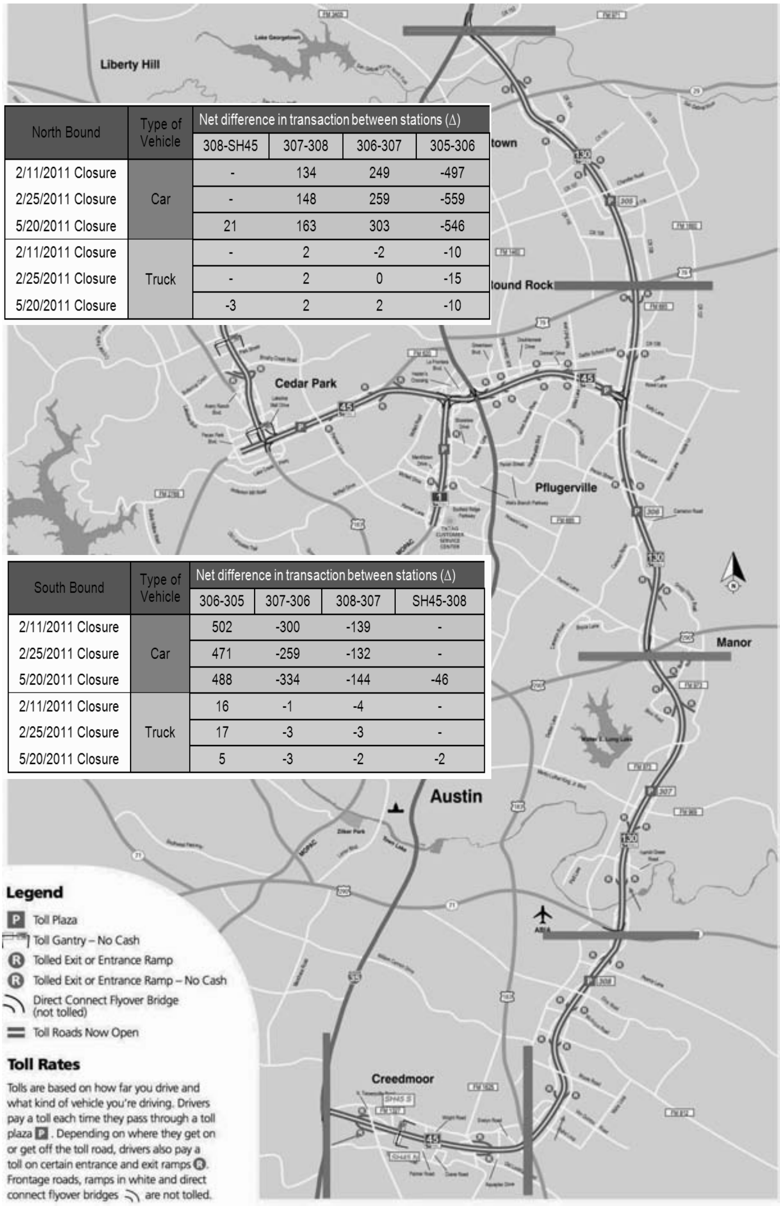

North Bound	Type of Vehicle	Net difference in transaction between stations (Δ)			
		308-SH45	307-308	306-307	305-306
2/11/2011 Closure	Car	-	134	249	-497
2/25/2011 Closure		-	148	259	-559
5/20/2011 Closure		21	163	303	-546
2/11/2011 Closure	Truck	-	2	-2	-10
2/25/2011 Closure		-	2	0	-15
5/20/2011 Closure		-3	2	2	-10

South Bound	Type of Vehicle	Net difference in transaction between stations (Δ)			
		306-305	307-306	308-307	SH45-308
2/11/2011 Closure	Car	502	-300	-139	-
2/25/2011 Closure		471	-259	-132	-
5/20/2011 Closure		488	-334	-144	-46
2/11/2011 Closure	Truck	16	-1	-4	-
2/25/2011 Closure		17	-3	-3	-
5/20/2011 Closure		5	-3	-2	-2

