Quantifying Greenhouse Gas Generation for Roadway Maintenance, Rehabilitation and Reconstruction Treatments

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ABSTRACT

Greenhouse gas (GHG) emission levels in Canada peaked in 2007 at 751 Mt CO_2e (carbon dioxide equivalents) and currently these levels are decreasing. Through the Copenhagen Accord, Canada has committed to a 17 percent reduction of 2005 GHG emission levels by 2020 to 607 Mt. To reach this target, any possible reductions to GHG emissions must be made. To reduce GHG emissions generated in roadway construction, it is important to quantify the amount of GHGs produced for various treatments and to identify which aspects of construction contribute the greatest.

This paper describes the development of a probabilistic model that quantifies the amount of GHGs generated through maintenance, rehabilitation, and reconstruction treatments for flexible pavement structures and includes the GHG emissions generated from the transportation, production and placement of materials. The maintenance treatments reviewed include: fog seal, slurry seal, micro surfacing, chip seal and ultra thin overlay. The rehabilitation and reconstruction treatments reviewed include: cold in-place recycling, mill and fill, full depth reclamation, and use of offsite recycled and virgin materials for reconstruction. To quantify the GHGs generated for each of these treatments a case study of a typical lane-km (3,700 m^2) is used.

The key parameters that contribute the greatest to the GHGs for each treatment were determined and it was found that material production contributed the greatest to GHG generation. Four primary sensitive parameters were determined for the maintenance treatments including equipment efficiency, the rate at which the treatment is applied and the asphalt cement and aggregate content of the treatment. For the rehabilitation and reconstruction treatments, the sensitive parameters where found to be the emissions value for the production of hot mix asphalt concrete and the amount of Portland cement added.

The City of Edmonton has been using foamed asphalt and recycled aggregates for the rehabilitation of roadways for a number of years. A case study quantifying the amount of GHG emissions generated through 33,888 m^2 of roadway reconstruction in the neighbourhood of King Edward Park is presented. Through the use of full depth reclamation for reconstruction it is estimated that approximately 52 percent or 700 t CO_2e less was generated compared to a traditional remove and replace with virgin materials.

INTRODUCTION AND BACKGROUND

All jurisdictions must continually monitor their roadway infrastructure and implement maintenance, rehabilitation or in some cases, reconstruction treatments based on the roadway's condition. Early identification and implementation of maintenance treatments can often postpone the need for more expensive rehabilitation and reconstruction treatments (TAC 1997).

Roadway engineers must take many factors into consideration when choosing when and what type of treatment to apply to a roadway section. By understanding the amount of greenhouse gas (GHG) emissions generated by various roadway maintenance, rehabilitation and reconstruction treatments and which processes produce the greatest amount of GHG emissions, further consideration for the environment can be included.

The GHG emissions that are considered under the Kyoto Protocol and Copenhagen accord are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perofluorocarbons (PFCs) (Environment Canada 2010, May and Caron 2009). In Canada, 98 percent of GHGs emitted are from CO_2, CH_4 sand N_2O while only two percent are SF_6, HFCs and PFCs (Environment Canada 2010). As such the model developed only considers the former three. GHG emissions can be reported in carbon dioxide equivalents (CO_2e) based on the a gas's 100 year global warming potential compared to CO_2 as shown in Figure 1. For example one CH_4 molecule is equal to 21 CO_2 molecules or CO_2e.

