Emissions Models as a Design Tool for Urban Transportation Planners

Daniel Handford and M. David Checkel

Abstract Urban transportation is a significant contributor of greenhouse gas emissions. Despite this, transportation planning projects are generally not optimized directly for greenhouse gas emission reduction because there are few practical tools available that quantify the impact of specific project features. Ideally, physics-based micro-simulations would be used to evaluate project features within large-scale networks to properly capture local driving behavior and extended traffic shifting effects. This is generally not practical because micro-simulations require excessive computational resources. A transportation emissions model, which includes a simplified micro-simulation, is described. This model micro-simulates transportation emissions across large-scale networks such that emissions from a metropolitan region can be calculated for multiple design options in a few hours on a personal computer. A variety of case studies are presented which demonstrate the utility of practical large-scale micro-simulations for transportation emissions. The requirement for large-area models is shown by scenarios which demonstrate traffic shifting effects due to local changes in network capacity.

Keywords Micro-simulation · Emissions · Transportation · Design · Traffic

1 Introduction

Urban transportation planning is typically focused on optimizing the capacity and safety of transportation systems. While realizing these goals is often thought to achieve reduced exhaust emissions, the environmental impacts of planning

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activities are rarely measured or modeled. This is because of a lack of practical and available tools to quantify the environmental impacts of transportation design. The critical requirement is the measurement and evaluation of environmental impacts of transportation improvement plans. If they can model the environmental impacts of transportation improvement plans, urban transportation planners can significantly reduce climate-changing emissions through appropriate transportation planning and infrastructure design.

The significance of climate-changing emissions from transportation sources is amplified in urban regions. To illustrate, transportation emissions account for 17 % of Canadian greenhouse gas (GHG) emissions (Environment Canada 2010). However, transport sources are more important within cities, contributing about 29 % of total GHG emissions for Edmonton (Bailie and Beckstead 2010) and 27 % for Calgary (The City of Calgary 2011). There are several reasons for this but urban congestion and inefficient traffic patterns are significant contributors. Urban transportation planners develop infrastructure and improve traffic control measures to reduce congestion and this is generally known to reduce emissions. However, most transportation modeling tools do not accurately measure the emissions impact of traffic behavior and thus provide little or no guidance in designing infrastructure or traffic control to reduce emissions. Realistically, to measure the impact of traffic planning on emissions, one requires detailed transportation models that work at the link and sub-link level to measure vehicle behavior as influenced by infrastructure features and traffic controls while also working at the whole- network level to account for the re-distribution of traffic over an entire multi-mode transportation network. Micro-simulation models are required to appropriately model infrastructure features, traffic controls and driver behavior at the link or sub-link level. Simultaneously, modeling must be extended across large-scale regions to accurately account for traffic displacement across other network links and across transportation modes. However, modeling an entire multi-mode transportation network with a micro-simulation is typically impractical due to the computational resources required. While the concept is theoretically possible using a supercomputer, it could only be justified as a research project rather than being routinely applied to optimize transportation system designs.

This chapter describes a traffic emissions modeling tool designed specifically to provide consistent and representative emissions data while operating over a range of transportation models from macro to micro. The tool includes vehicle tractive power and emissions sub-models developed for a range of vehicle types as well as multiple fuel types and energy sources and calibrated over a range from 1990 historical fleets through projected future fleets to 2050. The emissions sub-model can calculate emissions outputs based on the tractive power sub-model's internally generated speed trace or based on external speed traces generated by independent micro-simulation traffic models. More importantly, to provide useful emissions outputs for macro traffic models, the emissions tool has a micro-simulation vehicle motion generator efficient enough to produce vehicle motion models appropriate to each vehicle type on each link of a whole-region traffic simulation. Emissions are evaluated and stored at a link-level resolution so results can be displayed as mapbased graphics, providing strong visual feedback on where emissions effects are produced. This enables transportation planners to efficiently evaluate the GHG implications of infrastructure and transportation improvement plans, and allows them to use GHG emissions as a performance measure in their design decisions.

The emissions modeling tool is demonstrated through case studies that illustrate the effects of Policy, Infrastructure, and Traffic Control. Each case study discusses the options available and shows the use of GHG emissions modeling as a design optimization tool.

2 Background

The two most common types of transportation models are four-step models and micro-simulations. Four-step models are macro scale models used to estimate the load or demand that traffic will place on a network and the distribution of that load across network links. Micro-simulations, on the other hand, are used to estimate the capacity of a part of a network by directly modeling vehicle motions and interactions.

Four-step models model the demand characteristic of networks, and generally provide results that include the flow rate and average speed or delay on each link. GHG calculations applied to four-step model results are typically sets of emission factors known as Vehicle Kilometer Traveled (VKT) models, so named because they multiply the number of kilometers traveled by a weighted emission factor in units like kgCO2e/km. This type of analysis generally cannot capture the effects of local design features and driving behavior. Thus, even though a four-step model can provide link level resolution, it cannot be used to accurately predict emissions at the link level, particularly as a function of unique link characteristics. VKT models are most appropriate when applied to the entire network as an aggregated entity (Smit et al. 2008; Barth et al. 2001).

