
20. OCTA, 2001. Orange County Transportation Analysis Model (OCTAM) 3.1: Summary Document and Validation Report, June 2001.
21. Qu, T., Rilett, L. R., Zietsman, J., 2003. Estimating the Impact of Freeway Speed Limits on Automobile Emissions. Presented at 82nd Annual Meeting of Transportation Research Board, Washington D.C.
22. Quadstone Limited, 2004. Quadstone Paramics V5.1 Monitor User Guide
23. Rakha, H., M. V. Aerde, Ahn, K., Trani, A.A., 2000. Requirements For Evaluating Traffic Signal Control Impacts On Energy And Emissions Based On

- Instantaneous Speed And Acceleration Measurements. In Transportation Research Record, TRB National Research Council, Washington, D.C., 1738, 56-67.
24. Samuel, S., Austin, L., Morrey, D., 2002. Automotive Test Drive Cycles for Emission Measurement and Real-World Emission Levels - A Review. Proceedings of the Institution of Mechanical Engineers, Part D, Journal of Automotive Engineering 216, 555-564.
25. Schrank, D., Lomax, T., 2005. The 2005 Urban Mobility Report, Texas Transportation Institute, May 2005.
26. Smith, M., Druitt, S., Cameron, G., MacArthur, D., 1994. PARAMICS Final Report. Technical Rep. EPCC-PARAMICS-FINAL, Univ. of Edinburgh, Scotland, U.K.
27. USEPA, 2002. User's Guide to MOBILE6.1 and MOBILE6.2: Mobile Source Emission Factor Model EPA420-R-02-028. United States Environmental Protection Agency.
28. Vlioger, I. D., Keukeleere, D.D., Kretzschmar, J.G., 2000. Environmental effects of driving behavior and congestion related to passenger cars. Atmospheric Environment, vol. 34, 4649-4655.
29. Wang, Y., Nancy L.N., 2000. Freeway Speed Estimation Using Single Loop Outputs. In Transportation Research Record. TRB National Research Council, Washington, D.C., 1727, 120-126.
30. 511 SF Bay Area. Website: <http://www.511.org/> Accessed on 26th January 2006.

LIST OF FIGURES

FIGURE 1 Fundamental diagram of traffic flow

FIGURE 2 Driving profile of (a) I-405, (b) I-5, (c) Campus Dr, and (d) Culver Dr

FIGURE 3 Relationship between link speed and ESC

FIGURE 4 Proposed method to estimate emissions

FIGURE 5 Schematic diagram of evaluation procedure

FIGURE 6 Overview of the study network

FIGURE 7 Model validations

FIGURE 8 Time-dependent emission pollutants during the morning peak period

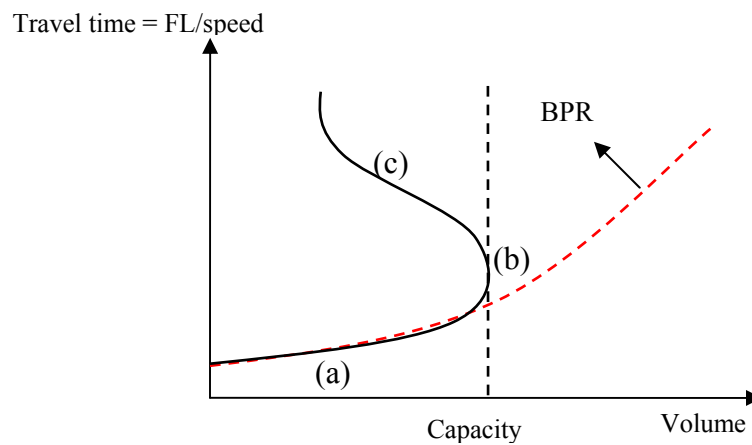


FIGURE 1 Fundamental diagram of traffic flow

Note: FL = Facility length

BPR = Bureau of Public Roads

(a) = indicates low flow, low density and low travel time

(b) = indicates curve turn back and goes to infinity

(c) = indicates low flow, high density and high travel time.