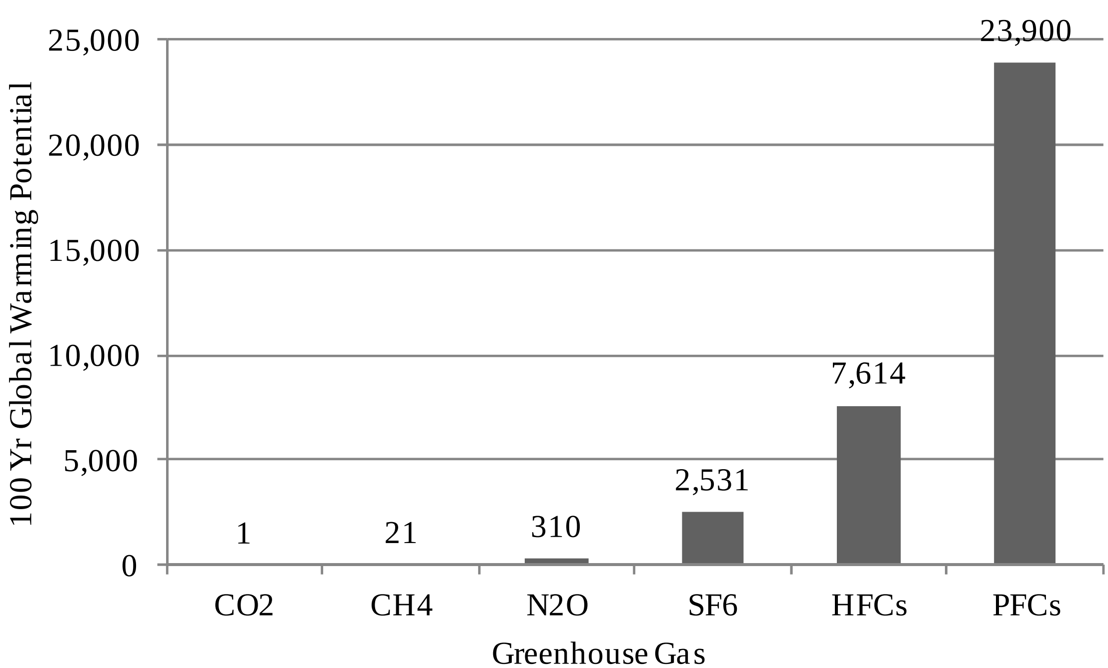

Figure 1 Greenhouse Gas 100 Year Global Warming Potentials (May and Caron 2009)

In 1990 the GHG emissions in Canada were reported to be 589 Mt CO_2e and rose steadily until they peaked in 2007 at 751 Mt CO_2e (Environment Canada 2012a). It has been estimated that from the 2011 emission rate, that if no action is taken, by 2020 GHG emission levels in Canada could be at 850 Mt CO_2e (Environment Canada 2012b). In 2002, Canada ratified the Kyoto Protocol and committed to a six percent reduction in GHG emissions compared to 1990 emission levels between 2008-2012 (May and Caron 2009). In December 2009, Canada agreed to the Copenhagen Accord and a reduction in GHG emissions of 17 percent from 2005 emission levels to 607 Mt CO_2e by 2020 (Environment Canada 2012a and 2012b). Figure 2 shows the reported emission rates in Canada as well as the Kyoto and Copenhagen targets.

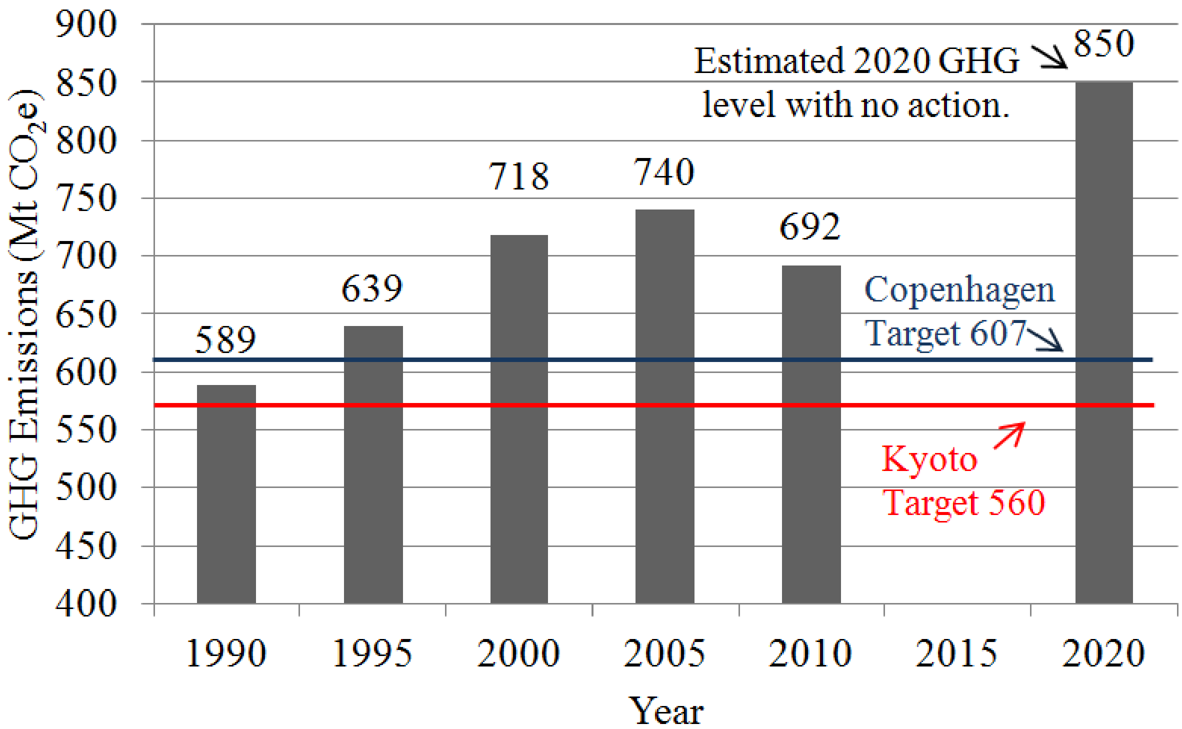

Figure 2 Greenhouse Gas Emissions in Canada

Canada formally withdrew from the Kyoto Protocol on December 15, 2011. If Canada had stayed in the Kyoto Protocol it would have had to purchase a significant amount of international carbon credits. The Government of Canada decided that investing the money domestically would be a better choice (Environment Canada 2012c). The Kyoto Protocol fails to include the United States, Brazil, China and India who together generate approximately 40 percent of the global GHGs (Environment Canada 2012b).