Micro-simulations generally model each vehicle on the part of the network being simulated, including the interactions between neighboring vehicles and possibly the effects of local infrastructure features on driving behavior. This produces a highly detailed record of events on the links being simulated and the result is that even for small networks or parts of networks, the computational effort required of a micro-simulation is large. The level of detail is helpful for emissions modeling because driving behavior can be appropriately modeled and emissions can be allocated geographically. However, simulations at sufficiently large scale to include traffic displacement across the network are generally not practical for day-to-day transportation planning and design activities (Handford and Checkel 2011).

The model described in this chapter uses a hybrid approach. Four-step model-based results for a whole network are used as the basis to generate representative micro-simulations on each link. These micro-simulations are then used to model fuel consumption and emissions. This methodology resolves emissions at the link level, captures driving behavior as affected by congestion and link design features, and also captures traffic shifting since large networks can be simulated. It allows for very large-scale analysis with micro-simulation accuracy while running rapidly enough on conventional desktop computers to provide for practical, day-to-day analysis of transportation design options.

3 Model Description

This section outlines the structure of the model, as well as the methodologies used in the sub-models.

3.1 Model Structure

The modeling tool used for this study consists of three parts or sub models; a simplified micro- simulation model, a tractive power model, and a power-based emissions model. The simplified micro-simulations use four-step Transportation Demand Model (TDM) link volume and speed results as inputs so the micro-simulations can be based on a macro-scale TDM analysis that accounts for traffic distribution across the network. The micro-simulations model generates appropriate vehicle speed traces or trajectories for each class of vehicle on each link and these are then passed to the tractive power model. Vehicle power is calculated at each time step in each trajectory and passed to the emissions model. That model uses power-based functions, (calibrated for vehicle type, year and ambient conditions), to calculate the fuel/energy consumption and emission rate at each time step. The inventory tool can then integrate over the trajectories, and sum the results for each vehicle type and link as well as creating network-wide inventories.

As an alternative starting point, speed trace data from experimental data, micro-simulations such as VISSIM or user defined vehicle trajectories can be used as input to the tractive power model. While such data sets typically don't cover a sufficient network area for whole-region analysis, this flexibility of inputs allows for a direct comparison between conventional, interaction-based micro-simulations such as experimental data, PTV's VISSIM model and the built-in simplified micro-simulation model. Figure 1 shows a flow chart for this model's application using the simplified micro-simulation and for use with other user-defined vehicle trajectories.

3.2 Simplified Micro-Simulation

The simplified micro-simulation model generates realistic vehicle trajectories for each vehicle type on each link being modeled, based on input provided by results from a macro-scale TDM, (such as EMME for example). Figure 2 shows the

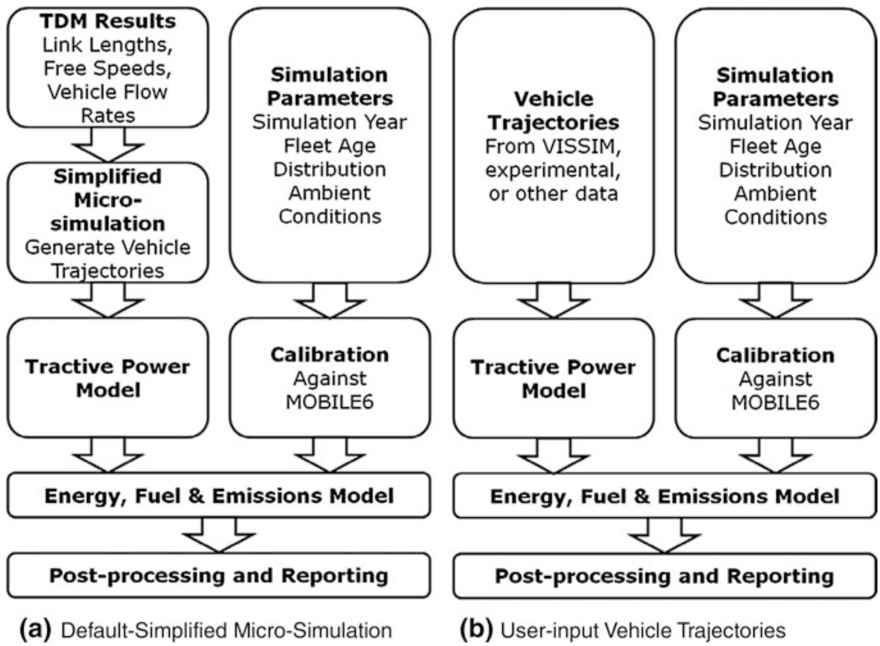

Fig. 1 Simulation flow chart. The emissions tool by default uses four-step travel demand model (*TDM*) results to generate vehicle trajectories (**a**), or can model the emissions based on vehicle trajectories specified by other means (**b**)