Travel time is estimated using following equation:

$$tf = t_0 * (1 + \alpha * (V/C)^\beta)$$

Where, tf – Final congested link traversal time

t_0 - link traversal time at free flow speed

V – Link Volume/flow in veh/hr/lane

C – Link Capacity

α – Coefficients (0.15)

β – Exponent (4.0)

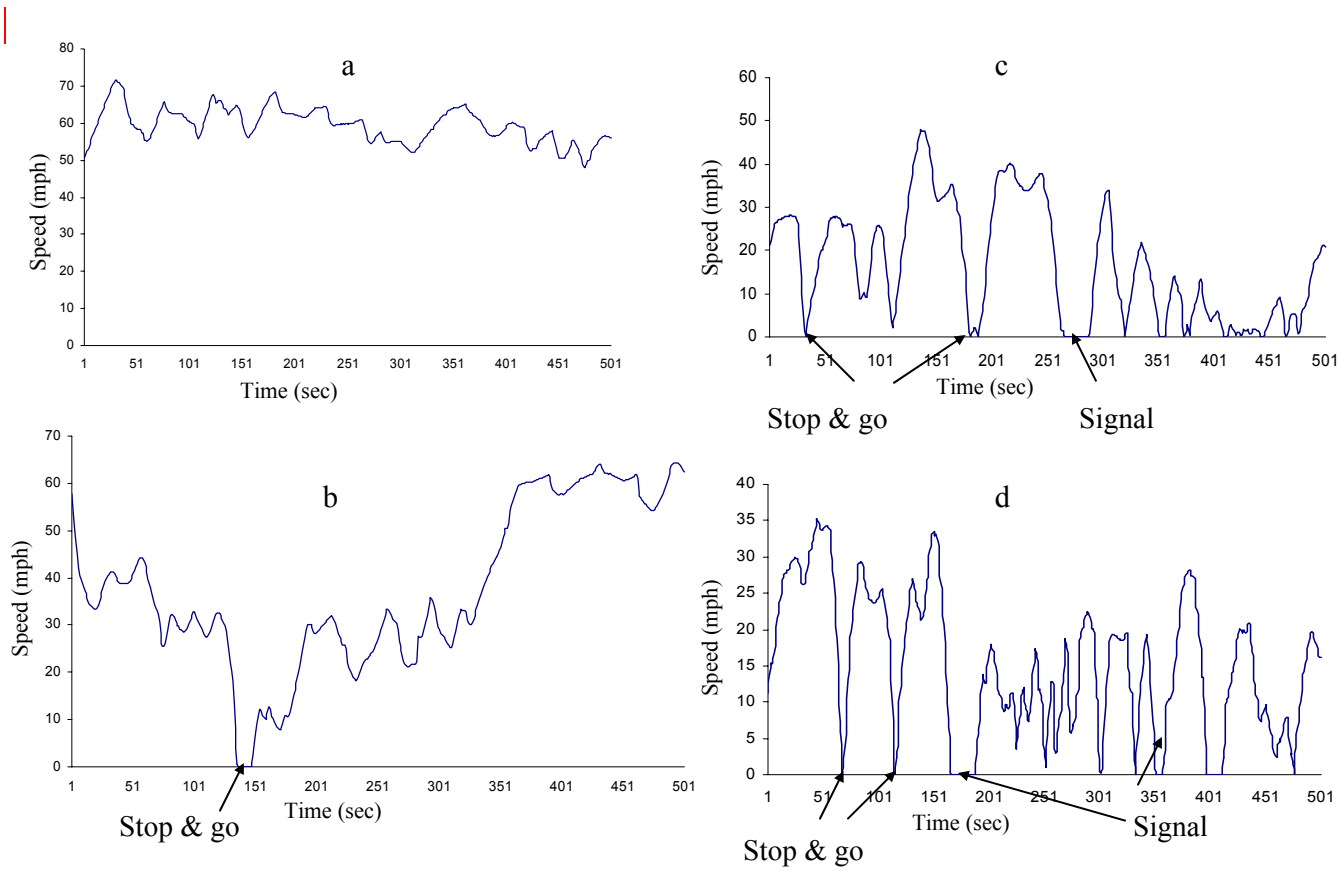


FIGURE 2 Driving profile of (a) I-405, (b) I-5, (c) Campus Dr, and (d) Culver Dr

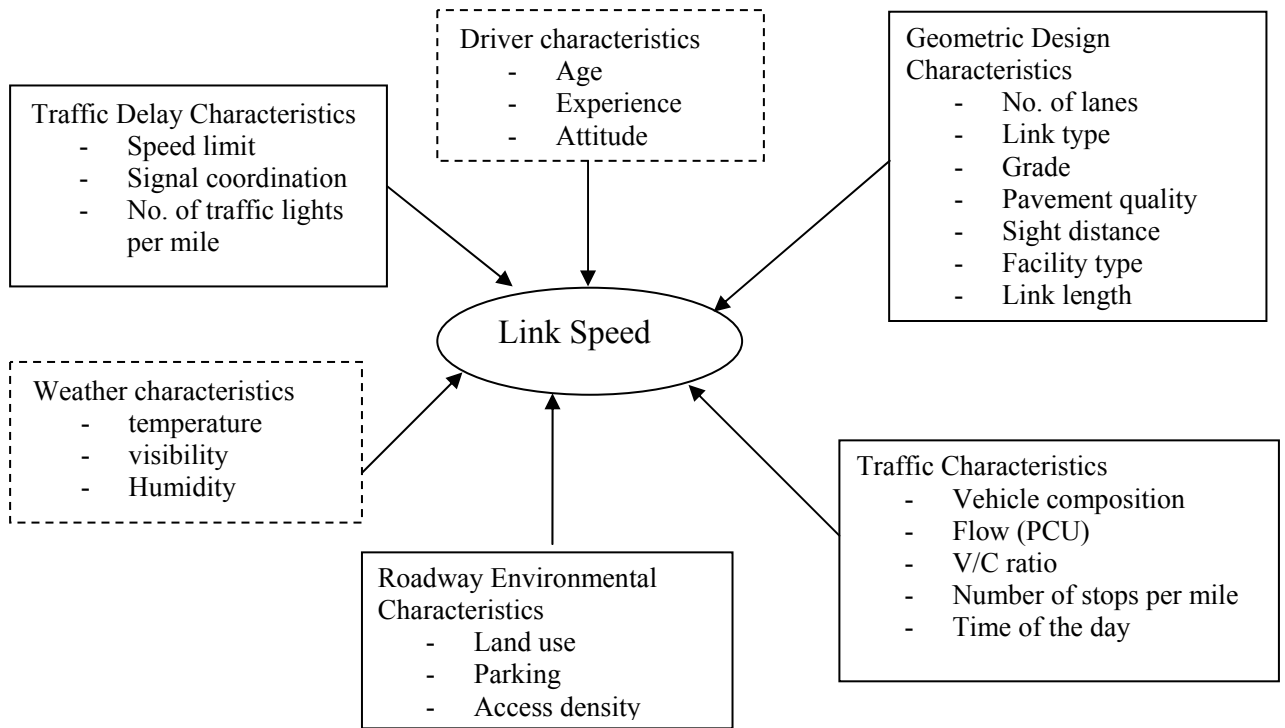


FIGURE 3 Relationship between link speed and ESC

Note: Variables inside the dotted boxes are not used in this study.