Figure 1: SH-130 segment/station descriptions and Net changes in southbound SH 130 traffic transactions among successive toll stations during closures

station, station 305, averaged 331 per hour across the three closures. As an extreme but unlikely estimate of the fraction of traffic that originated on IH-35 and traveled through to points north of Austin, 331/446 or 74% could possibly have traveled through to points north of Austin or 26% were destined for Austin. For the southbound direction, toll station 305 provides the first counts after the SH130-IH35 interchange and this volume averaged 275 per hour across the three closures. At the southern end of SH 130, toll station 308 averaged 326 per hour across the three closures or roughly 118% of the first southbound counts at station 305. Using the previously described logic, then all of the possible southbound traffic was destined for points south of Austin.

Comparisons for Different Times of Day during the Closures: The previous analysis was based upon average hourly volumes across the closure times, but volumes and patterns vary significantly among the times of day during which the IH-35 closures were active. If one considered every hour of the day to be a distinctive case the result would be specific but rather difficult to understand. To simplify the analysis, the 24 hours of the day were combined into 3 time slices or groups: Time 1 (midnight to early morning 2300-0600), Time 2 (morning and late evening 0700-0900, 1900-2200), and Time 3 (mid-day through PM peak 1000-1800).

The reason to choose this grouping is that traffic volume patterns during weekends are different from week days. By looking at the data and performing multiple range tests, we determined that "rush hours" on weekends start later in the morning than weekdays and continue until early evening. To be able to see the changes during the closure compared to typical conditions, typical hourly traffic volumes were developed for the three generalized time frames. Analysis shows that the number of trucks using SH-130 during closures increased by more than three times the typical volumes. Car transactions also increased significantly during all time groups for the closure conditions. Although patterns of entering and exiting traffic are similar across the three time periods, numbers of transactions or volumes are much greater during day time hours, that is Time 3 (1000 through 1800 hours). That is, in the northbound direction there are net increases in traffic volume through all stations until the northern most station 305 where the net decrease is approximately equal to the sum of the net gains across the previous stations. This indicates a very large fraction of the SH-130 northbound traffic is destined for points in Austin rather than points north of Austin. In the southbound direction only the section between stations 305 and 306 shows a net traffic volume increase with the three more southern sections showing net volume decreases. Like the northbound direction, this seems to indicate that a very large fraction of the southbound traffic is destined for points in Austin rather than locations south of Austin.

Figure 2 presents numbers of transactions for the four toll stations along SH-130 for the daytime conditions (1000 to 1800 hours) for the northbound and southbound directions respectively. The Figures illustrate the same concepts stated in the previous paragraph, that is, northbound volumes reach a maximum at station 306 located just south of the SH-45 and US-79 exits. Stations 308 and 305 at the south and north ends of SH-130 have the smallest traffic volumes again, showing that the "through" traffic is a small fraction. Southbound volumes reach a maximum at station 306 just the south of SH-45 and US-79 entrances and decrease to the smallest level at station 308 the most southerly transaction station.

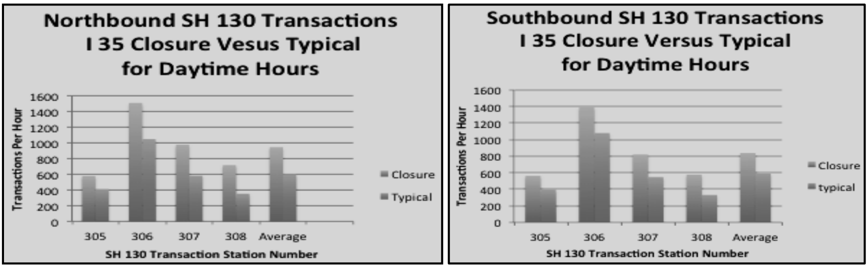

Figure 2: SH 130 transactions by toll station during daytime hours [Station 308 is most southerly, 305 is most northerly].