Fig. 2 Inputs and outputs for the simplified micro-simulation

inputs and outputs of the simplified micro-simulation. Rather than model each individual vehicle interacting with neighboring vehicles, the simplified micro-simulation finds a vehicle trajectory that satisfies the link length and average speed, while attempting to follow rules which emulate real traffic. For example, vehicles will attempt to travel at the free speed, and will slow or stop as necessary to make the average speed correspond to the specified delay on that link. This method has several advantages for simulating transportation emissions. The use of vehicle trajectories rather than average speeds or other aggregated network parameters means that driving behavior and vehicle power demand can be modeled appropriately, including using link-specific parameters like speed limits, gradients and the like. The use of a single vehicle trajectory for each class of vehicle on each link rather than modeling each vehicle and its interactions with others makes the simulation fast enough to be run on conventional computers, even when considering multiple design options or parameter optimizations. The vehicle trajectories, once generated by the simplified micro-simulation or entered as user-defined parameters, are passed to the tractive power model.

3.3 Tractive Power Model

The tractive power of each vehicle is calculated at each time step of the vehicle trajectory. It is a function of the vehicle trajectory (acceleration and speed), of link parameters (like gradient) and of class-specific vehicle properties, (frontal area, drag coefficient, rolling resistance coefficient, and mass). Tractive force is calculated as the sum of the forces required to overcome the vehicle's resistance to motion and to provide the acceleration. Tractive power is the product of the tractive force and vehicle speed. A physics-based model following that of Sovran and Bohn (1981) is used as the basis for vehicle tractive force. This model includes rolling resistance, aerodynamic drag resistance, and acceleration:

$$F = M\frac{dV}{dt} + R + D$$

where F is the tractive force, V is the vehicle speed, M is the vehicle mass, R is the rolling resistance, and D the aerodynamic drag. Rolling resistance and drag are further described by:

$$R = (r_0 + r_1 V)Mg$$

$$D = C_D A \frac{V^2}{2}\rho$$

where r_0 and r_1 are static and speed-variable coefficients of rolling resistance, V the vehicle velocity, g the acceleration of gravity, C_D the drag coefficient, A the vehicle frontal area, and ρ the density of the air through which the vehicle travels. Many models assume that rolling resistance is not a function of speed and set r_1 equal to zero (Society of Automotive Engineers 2003; Heywood 1988); this assumption is generally valid for speeds less than 110 km/h and is used in the proposed model. Ultimately, the tractive power model takes the following form:

$$P = M\frac{dV}{dt} + (r_0 + \sin\theta)Mg + C_D A \frac{V^2}{2}\rho$$

where θ is the angle representing the slope of the roadway.

3.4 Fuel Consumption and Emissions Model

The vehicle tractive power trace is used to calculate the instantaneous emission rate of each pollutant through a set of fuel consumption and emission functions. The functions used are based on correlations to chassis dynamometer testing done at the University of Alberta (Busawon and Checkel 2006; Checkel 1996). The functions return fuel consumption and emission rates in units of g/s given inputs of power p, in kW, and vehicle speed v, in m/s, and molar mass M. Carbon dioxide is calculated based on the conservation of the mass of carbon in the fuel and the exhaust, allowing for carbon monoxide and unburned hydrocarbons. The fuel consumption and emissions functions are calibrated to the MOBILE6 dataset based on:

- vehicle class and fuel type
- simulation year and ambient temperature
- fleet age distribution
- electricity supply properties (for grid-charged plug-in-hybrids and electric vehicles)
- hybrid and electric vehicle market shares.

The data sources used to calibrate the fleet are selected based on availability and relevance. Canadian fleets, (as modeled in the studies presented here), are calibrated to:

- the MOBILE6 model for emissions sources including running, evaporative, cold start, and brake and tire particulates
- the NRCan transportation database for fuel consumption
- the market share estimates of NRCan, and
- electric grid emission factors from LCA (Life Cycle Asssessment) studies for the relevant grid.

This calibration allows for an accurate representation of user-defined vehicle fleets; it also allows users to investigate the impacts of changes to the vehicle fleets such as might occur with technological changes or policy initiatives like green incentives.

4 Case Studies

The model described here is used to calculate emissions for various simulation scenarios. The scenarios include changes to the vehicle fleet composition, changes to transportation infrastructure, and changes to traffic control measures. These scenarios demonstrate the utility of using large-scale transportation micro-simulation to estimate emissions.