OBJECTIVE

The objective of this study was to develop a probabilistic model that quantifies the amount of GHG emissions that are generated from various maintenance, rehabilitation and reconstruction techniques.

SCOPE

The scope of the probabilistic model includes three sub-models that account for material production, placement and transport. Only the material that composes the pavement structure will be considered. Earthworks to bring a roadway to grade is not included in the model. The maintenance treatments considered for this work are fog seal, slurry seal, micro surfacing, chip seal and ultra thin overlay. The rehabilitation and reconstruction treatments are: cold in-place recycling (CIPR), mill and fill, full depth reclamation (FDR) and the removal and replacement of the roadway structure with the use of virgin and recycled materials.

MODEL DEVELOPMENT

The fundamental based, discrete probabilistic model developed is constructed on three sub-models for material production, transportation and placement. The framework on which the model is built is shown in Figure 3. There are two types of variables in this model, discrete variables which are known values such as roadway area and non discrete variables which have uncertainty in their values (Park 2007). For non discrete variables a low, average/most likely (Avg/ML) and high value are entered into the model. This allows the results of the model to be reported as a range, including the low and high value and an expected value which uses the Avg/ML values in the calculations. The probability assigned to the high and low value is 0.3 and 0.4 is assigned to the Avg/ML value. There are also two types of inputs for the model, those that are specific to a project that are entered by the user and those that do not change such as the GHG emissions that are generated through the production of one tonne of aggregate or the GHG emission rate used for fuel.

TREATMENT DESIGNS

Roadway maintenance treatments and designs are determined specifically for a roadway section. For each treatment, a treatment design/proposed new structure must be established. A typical design for each treatment is used for this work. The assumed designs for the maintenance, rehabilitation and reconstruction treatments are summarized in Table 1 to Table 3. To compare these treatments, the GHG emissions for a lane-kilometre (lane-km), 3,700 m^2 of roadway is used.