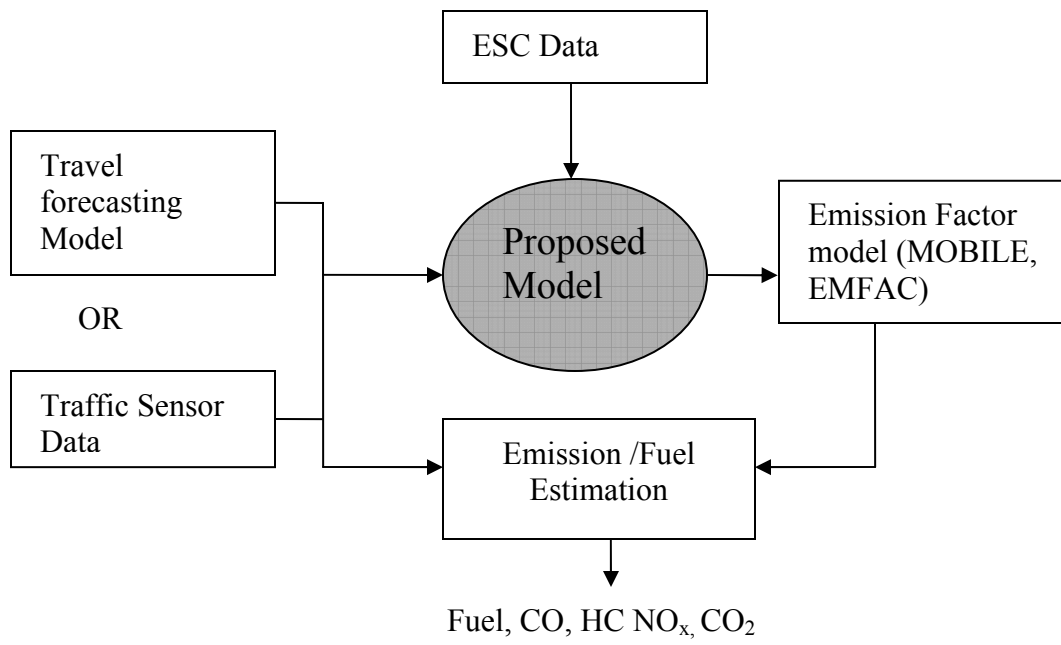


FIGURE 4 Proposed method to estimate emissions

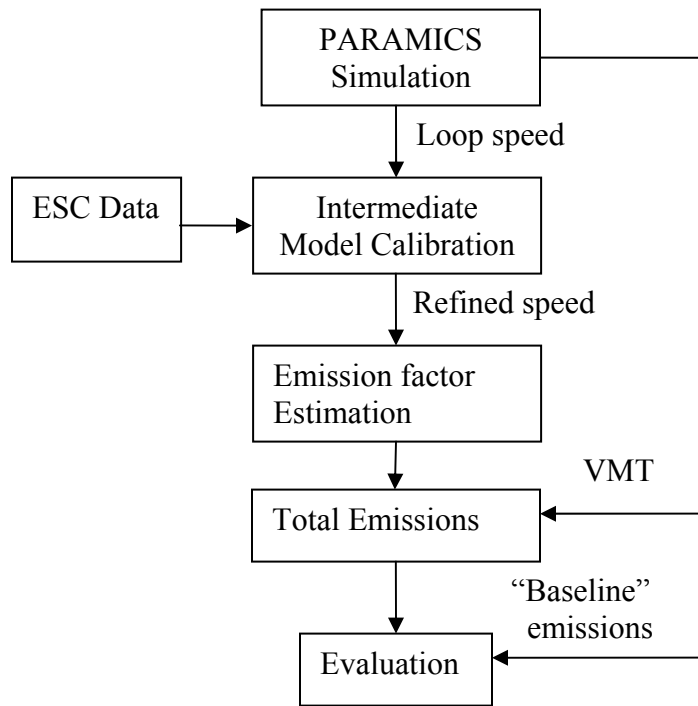


FIGURE 5 Schematic diagram of evaluation procedure

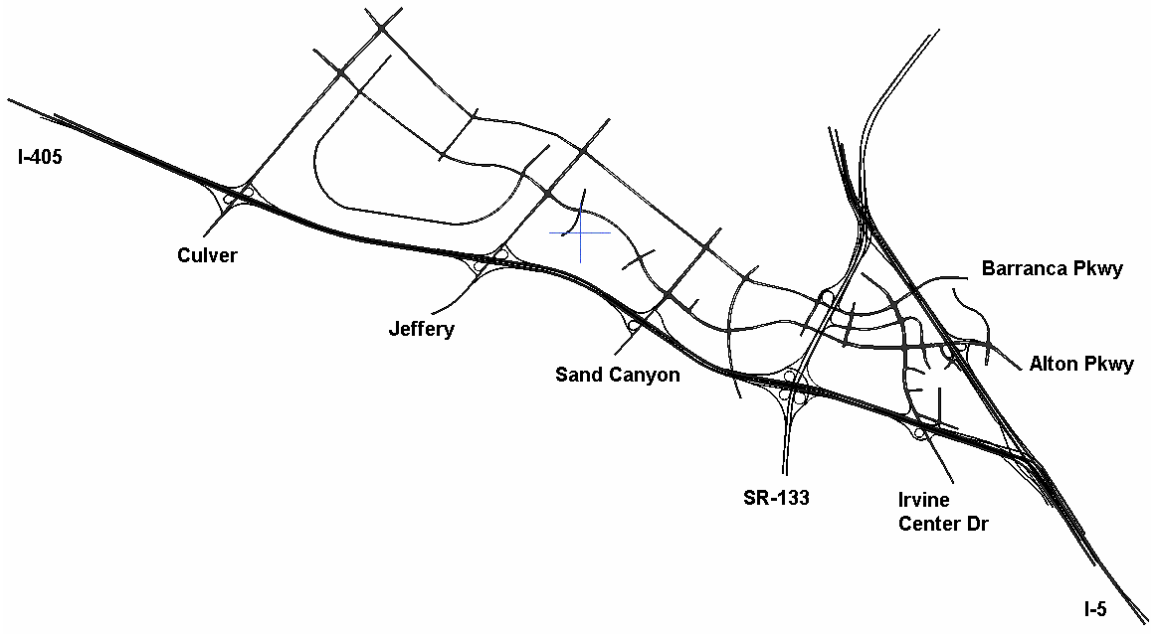


FIGURE 6 Overview of the study network

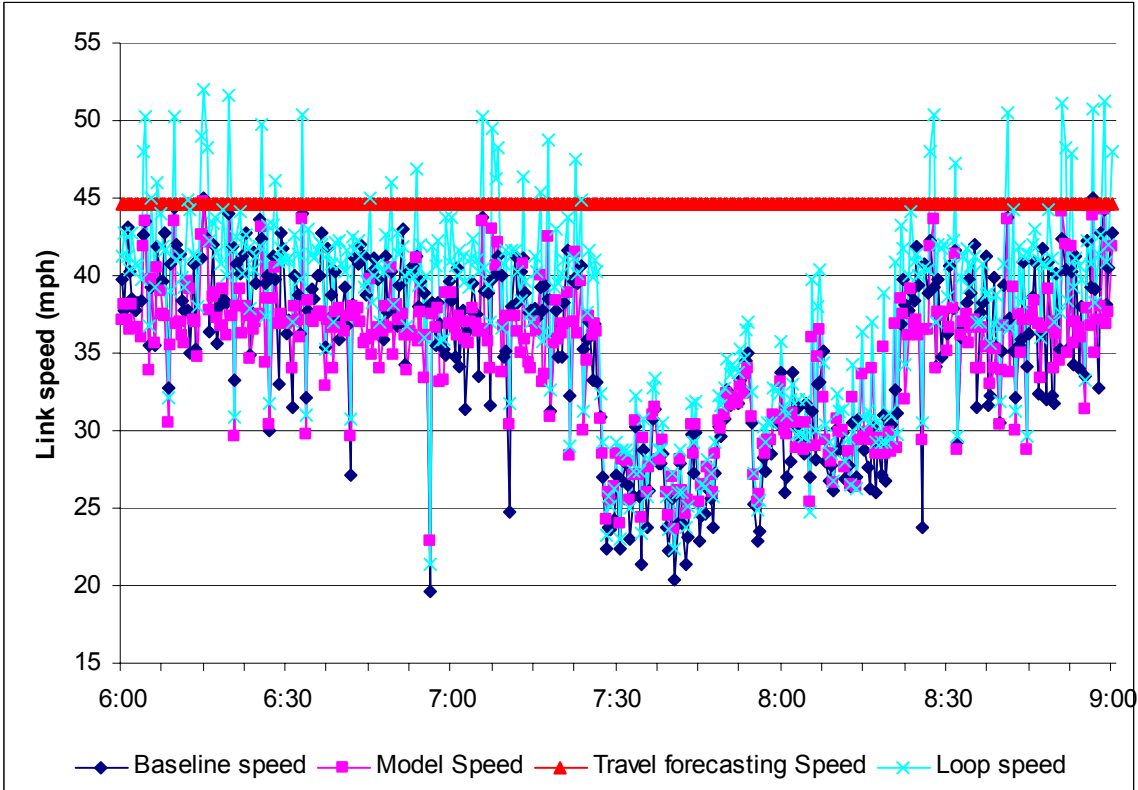


FIGURE 7 Model validation

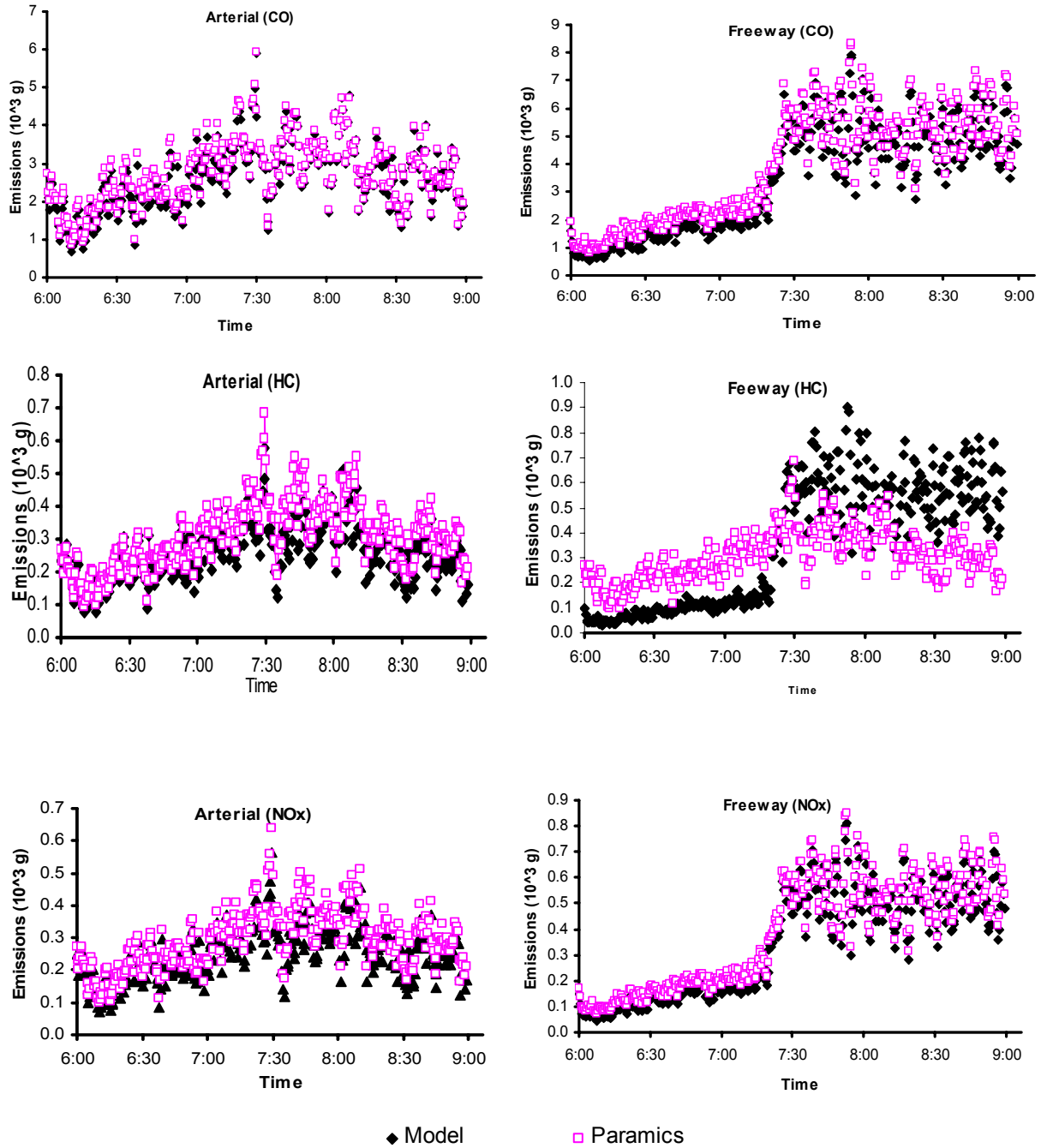


FIGURE 8 Time-dependent emission pollutants during the morning peak period

LIST OF TABLES

TABLE 1 Summary of variables considered for analysis

TABLE 2 Regression model to estimate refined link speed

TABLE 3 Comparison of total emissions and average link speeds of selected links

TABLE 1 Summary of variables considered for analysis