4.1 Case Study of Policy Application

The first two scenarios presented investigate the potential effectiveness of using publicly funded incentive programs to reduce the GHG emissions of the vehicle fleet. One scenario considers the use of incentives to encourage scrapping old vehicles (>10 years) in favor of new vehicles; the other considers the use of similar incentives to encourage the purchase of hybrid vehicles rather than conventional gasoline vehicles. The two scenarios both model three-year programs beginning in a major Canadian municipality (Edmonton) in 2013, with the incentive set at $3,000 per vehicle. Essentially, a limited number of drivers are given a monetary incentive in the amount of $3,000 if they chose to participate in the program by purchasing a new vehicle with reduced GHG footprint. The programs are assumed to have an incentive budget of $45,000,000 and thus provide incentives to 15,000 vehicle owners, distributed evenly over the three years to 5,000 vehicle owners per year. These scenario conditions allow for a comparison between the two hypothetical incentive models and demonstrate the utility of modeling emissions with a dynamic fleet. These alternatives are chosen to illustrate that this type of analysis can be used to inform policy makers of the effectiveness of such public programs.

The base case for both scenarios is a macro-scale TDM for the City of Edmonton on a typical fall weekday. It is estimated that there are approximately 746,000 active light duty vehicles and that 37,300 of those are new vehicles. The traffic demand is assumed to increase at a rate of 2 % per year and this analysis does not account for any increases in road capacity.

The first scenario models accelerated scrappage rates using new vehicle purchase incentives. For each of the three program years (2013–2015), an additional 5,000 new vehicles are introduced into the fleet, and 5,000 vehicles aged more than 10 years are retired. It is assumed that there would be sufficient demand for the incentives. Figure 3 shows the evolution of the fleet age distribution from the base year through to 2018.

The second scenario models the introduction of a hybrid vehicle incentive program. For this scenario, the fleet age distribution remains unchanged, but for each of the three years of the program (2013–2015), the number of new hybrids brought into the fleet is increased by 5,000 as a result of the incentive program.

The results of these new vehicle incentive studies are shown in Fig. 4. The introduction of more efficient technologies with fleet turnover is expected to lower CO2 emissions for a fixed amount of traffic but the rising trend of the baseline case shows that this is overcome by the anticipated 2 % yearly increase in traffic demand. Both the scrappage and hybrid incentive programs have the potential to reverse that trend and reduce the overall CO2 emissions over the three-year program period. For the parameters chosen, the hybrid incentive program provides a greater effect CO2 emissions than the scrappage program. The anticipated end of the programs in 2015 results in an upward inflection in their emission trends as the

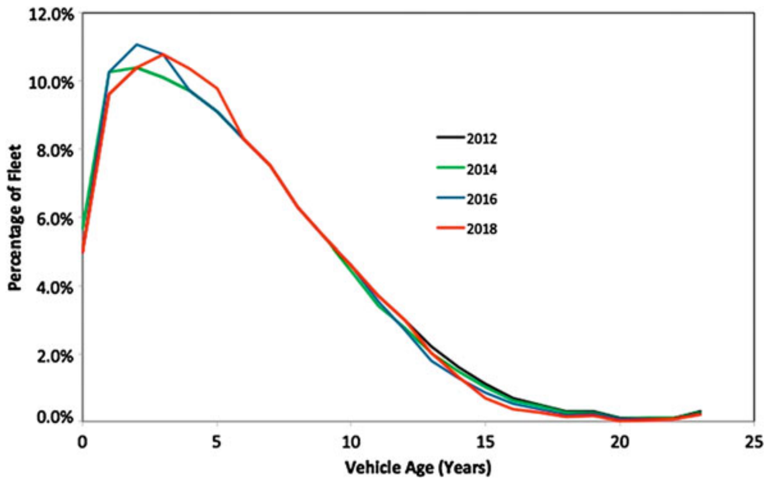

Fig. 3 Fleet age distribution for scrappage incentive program starting in 2013

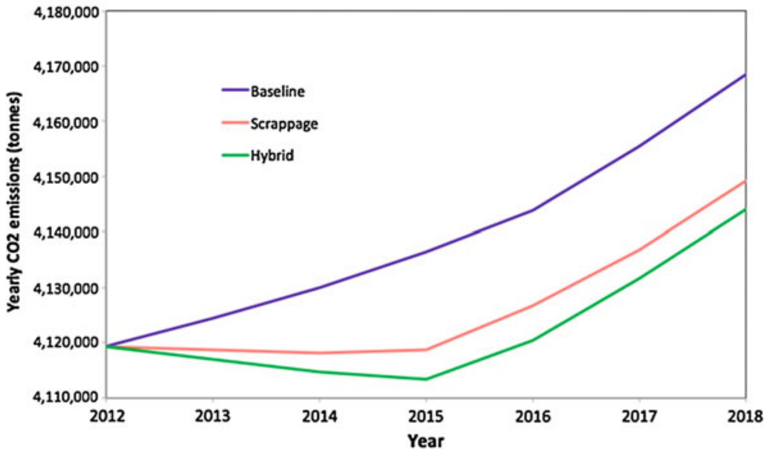

Fig. 4 Effect of two incentive programs on estimated yearly tailpipe CO2 emissions in Edmonton for light duty vehicles. Baseline model reflects normal fleet replacement rates combined with a 2 % increase in traffic per year

fleet continues to turn over and age with replacement strategies reverting to the baseline conditions.