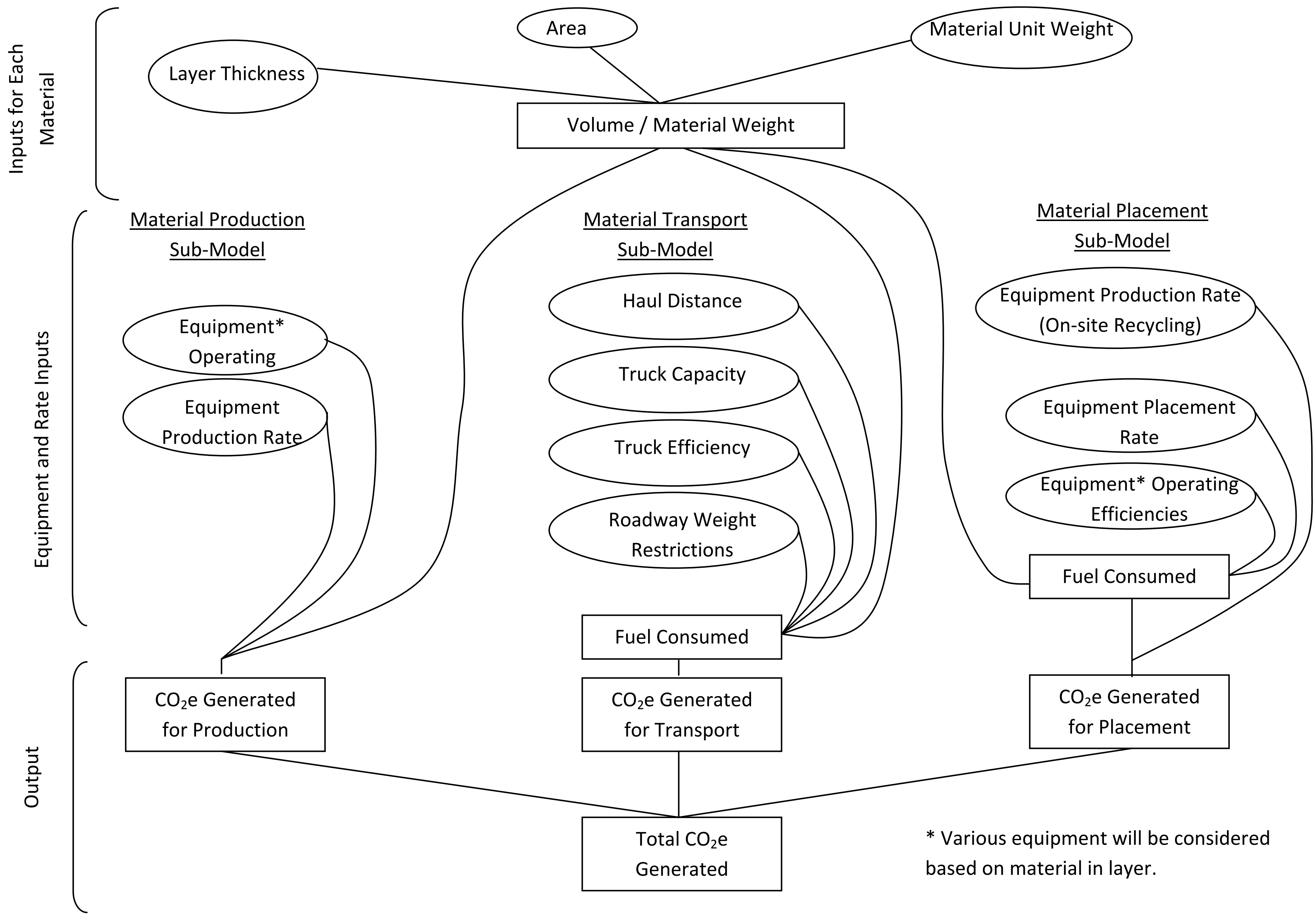

Figure 3 Model Formulation Flow Chart

Table 1 Maintenance Treatment Designs (Asphalt Institute 2007, ISSA 2010)

Treatment	Material	Low	Avg/ML	High	Unit
Fog Seal					
	Emulsion	0.45	0.575	0.7	l/m^2
	Water	NA	1	NA	parts
Slurry Seal					
	Asphalt Cement*	7.5	10.5	13.5	%
	Aggregate Mixture Application*	5.5	6.75	8.0	kg/m^2
Micro surfacing					
	Aggregate	5.4	10.85	16.3	kg/m^2
	Portland Cement (mineral filler)*	1.5	2.25	3.0	%
	Asphalt Binder*	5.5	7.5	9.5	%
Chip Seal					
	Aggregate	5	16	27	kg/m^2
	Asphalt	0.5	1.6	2.7	l/m^2
Ultra Thin HMAC^{+} Overlay					
	Overlay thickness	NA	25	NA	mm

*based on dry weight of aggregate
$^{+}$ hot mix asphalt concrete

Table 2 Rehabilitation Treatments (FCM/NRC 2005)

Method	Low	Avg / ML	High	Unit
Mill and Fill				
Mill Depth	NA	50	NA	mm
HMAC Placement	NA	100	NA	mm
Tack Coat	0.2	0.45	0.7	l/m^2
CIPR				
Asphalt Emulsion	0	0.75	1.5	%
Cement	0	1.5	3.0	%
HMAC Overlay	NA	50	NA	mm

Table 3 Reconstruction Treatment Design Parameters (Asphalt Institute 2007, FCM/NRC 2005)

Method	Low	Avg / ML	High	Unit
FDR				
Asphalt Emulsion	2.0	2.75	3.5	%
Cement	1	2	3	%
Aggregate	0	2.5	5.0	%
HMAC Overlay	NA	50	NA	mm
Remove and Replace Virgin				
Remove Asphalt Concrete	NA	150	NA	mm
Further Excavation	NA	500	NA	mm
Asphalt Concrete Overlay	NA	75	NA	mm
Asphalt Concrete Base	NA	75	NA	mm
Virgin GBC	NA	200	NA	mm
Virgin Subbase	NA	300	NA	mm
Cement for Stabilized Subgrade	NA	10	NA	kg/m^2
Remove and Replace Recycled				
Remove Asphalt Concrete	NA	150	NA	mm
Further Excavation	NA	500	NA	mm
Asphalt Concrete Overlay	NA	75	NA	mm
Asphalt Concrete Base	NA	75	NA	mm
Recycled PCC Base	NA	200	NA	mm
Recycled PCC Subbase	NA	300	NA	mm
RAP Content in Asphalt	NA	10	NA	%

RESULTS

Using the model, the theoretical GHG emissions were determined for each treatment as shown in Figure 4 and Figure 5. The expected values are indicated on the figure and the bar for each value represents the low and high values that were generated. As the overall model is constructed by three sub-models the portion that each sub-model contributes to the total GHG emissions that are generated are shown in Figure 6 and Figure 7 and the values are summarized in Table 4.

For all treatments, the largest contributor to the GHG emissions is the production of materials. For the rehabilitation and reconstruction treatments, the in-place recycling techniques show significant reductions for equipment and transport compared to the full reconstruction of a roadway. When comparing the removal and replacement of virgin and recycled materials, the use of recycled materials shows a reduction of five percent in the transport of materials.