Fuel Conservation Analysis

More efficient traffic operational strategies that relieve roadway congestion can have a significant impact on fuel consumption by increasing fuel economy. The choice of route can significantly affect fuel consumption and emissions. As mentioned earlier, during the SH-71/IH-35 interchange construction, two diversion plans were defined to control the traffic: a local detour with total distance of 27 miles and a network diversion with total distance of 47 miles. In the local detour route, because of the large proportion of traffic not diverted that remained on IH-35, there was level of service F (LOS F: heavy traffic conditions) characterized by stop-and-go traffic with average speeds of 15 mph on IH-35. The network diversion plan, although a longer distance provided an average speed of 65 mph.

Stop-and-go traffic, characterized by repetitive cycles of complete stops for 5 to 20 seconds followed by movement at speeds of 5 to 15 miles per hour tends to increase fuel consumption. Since stop-and-go fuel consumption rates are different during different parts of the cycle, one might describe fuel consumption using a three term model. The first term might represent stopped vehicles with idle fuel consumption rates, the second term could describe fuel consumption for vehicles accelerating from a stop, and the third term might represent stochastic effects of vehicle movements which consume excess fuel. In general vehicles have the smallest fuel consumption rate during idling while stopped and consume more fuel after they start moving. However, when a vehicle is stopped and the engine left running, it is producing zero mpg. Consequently, idling could be considered as negative mpg since no work is being done.

In the IH-35 case study, to evaluate fuel consumption on two different routes, a general graph which illustrates fuel economy at different speeds and across different traffic conditions is required. The Transportation Energy Data Book (2010) is the best available source that has "Fuel Economy-Speed" data (Figure 3). This graph tends to indicate that with time, manufacturers have produced cars that exhibit greater fuel economy at higher speeds. The 1997 curve indicates best fuel economy at speeds of 50 to 60 mph. Since the latest graph is for 1997, one might expect that newer cars could produce greater fuel economy at higher speeds than 55 mph.

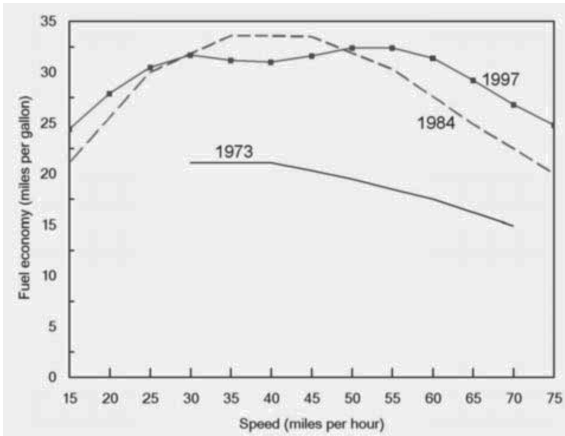

Figure 3: Fuel Economy (mpg) versus Speed (mph)
[Source: Figure 4.2 of the Transportation Energy Data Book, 2010].

Limited studies have been done on stop-and-go traffic to estimate general fuel consumption rates corresponding to vehicle acceleration/deceleration and idling. Silva et al. (2006) evaluated three numerical models to estimate fuel consumption of gasoline light-duty vehicles. Models were used to simulate fuel consumption across a variety of traffic condition. Cruise speed was compared with several stop and go situations (up to 9 stops). Their findings predict up to 67 percent increases in fuel consumption.

According to figure 3, fuel economy at constant speeds 15 and 65 mph are 25 and 30 miles per gallon, respectively. Considering the fact, that Figure 3 shows fuel consumption at steady state speeds, additional fuel consumption due to accelerating/decelerating and idling should be included in estimates of total fuel consumption for the IH-35 diversion route. Although the average speed was 15 mph, vehicles were spending large portions of time in queues idling and repetitively acceleration and decelerating to the stopped condition.

The likely fuel economy of stop-and-go operations on IH-35 was dramatically poorer compared to a 15 mph steady-state speed. One might logically infer that considering "lost" fuel due to idling during long duration stopped times and the measured 67 percent increase due to acceleration and deceleration, the very heavily congested stop-and-go situation on the I-35 diversion route could have produced fuel consumption rates as much as twice the steady-state speed condition on the alternate route. The distance for the alternate route is less than twice the IH-35 route. Considering these two facts, taking the longer but steady state higher speed alternate route could saved fuel and time.