In general the objective of policy makers is to mitigate the largest quantity of GHG possible for their given budget. This type of analysis lends itself well to this goal; the program budget and emissions mitigated can be used to calculate the cost of reducing GHG's on a $/tonne basis, and then compared to alternative projects. The cost effectiveness of the programs outlined in these studies is summarized in

Table 1 Estimated CO_2 emissions savings for the scrappage and hybrid models, and their cost effectiveness over the three years of the program and three concurrent years

	Scrappage Model (kg)	Hybrid Model (kg)
2012	–	–
2013	5,860	7,550
2014	11,800	15,300
2015	17,700	23,100
2016	17,200	23,500
2017	18,700	23,900
2018	19,100	24,300
Total (6 years)	*90,300*	*118,000*
Program cost	*$45,000,000*	
Mitigation cost ($/tonne)	*$498*	*$382*

Table 1 for the assumed parameters, the hybrid incentive scenario at $382 per tonne is more effective than the scrappage incentive scenario at $498 per tonne. However, both programs are relatively expensive compared to typical carbon prices ranging around $15 per tonne based on energy conservation programs. The ability to estimate the emissions savings and cost effectiveness of potential GHG reduction programs allows policy makers to compare different concepts and use their budgets as effectively as possible.

4.2 Case Studies in Infrastructure Design

This case studies the emissions effects of infrastructure changes by investigating the closure of a major urban bridge. The study illustrates the importance of large-scale simulations that capture traffic shifting effects as well as local congestion.

The study focuses on the effects of closing a bridge on a major artery into the downtown zone of Edmonton, Canada. Figure 5 shows maps of link-based specific emission rates for the two scenarios: (a) with the bridge open, and (b) with the bridge closed. The primary consequences of a bridge closure are that traffic must use alternative river crossings, and that the increased loading will cause congestion at these points. A secondary effect is that some travelers will choose alternate modes of transportation such as public transit and the vehicle kilometers traveled on the network will decrease. This mode-shifting effect is captured by mode choice model implemented in the four-step TDM used to generate the two cases. These suspicions are confirmed by the results shown in Table 2. The importance of traffic shifting and the necessity of large-scale modeling is illustrated by presenting results for a range of study boundary radii. While the regional model does not show a significant change in average speed, travel (VKT), or GHG emissions, the traffic volumes within a 0.5–1 km radius of the bridge are significantly lower, and vehicle travel is both slower and less efficient. The results indicate that, for this

Table 2 Relative increase of GHG emissions, average speed, and traffic (VKT) for the bridge closure scenario

	Relative increase due to bridge closure			
Radius (km)	GHG (kgCO2e) (%)	Average speed (kph) (%)	VKT (%)	GHG (gCO2e/VKT) (%)
0.5	−63.7	−11.1	−67.4	11.3
1	−12.5	−2.5	−19.4	8.6
1.5	−4.2	−3.4	−7.8	3.9
2.5	*−1.7*	*−0.6*	*−2.8*	*1.2*
5	−0.7	−0.5	−0.9	0.3
10	−0.1	−0.1	−0.1	0.0
Region	−0.1	0.0	0.0	0.0

The bridge is at the center of the expanding radius that bounds the simulation

case, a minimum radius of 2.5–5 km from the closed bridge would be required to capture traffic shifting effects, mostly of traffic onto alternative bridges. (This radius would be different for other cases depending on the traffic volume crossing the bridge and the capacity and proximity of alternative routes). In this case, the displacement of some vehicle trips to light rail transit roughly balanced the increased distance traveled by vehicles detouring around the closed bridge so, on a city-wide basis changes in vehicle mileage and CO2 emissions were minimal. This result would have been difficult to foresee and to confidently predict without the capability to model both traffic and emissions on a whole-network basis.

4.3 Case Studies in Traffic Control Measures

The following two scenarios relate to traffic control measures; increasing the speed limit on a major freeway, and changing from signalized intersections to free flowing interchanges on a ring road. Each of these case studies includes a baseline case and the altered case where, effectively, the capacity of a major artery is increased and traffic is likely to shift towards that artery. These case studies demonstrate the advantages of large-scale micro-simulation models for a complete understanding of the transportation issues being modeled.