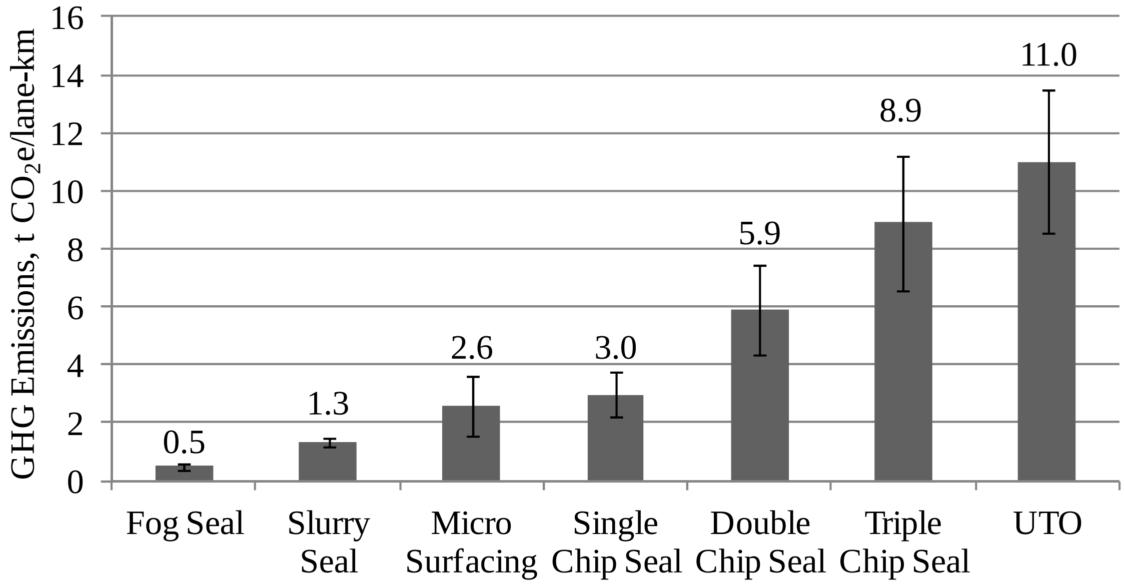

Figure 4 Modeled Maintenance Treatment Greenhouse Gas Emissions

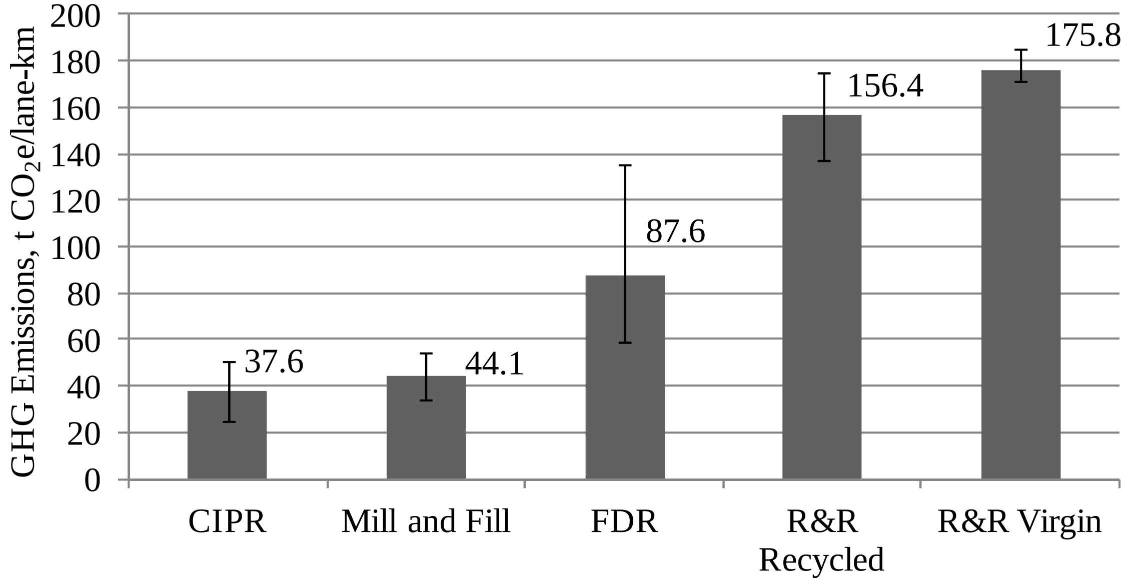

Figure 5 Modeled Rehabilitation and Reconstruction Treatment Greenhouse Gas Emissions