CONCLUSION

During the IH-35/ Ben White Boulevard construction, the increase in SH-130 (as an alternative path) traffic volumes clearly indicates diversion from IH-35. However, the volumes diverted from an IH-35 path were small in both the northbound and southbound directions. For northbound, the SH-130 toll transaction station closest to SH-35 showed over twice the typical traffic volume during the closures; however, this increase was only about 350 car transactions per hour. In other words, even if all of the 350 vehicles per hour were diverted from IH- 35, it would still represent a very small fraction of one freeway lane. As for southbound, the station nearest to the beginning of SH-130 showed a maximum increase of about 165 vehicles per hour.

Based upon both volume and net difference tables, one might hypothesize that a large fraction or specifically more than half of the weekend traffic on SH-130 northbound and southbound appears to be destined for locations in the metropolitan area rather than locations north or south of the Austin area. In addition, the location of the construction zone could have had a significant effect on traffic pattern changes. Since the construction zone was located south of the metropolitan area, the south bound traffic was more likely to be informed about the closure. Considering these facts together, one can logically speculate that the volumes of traffic diverted from IH-35 paths were small for several reasons:

- If most IH-35 travelers were destined for metro-Austin they would not likely consider the SH-130 path, as it would cause them to travel "out of their way" to reach their destination.
- Travelers may have been unfamiliar with the many connections between SH-130 and their metro-Austin destinations.
- IH-35 travelers likely did not perceive the level of congestion that would develop on that freeway as the result of the main lane closures.

SUGGESTIONS

To ameliorate the lack of diversion from IH-35 to SH-130 the following suggestions are provided for future diversion efforts: 1) Provide comparative travel times for IH-35 and SH-130 through forecasts or through real-time information delivery means, including changeable message signs (CMS), highway advisory radio, television and other traffic condition outlets. 2) Provide information through CMS's, TV, and newspapers regarding the ease of connection from SH-130 to metro-Austin destinations. 3) If the diversion road is a toll road that is made free for the diversion plan, communication of the free status to travelers is vitally important. 4) For travelers who are not familiar with alternative paths (like SH-130) graphical signage showing schematic maps could be provided along the path leading to diversion routes. Finally, providing estimates of fuel consumption for alternative diversion paths could influence travelers in their route choice decision.

REFERENCES

AASHTO Summary Report on work Zone Crashes. Standing Committee on Highway Traffic Safety. American Association of State Highway and Transportation Officials, Washington, D.C. 1987.

Chu, L., Kim, K. K., Chung, Y., and Recker, W., *Evaluation of Effectiveness of Automated Workzone Information Systems.* Transportation Research Record, vol. 1911, pp. 73–81, 2005.

Dudek, C.L., Huchingson, R.D., Stockton, W.R., Koppa, R., Richards, S.H., and Mast, T.M., *Human Factors Requirements for Real-Time Motorist Information Displays*, U.S. Department of Transportation, Washington, DC, Vol.1-Design Guide Report FHWA-RD-78-5. FHWA, September 1978.

Dudek, C.L., *Changeable Message Signs. NCHRP Synthesis of Highway Practice 61.* Transportation Research Board, National Research Council, Washington, DC, 1979.

Dudek, C. L., and Richards, S. H., *Traffic Capacity through Urban Freeway Work Zones in Texas*, Transportation Research Record 869, p.p 14-18, 1982.

Dudek, C.L., *Changeable Message Signs. NCHRP Synthesis of Highway Practice 237.* Transportation Research Board, National Research Council, Washington, DC, 1997.

Dudek, C., Trout, N., Booth, S., and Ullman G., *Improved Dynamic Message Sign Messages and Operations.* Report No. FHWA/TX-01/1882-2. Texas Transportation Institute, College Station, TX, October 2000.

Dudek, C.L., *Dynamic Message Sign Message Design and Display Manual.* Report No. FHWA/TX-04/0-4023-P1. Texas Transportation Institute, College Station, TX, March 2004.