In the first case study, a major suburban freeway crosses a metropolitan region outside the inner core in the East-West direction. The speed limit is 80 km/h (kph) baseline, and the effects of an increase to 90 kph are studied. With lower travel time on the freeway, some traffic that would otherwise use nearby roads is attracted to the faster flowing freeway. The problem is studied using three boundaries to demonstrate the importance of large-scale modeling. The narrowest boundary is only the freeway, the second includes roads in the immediate vicinity and the largest includes the entire metropolitan region. The three boundaries are shown graphically in Fig. 6. Figure 6 also illustrates the resulting link traffic

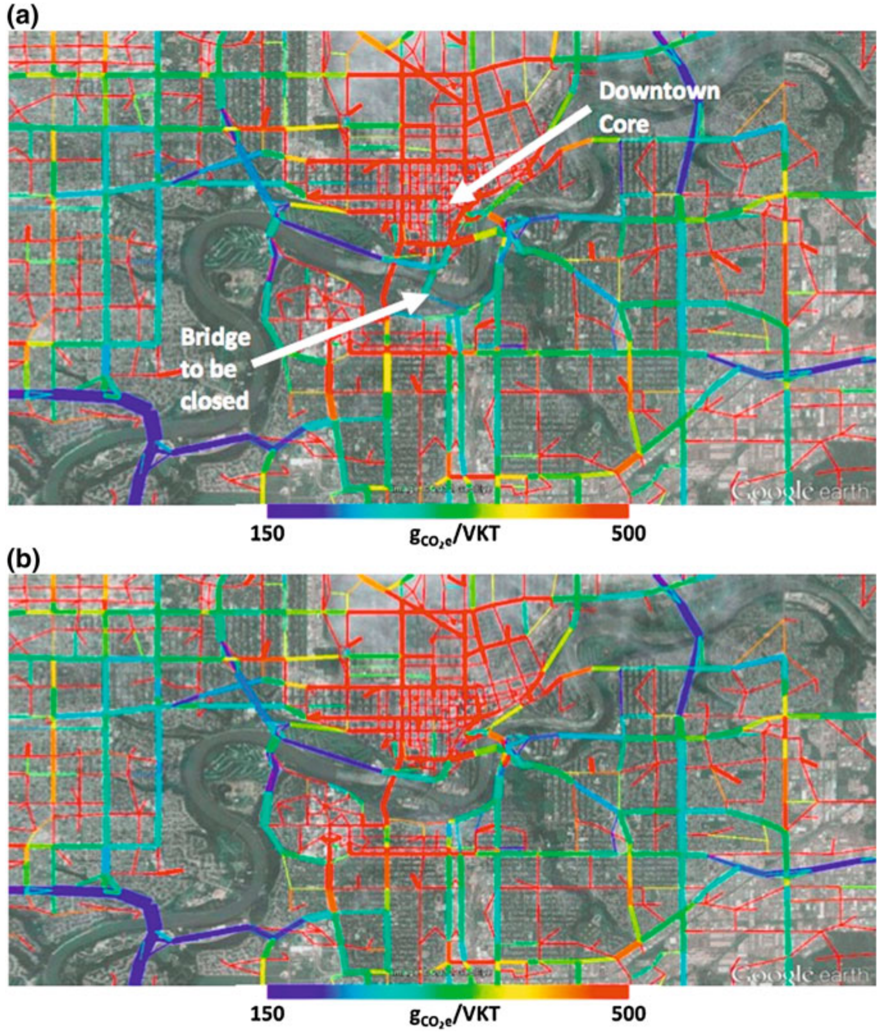

Fig. 5 Bridge closure case study models showing distance specific GHG emissions: **a** is the base case with the bridge open, and **b** is the case with the bridge closed. Line width shows traffic volume, and color shows CO2 specific emission rate (see *scale*)

volumes (as line width) and the specific CO2 emission rates (as line color). Table 3 provides numeric results for the three different boundaries.

Considering only the freeway, a higher speed limit produced faster travel (by 5 %) and a marginally lower specific CO2 emission rate (by 1 %) because of vehicle efficiency and smoother flow. However, the increased traffic on the link (up by 7 %) raised overall CO2 emissions along the freeway by 6 %.

The extra traffic using the freeway is displaced off lower-speed, less-efficient links but must also drive further to access the freeway. Does this result in greater