<p>Geometric Design</p> <ul style="list-style-type: none"> • Number of lanes: Ranging from 2 to 6 in each direction • Pavement quality: 0- bad quality; 1- Good quality • Link type: 1- curved; 0- straight • Facility type: 1 – freeway, 0 – otherwise 1 – arterial, 0 – otherwise 1 – ramp; 0 - otherwise • Presence of bike paths in arterial streets: 0-No; 1-Yes
<p>Traffic Characteristics</p> <ul style="list-style-type: none"> • V/C ratio: ranging from 0.3 to 1.1 • Loop Speed: ranging from 12 to 84 mph • Travel forecasting speed: ranging from 3.4 to 60 mph • Loop Volume: 0 to 11520 vph per direction
<p>Traffic Delay Characteristics</p> <ul style="list-style-type: none"> • Time of the day: 0 – off-peak period; 1- peak period • Presence of stop sign in the link: 0 – No; 1-Yes • Presence of traffic signal: 0-No; 1-Yes • Speed limit: Ranging from 25 mph to 65 mph
<p>Roadway Environmental Characteristics</p> <ul style="list-style-type: none"> • Landuse: <ul style="list-style-type: none"> 1 – residential, 0 - otherwise 1 - commercial, 0 - otherwise 1 - mixed landuse, 0 – otherwise. • Access density: ranging from 0 to 11 intersections per mile

TABLE 2 Regression model to estimate refined link speed

Variables	Coefficient	P-values
Loop speed	0.714	0.000
Speed limit	0.51	0.000
Mixed landuse	2.46	0.032
Link type	3.84	0.006
Link length	12.83	0.002
Access density	-1.34	0.003
Constant	-21.62	0.000
N – 1400; R ² – 69.96%; Adj. R ² – 69.5%		

TABLE 3 Comparison of total emissions and average link speeds of selected links

Link	Link Type	Loop Speed ¹ (mph)	Travel forecasting Speed ² (mph)	Model Speed ³ (mph)	Paramics Total Emissions ⁴ (10 ³ g)			Travel forecasting Total Emissions ⁵ (10 ³ g)			Model Total Emissions ⁶ (10 ³ g)		
					VOC	CO	NO _x	VOC	CO	NO _x	VOC	CO	NO _x
8:10	Freeway	53.0	60.0	54.8	439	3920	401	423	3910	401	426	3924	402
10:12	Freeway	35.3	60.0	36.2	2	19	2	2	18	2	2	20	2
188:222	Freeway	44.7	60.0	48.7	2	23	3	2	23	2	2	23	3
144:138	Arterial	22.4	41.5	23.2	89	764	79	85	743	77	89	757	79
233:121	Arterial	26.1	44.1	28.4	15	139	14	12	126	13	15	137	15
149:121	Arterial	27.5	41.9	29.2	3	27	3	2	26	2	3	27	3
62:138	Arterial	23.8	41.4	25.6	30	326	34	24	325	34	29	323	33
264:20	Ramp	34.4	41.1	37.7	22	178	19	21	174	16	22	170	18
318:320	Ramp	29.3	41.1	29.5	6	50	5	5	47	5	6	50	5

Note:

¹ Estimated from a PARAMICS simulation

² Estimated from OCTAM 2001 travel forecasting model

³ Refined speed from intermediate model

⁴ Calculated using PARAMICS plug-in with simulated link speed as inputs

⁵ Calculated using MOBILE with link speed from travel forecasting model

⁶ Calculated using MOBILE with refined speed from intermediate model