Dunston, Phillip S., Mannering, Fred L., *Evaluation of the Full Weekend Closure Strategy for Highway Reconstruction Projects: I-405 Tukwila to Factoria.* Washington State Transportation Center, Washington State Department of Transportation, Olympia, WA, 1998.

Effinger J., Liu Y., Horowitz A., *Quantifying Traveler Diversion And Its Impact During A Weekend Full Freeway Closure: A Case Study With I-43/I-894 In Milwaukee.* Transport Chicago Conference. 2011.

Full Road Closure for Work Zone Operations: A Cross-Cutting Study. Federal Highway Administration Work Zone Program, Federal Highway Administration, Washington, DC, 2003.

Full Road Closure for Work Zone Operations: A Case Study. Accelerating Construction and Reducing Crashes During the Rehabilitation of a Major Downtown Route - M-10 Lodge Freeway in Detroit, Michigan, Federal Highway Administration, Report No. FHWA-HOP-05-013, 2004.

Halloin, D.M., *Impediments to the Effective Use of Portable Variable Message Signs in Work Zones.* In Compendium of Graduate Student Papers on Advanced Surface Transportation Systems. Southwest Region University Transportation Center, Texas A&M University, College Station, TX, August 1996.

Helmuth, J. L., *Visual Complexity in Highway Work Zones: An Exploratory Study.* MS thesis. Department of Civil Engineering, Texas A&M University, College Station, 2002.

Highway Capacity Manual. Transportation Research Board.Washington, D.C., 2010.

Khattak, A. J., *Commuters' Enroute Diversion and Return Decisions: Analysis and Implications for Advanced Traveler Information Systems.* Transportation Research part A, vol. 27A, no. 2, pp. 101–111, 1993.

Khattak, A., Kanafani, A., and Colletter. E. L., *Stated and Reported Route Diversion Behavior: Implications on the Benefits of ATIS.* Research report, ucb-its-prr-94-13, Institute of Transportation Studies, University of California, Berkeley, 1994.

Krammes, R. A., and Lopez, G. O., *Updated Capacity Values for Short-term Freeway Work Zone Lane Closures.* Transportation Research Record 1442, Transportation Research Board, Washington, D.C., 49–56, 1994.

Lee, E. B. and Yu, A., *A Validation Study of Microscopic Traffic Simulations for Urban Freeway Reconstruction with high-traffic volume.* Presented at the 84th annual meeting of Transportation Research Board, 2005.

Manual on Uniform Traffic Control Devices. FHWA, U.S. Department of Transportation,Washington, DC, 2003.

MassHighway. *Project Development and Design Guide,* chapter 17 (work zone management) Boston, MA. 2006. Accessible at: http://www.vhb.com/mhdGuide/mhd_GuideBook.asp

Peeta, S., Ramos, J. L., and Pasupathy, R., *Content of Variable Message Signs and On-line Driver Behavior.* Presented at the 79th annual meeting of the Transportation Research Board, 2000.

Pigman, J. G., and Agent, K. R., *Highway Crashes in Construction and Maintenance Work Zones.* Transportation Research Record 1270, Transportation Research Borad, Washington D.C., pp12 – 21, 1990.

Portable Changeable Message Sign Handbook PCMS. Report No. FHWA-RD-03-066.FHWA, U.S. Department of Transportation, Washington, DC, 2003. Accessible at http://www.tfhrc.gov/pavement/ltpp/reports/03066/.

Road-User Cost for SP 6211-81: Reconstruction of TH-36 in North Saint Paul. Minnesota Department of Transportation, St. Paul, MN, 2006.

Rouphail, M. N., and Tiwari, G., *Flow Characteristics at Freeway Lane Closures*, Transportation Research Record 1035, pp. 50-58, 1985.

Schrock, D. S., Ullman, G. L., Cothron, A. S., Kraus, E., and Voigt, A. P., *An Analysis of Fatal Work Zone Crashes in Texas.* Report FHWA/TX-05/0-4028-1, FHWA, U.S. Department of Transportation, 2004.

Silva, C.M, T.L. Farias, H.C. Frey, and N.M. Rouphail, *"Evaluation of Numerical Models for Simulation of Real-World Hot-Stabilized Fuel Consumption and Emissions of Gasoline Light-Duty Vehicles.*" Transportation Research Part D, pp 377-385, 2006.