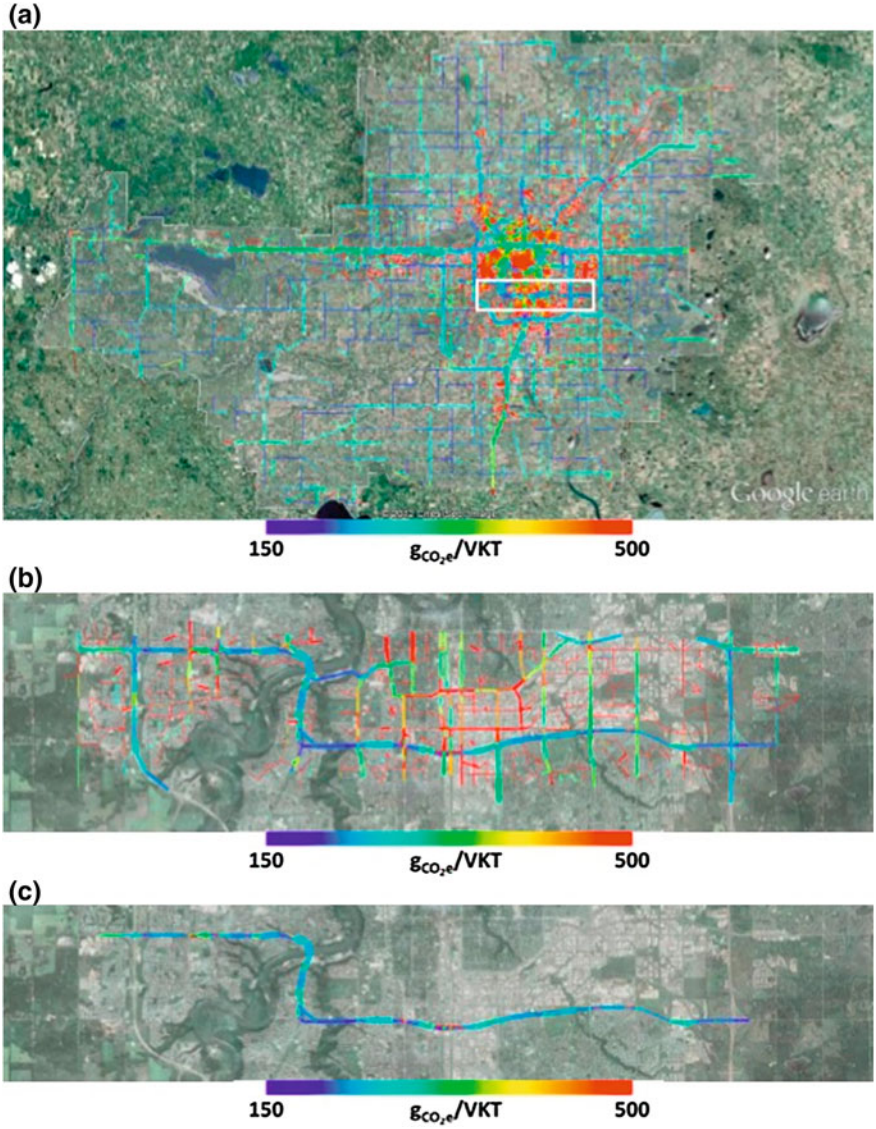

Fig. 6 Baseline case with 80 kph speed limit, showing the model boundaries: **a** Metropolitan region with freeway vicinity shown in *white box*, **b** Freeway and vicinity links, and **c** Freeway only

or lesser CO2 emissions? The study is repeated with broader boundaries to capture the effects of traffic displacement. At the freeway + vicinity level, overall travel rises by 2 % with a corresponding 1 % increase in CO2 emissions. This now covers about 3 times as much travel as the freeway itself and the result is interpreted to indicate that the extra travel of getting vehicles to/from the freeway still

Table 3 Model results for weekday peak hour travel of an increased speed limit on trans-urban freeway

Speed Limit (kph)	GHG (kgCO2e)	Average Speed (kph)	VKT (km)	GHG (gCO2e/VKT)
Freeway only (Fig. 6c)				
80	78,211	59.94	338,181	231
90	82,641	62.88	361,426	229
Absolute increase	*4,430*	*2.94*	*23,245*	–
Relative increase	*5.7 %*	*4.9 %*	*6.9 %*	*−1.1 %*
Freeway and vicinity (Fig. 6b)				
80	367,740	49.01	1,015,172	362
90	372,105	49.88	1,037,268	359
Absolute increase	*4,365*	*0.87*	*22,096*	–
Relative increase	*1.2 %*	*1.8 %*	*2.2 %*	*−1.0 %*
Metropolitan region (Fig. 6a)				
80	2,445,858	53.98	6,703,818	365
90	2,445,944	54.15	6,707,263	365
Absolute increase	*86*	*0.17*	*3,445*	–
Relative increase	*0.0 %*	*0.3 %*	*0.1 %*	*0.0 %*

provides an overall increase in CO2 emissions. However, at the urban region level, (encompassing 19 times as much travel as the freeway), the effect of reduced demand on other links across the region becomes apparent. As a result, the overall travel distance and overall CO2 emissions still increase by a marginal amount but less than indicated by the freeway vicinity itself.

The second scenario in traffic control measures examines changing a section of a major outer ring road from signalized intersections to free flowing interchanges. The distance specific GHG emission maps are shown in Fig. 7 and the numeric results in Table 4. This type of development on a high-speed outer ring road is expected to improve travel times and Table 4 confirms the average speed improvement both locally (5 % for the ring road and vicinity) and over the whole metropolitan region (0.6 % which is significant). The efficiency of the vehicles on the network is also improved as is indicated by reduced distance-specific GHG emissions (3.2 % lower in the vicinity and 0.3 % averaged over the entire region). However, given the peripheral nature of the outer ring road, vehicle mileage increases significantly to access that increased capacity and thus overall traffic volume (measured by vehicle kilometers travelled) increases significantly (by 6 % for the vicinity and 1 % over the urban region).