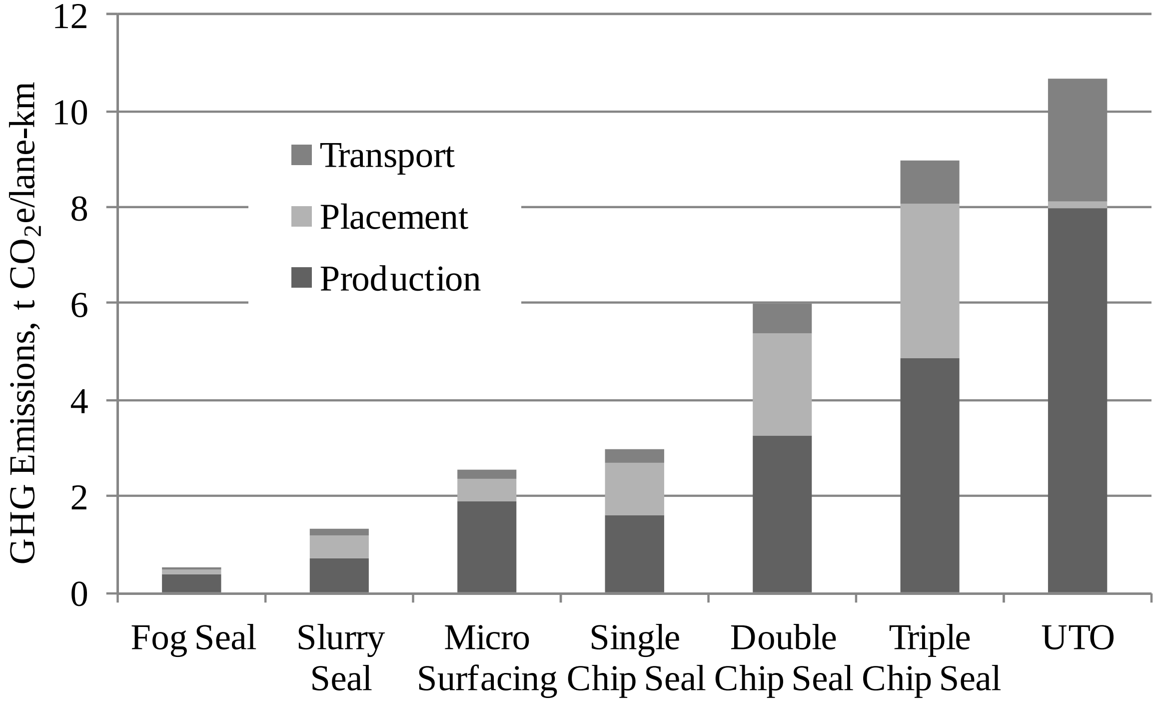

Figure 6 Maintenance Treatment Sub-model Contribution to Greenhouse Gas Emissions

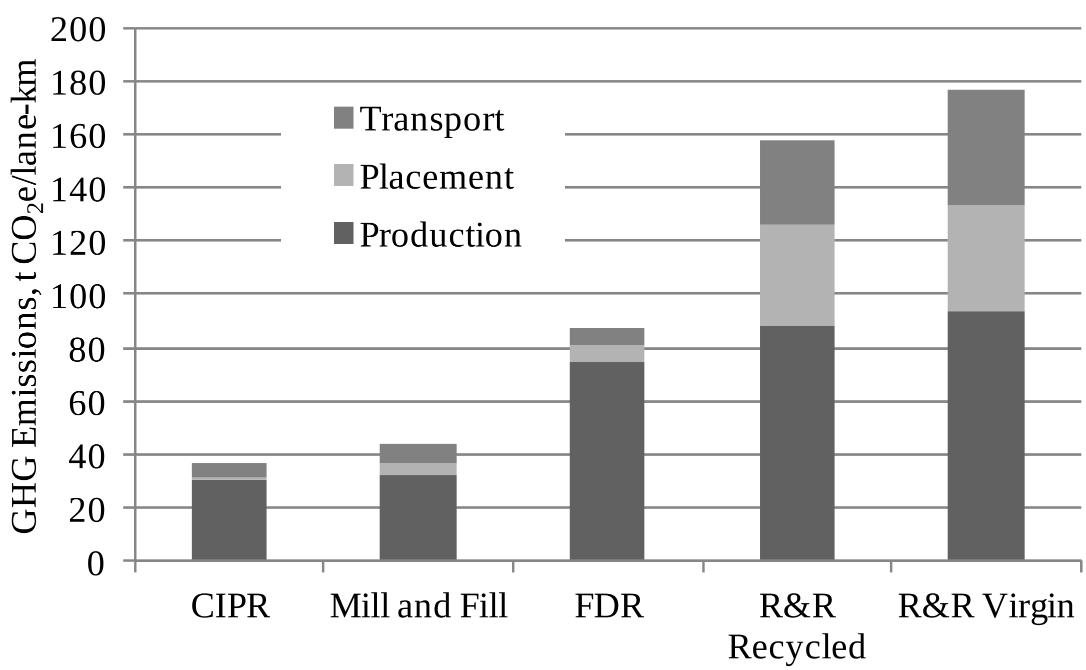

Figure 7 Rehabilitation and Reconstruction Treatments Sub-model Contribution to Greenhouse Gas Emissions