Ullman, G.L., Ullman, B.R., Dudek, C.L., Williams, A., and Pesti, G., *Advance Notification Messages and Use of Sequential Portable Changeable Message Signs in Work Zones.* Report No. FHWA/TX-05/0-4748-1. Texas Transportation Institute, College Station, TX, July 2005.

Weng, J., Meng, Q., *Work Zone Capacity Estimation Using an Ensemble Tree Approachl.* Transportation Research Board, TRB 91th Annual Meeting CDROM, 2012.

Zhang, H. Michael; Chen, Yi-Ru; Lim, Robert; and Qian, Zheng; What Happens When a Major Freeway is Colsed for Repair: The case of Fix-I5 in Downtown Sacramento, Transportation Research Record, TRB 91th Annual Meeting CDROM, 2012.

Evaluating Community Transportation Emission Methodologies

Daniel Hegg[1], B.Comm. M.Sc. EMIT. LEED™ David Roewade[2], B.E.S., M.E.S., EP and Lisa J. Scott[3], B.A.

[1]Stantec Consulting, Stantec Climate Services, 400-655 Yee Road, Victoria British Columbia, V9A 6X5; PH: (250) 217-9729; email: Daniel.hegg@stantec.com
[2]Region of Waterloo, Sustainability Office, 50 Queen Street North, 7th floor, Kitchener Ontario, N2H 6P4; PH (519) 575-4757 Ext. 3308; email: droewade@regionofwaterloo.ca
[3]Stantec Consulting, Sustainable Development (Practice and People), 401 Wellington Street, Toronto Ontario, M5V 1E7; PH (416) 598-7149; email: lisa.scott@stantec.com

ABSTRACT

Many communities have committed to reducing their greenhouse gas (GHG) emissions. Fulfilling these commitments often includes: inventorying emissions, development of a local action plan, reduction targets and measuring progress from plan implementation. Using Waterloo Region as a case study, a comparative analysis of estimation methodologies for community transportation emissions was conducted. The transportation sector is often a large part of many local GHG emission profiles and can be difficult to effectively measure. Three commonly used methodologies were compared and evaluated, vehicle kilometers traveled (VKT), vehicle registration methodology and retail fuel sales. The evaluation considered accuracy of data inputs and outputs, resources required ability to replicate for future inventories, and the ability to reflect impacts from the implementation of local actions. It was concluded that the fuel sales method is the least arduous, is reasonably accurate to replicate and suitable for monitoring progress. Municipalities would benefit to obtain fuel sales data within their jurisdictional boundaries to estimate local transportation emissions for their inventory as it will also better reflect progress from implementing their reduction initiatives. Vehicle registration data can further assist with estimating potential reductions from the proposed action plan.

CONTEXT

Despite decades of international policy debate on climate change, atmospheric carbon dioxide (CO_2) concentrations have continued to rapidly increase towards levels of great scientific concern.[i] The Intergovernmental Panel on Climate Change has identified that anthropogenic greenhouse gas (GHG) emissions unequivocally have been the dominant influence on the forced change in our climate over natural influences during the past 60 years.[ii] Moreover, the signs of climate change and variability are becoming increasingly evident with impacts already felt in numerous parts of the world including Canada.[iii]

There is a growing body of international research on the role of local government and community action in climate change policy.[iv] With regard to GHG mitigation, urbanized areas have been estimated to consume two thirds of global primary energy resources and are responsible for 40% to 70% of the world's CO_2 emissions.[v] This will intensify as more than half of the world's current population already lives in towns and cities and urban populations are expected to grow to two thirds of the global population by the year 2030.[vi] Many cities are also already dealing with the effects of climate change. Furthermore, nearly all urbanized areas are at risk as they cluster both people and vulnerable infrastructure (i.e., water, transportation, energy) into relatively small areas. Therefore, actions at the community level can play a critical role in reducing anthropogenic influences on climate change.