The end result of this study is a significant increase in GHG emissions for the region as a consequence of increased ring road capacity. This result can be troublesome for a transportation planning department; it reduces average network travel times, but increases the GHG's emitted on the network. However, the city in question is growing rapidly so projections into the future with a larger urban footprint and higher traffic show that, in the future, these infrastructure improvements alleviate congestion that would otherwise raise GHG emissions even further.

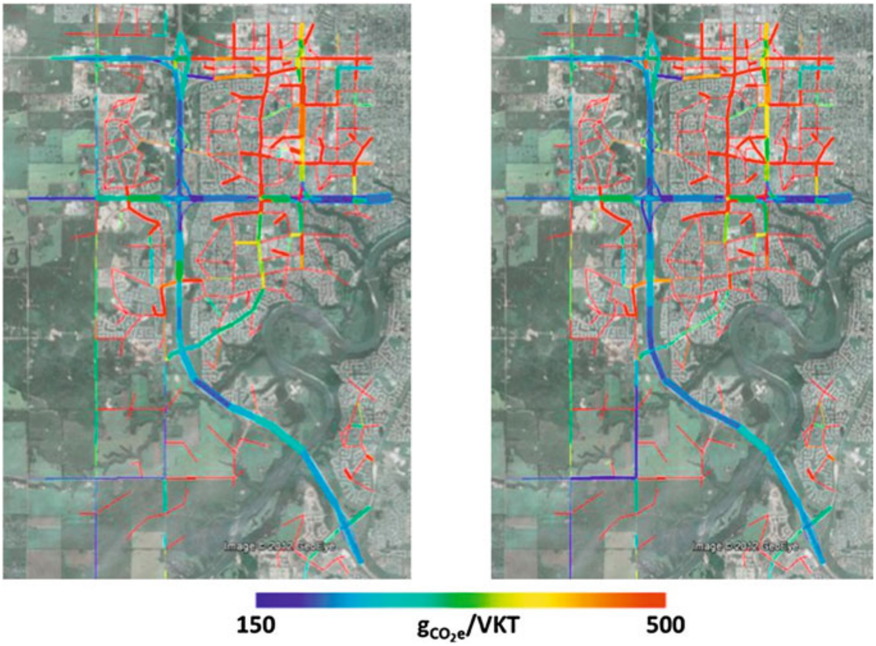

Fig. 7 Baseline case for outer ring road with signalized intersections (*left*) and free flowing interchanges (*right*)

Table 4 Model results for outer ring road section with signalized intersections and with interchanges, for both the near vicinity and the metropolitan region

	GHG (kgCO2e)	Average speed (kph)	VKT	GHG (gCO2e/VKT)
Outer ring road and vicinity				
Signalized	155,652	50.34	421,263	370
Interchange freeflow	160,345	52.76	448,146	358
Absolute increase	*4,693*	*2.42*	*26,883*	–
Relative increase	*3.0 %*	*4.8 %*	*6.4 %*	*−3.2 %*
Metropolitan region				
Signalized	2,308,021	53.98	6,703,818	344
Interchange freeflow	2,321,847	54.3	6,764,181	343
Absolute increase	*13,826*	*0.32*	*60,363*	–
Relative increase	*0.6 %*	*0.6 %*	*0.9 %*	*−0.3 %*

5 Conclusions

The approach illustrated in this chapter has been to apply simplified micro-simulations to large-scale transportation planning studies to rapidly calculate emission inventories for transportation networks in a way that responds to design choices at the project level. The advantages of this approach have been illustrated with a series of case studies showing the ability to respond to policy choices, infrastructure design parameters and traffic control parameters. The modeling tool described is flexible and generates both numeric values and visual output. Both can be used to inform decision makers of the environmental impacts of various transportation and GHG management strategies. The case studies in this chapter have focused on GHG reduction potential but the model also includes criteria pollutants like smog precursors and particulates where the localization of impacts might be even more important.

Case studies illustrated the evaluation of policy choices such as green incentives for hybrid vehicles or vehicle scrappage, providing a means of evaluating the cost effectiveness of proposed programs. Traffic control strategies and plans can also be evaluated for their environmental impact, and the change in overall emissions as well as any shift of emissions between modes can be captured. Infrastructure designers can use large-scale micro-simulation to model the impacts of their design concepts. Furthermore, the simplified micro-simulation used for this study allows for the rapid turnover of such design studies and optimizations with conventional desktop computers.

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David Checkel has a B.Sc. in Mechanical Engineering (1976) and a Ph.D. in Engineering/Combustion from Cambridge University (1981). He taught Mechanical Engineering at University of Alberta from 1981 through 2010 and continues to supervise graduate students. His research interests have focused on energy, fuels and emissions, particularly automotive power trains, alternative fuels, vehicle emissions and life cycle assessment. He has worked extensively with project vehicles including hybrid electric, solar, propane, alcohol, natural gas, bio-diesel, dual fuel and other power train systems. This has led to a strong interest in vehicle simulation and design, in-use testing systems, vehicle emission simulations and the life cycle assessment of energy systems.