Table 4 Sub-model Contribution to Greenhouse Emissions for Treatments

	GHG Emissions (%)		
	Production	**Equipment**	**Transport**
Fog Seal	82	14	4
Slurry Seal	52	38	10
Micro Surfacing	73	18	9
Chip Seal	55	36	10
Ultra Thin Overlay	73	1	23
Mill and Fill	73	10	17
CIPR	81	4	14
FDR	86	6	7
R & R Virgin	53	22	25
R & R Recycled	57	24	20

Further review of the modeled values identified the primary sensitive parameters. To quantify which parameters were the most sensitive, the difference between the high and low value from the respective parameter was determine and divided by the expected value. Figure 8 and Figure 9 show the most sensitive parameters for the maintenance and rehabilitation and reconstruction treatments respectively.

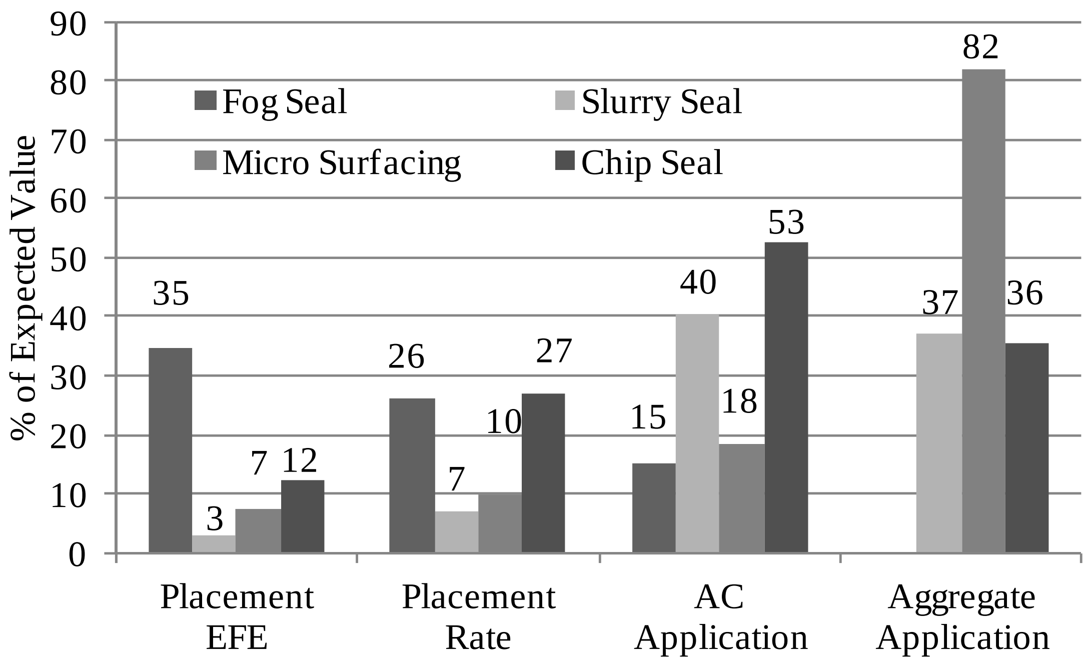

Figure 8 Maintenance Treatment Sensitive Parameters

For the maintenance treatments, four sensitive parameters were identified and include equipment efficiency (EFE) for placement, the rate at which the material is placed and the rate at which the asphalt cement and aggregate are added to the treatment. For the rehabilitation and reconstruction treatments, two sensitive parameters were identified which are the hot mix asphalt concrete (HMAC) plant production and the application rate of Portland cement.