Municipalities have a great opportunity to portray themselves as a legitimate player in the global effort to mitigate climate change if they can demonstrate accountability to their public GHG reduction commitments. In order to do this, local government and communities need to understand the relationship between the various data inputs and outputs within mitigation frameworks in order to effectively achieve and measure their progress towards established reduction targets. In Canada, some 240 municipalities are participating in the Federation of Canadian Municipalities Partners for Climate protection program which is a framework for local GHG mitigation.[vii] The upper tier Regional Municipality of Waterloo along with its three local city government bodies have all committed to this program in the past and have recently joined forces to develop and effective GHG reduction strategy. The ability to measure the effectiveness of implementing their strategy is founded in their methodological approach to developing the local emissions inventory and action plan. The Waterloo Region experience is a good backdrop to analyze the role that emission methodologies play in enabling municipalities to develop a sound base to their GHG reduction strategies which is critical for accountability in measuring progress towards reduction targets.

INTRODUCTION

Since the 1990's, local governments around the world have committed to reducing their greenhouse gas (GHG) emissions from both their municipal (corporate) operations as well as on a community-wide scale. Frameworks to fulfill these commitments often include an inventory of emissions borne from local activities, development of an action plan, establishing reduction targets relative to the baseline year and, measuring progress from implementation of the plan.

Efforts to measure, manage and reduce municipal corporate emissions are for the most part relatively straightforward due to clear ownership, access to data and numerous internal mechanisms to set and fulfill corporate GHG emissions reduction goals. For example, reducing emissions from the municipal fleet can be directly affected by the type of vehicles and fuel purchased, equipment installed and driver routes established. Community GHG emissions on the other hand, while geopolitically based, are influenced by a wide variety of stakeholders and therefore require significant coordination and collaboration to manage. Nevertheless, any community has to understand and address this challenge once they are committed to developing local climate action plans if they want to demonstrate progress towards achieving their GHG reduction goals.

Selection of emission estimation methodologies at the inventory stage can directly and indirectly affect the likelihood of success in terms of effectively measuring and achieving progress towards a local reduction target. This is particularly the case at the community scale where there are more data sources and wide spread influential control over the type of activities that cause GHG emissions at this scale.

Emission sources typically measured within community GHG inventories include:

- Residential, industrial and commercial stationary energy consumption (e.g. electricity and natural gas);
- Transportation (e.g. gasoline/diesel);
- Waste (e.g. methane from landfills) and;
- Agricultural activities in rural areas within a county or regional municipality (e.g. enteric fermentation in livestock).

Transportation emissions are often a large part of the community carbon footprint and one of the more difficult emission sources to effectively measure. This is also an emission source that can be influenced by a variety of land-use policy mechanisms, infrastructure investment and behaviourial change programs and incentives available to local municipalities.

Community transportation emissions are mainly derived from the combustion of fuel in personal and commercial/industrial vehicles used within a community. Tracking and reducing these emissions is difficult due to the lack of operational control in tracking variables such as; kilometers driven, personal preference of vehicles (e.g. type and make of vehicle), limited access to data sources (e.g. insurance, card-lock) along with the magnitude of data sources and the level of accuracy that can be captured. The identification of the objective (transportation planning or emissions measurement) is necessary as this defines which method or methods to capture and measure community transportation emissions should be used. By analyzing different emissions estimation methods in conjunction with different municipal and community objectives the relationship between data inputs, outputs and their interdependencies can emerge.

The Waterloo Region was utilized as a case study for conducting a comparative analysis of transportation estimation methodologies at the community scale. Three commonly used methodologies for estimating community transportation emissions were compared and contrasted on the basis of: accuracy, staff and financial resources required; ability to replicate methodology to compile future inventories; and the ability to reflect impacts from the implementation of various GHG reduction initiatives within local climate action plans. In addition to identifying advantages and disadvantages of each emission estimation method, a conceptual framework to consider the objective (policy or measurement), various data inputs and inputs and their relationship in the context of the stages associated with community GHG action planning is included. The article concludes with the proposed framework that would help municipal staff assess how and what methods would best enable them to set GHG related transportation policy or track progress towards community transportation emission reduction targets.