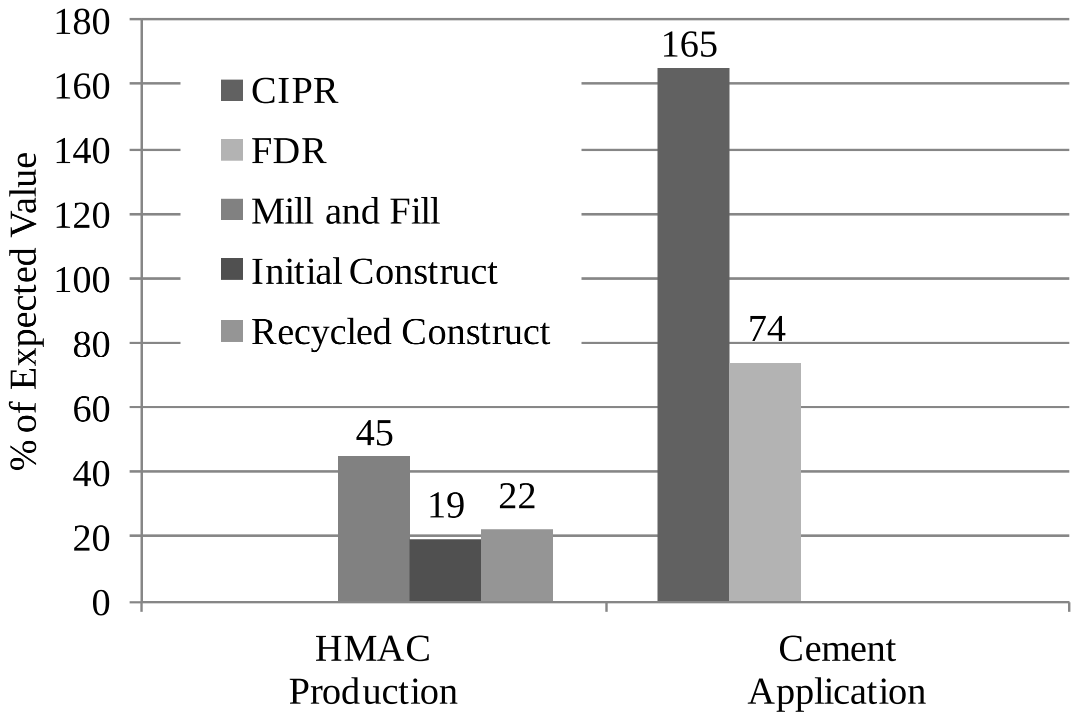

Figure 9 Rehabilitation and Sensitive Parameters

CASE STUDY

By modeling and understanding which areas of roadway maintenance and construction contribute to GHG emissions, jurisdictions are able to consider the environment when making decisions for future roadway maintenance. Recently the City of Edmonton has developed a number of strategic plans looking forward to 2040. The environmental strategic plan entitled "*The Way We Green"* indicates that one of the long term goals is to be a carbon neutral city (City of Edmonton 2011). To become carbon neutral, quantifying the emissions that are generated and the reductions that are achieved is important.

The Transportation Services Branch at the City of Edmonton for many years has implemented the use of rubble materials within city roadways and uses in-place recycling techniques to rehabilitate roadways whenever possible. In 2012, the City of Edmonton began the renewal of the King Edward Park Neighbourhood.. The work consisted of the removal and replacement of sidewalks and curb and gutter as well as the reconstruction of the roadways. The roadway work for 2012 consisted of 33,888 m^2 of roadway, 1,842 m^2 was reconstructed with virgin materials and 32,046 m^2 was recycled in-place through FDR. The reconstructed structure consisted of 150 mm cement stabilized subgrade, 300 mm 20 mm granular base course and 100 mm asphalt concrete. The FDR structure was 175mm foamed with 1.0 percent cement and 2.5 percent oil and either 50 or 75 mm asphalt concrete.

The modeled amount of GHG emissions that was generated from only the roadwork in King Edward Park is 640 t CO_2e. Had all of the roadways been reconstructed with virgin materials rather than recycled in place, the modeled GHG emissions that would have been generated is 1,340 t CO_2e. Through the use of FDR, the reduction of GHG emissions generated compare to traditional remove and replace with virgin materials is 700 t CO_2e or 52 percent.

SUMMARY AND CONCLUSIONS

Historically, GHG emissions in Canada have been on the rise and only recently have they started to decline. To continue achieving reductions in GHG emissions, it is important to quantify the amount of GHGs that are generated. By understanding which processes in roadway construction contribute the greatest to GHG generation, further reductions may be achieved by looking for processes that may further reduce the overall GHG emissions that are generated.

Through the development of a probabilistic model, the amount of GHG emissions generated for various maintenance treatments were determined and in increasing order of GHG emissions are: fog seal, slurry seal, micro surfacing, single, double and triple chip seal and an ultra thin overlay. For the rehabilitation and reconstruction treatments in increasing order of GHG emissions the treatments are: CIPR, mill and fill, FDR and remove and replace with recycled material and virgin material.

Further review of the sub-model numbers indicated that for all of the treatments the production of the materials was the greatest contributor to the amount of GHG emissions that are generated. For fog seal, slurry seal, micro surfacing, chip seal and remove and replace with recycled materials the second largest contributor is the equipment used for the placement of the materials followed by the transport. For all of the other treatments the second greatest contributor is the transportation of materials followed by the equipment.

Finally the sensitive parameters were determined. The sensitive parameters for the maintenance treatments were the efficiency of the equipment, the placement rate of the treatment and the amount of asphalt cement and aggregate that is included in the treatment. For the rehabilitation and reconstruction treatments the sensitive parameters are the production of HMAC and the application rate of Portland cement concrete.

By quantifying the GHG emissions generated by various roadway treatments, decision makers can consider GHG emissions when deciding which treatments to implement. Further research can also be pursued in the areas such as HMAC production where the greatest GHG emissions are generated to further reduce the emissions that are generated.

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