MODELLING THE INFLUENCE OF FUSED GRID NEIGHBOURHOOD DESIGN PRINCIPLES ON GREENHOUSE GAS EMISSIONS WITH EMPHASIS ON STREET CONNECTIVITY

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Introduction

Transportation is one of the major contributors of Greenhouse Gas (GHG) emissions all over the world. In Canada, transportation was the second largest source of GHG emissions in 2014, accounting for 23% of the total emissions nationwide (Environment Canada, 2016). At the provincial level, 38.4% of British Columbia's GHG emissions came from the transportation sector (BC Ministry of Environment, 2016). Such high levels of GHG emissions can be attributed to the large expansion of the urban road network and automobile dependency in North America. It is very important to shift the paradigm and start planning our communities in a way that hinder automobile dependency and encourage people to use more sustainable modes of transportation. One of these efforts is the fused grid neighbourhood model developed to preclude the disadvantages and retain the benefits of current road network patterns such as traffic shortcutting in the traditional grid pattern and navigation disorientation in the recent suburban culs-de-sac model (Sun and Lovegrove, 2013). The fused grid model consists of several 16-hectare modules (ideally four) that provide vehicular accessibility for local traffic only and keep non-local traffic on the periphery of the modules while maintaining full pedestrian/cyclists accessibility via central green spaces and off-road pathways as shown in Figure 1. Perimeter roads in the fused grid model facilitate through traffic as per the following spacing: 1) collectors at 400 metres; 2) minor arterials at 800 metres; and 3) arterials at 1,600 metres. The classification, spacing, and alignments of the perimeter roads can be designed according to the existing ground conditions and planned land use activities. The model also provides convenient local services and amenities within a five-minute walking distance by classifying blocks located between the perimeter one-way couplet roads as mixed land use zones. All intersections in the neighbourhood are controlled by roundabouts or three-way intersections to reduce the severity of collisions. Several studies have been found in the literature that address the benefits of the fused grid model in various aspects including: safety (Sun and Lovegrove, 2013), traffic performance (IBI Group, 2007), walkability (Frank and Hawkins, 2007), and transportation modal share (Masoud et al. 2017). While previous research like Frank and Hawkins (2007) and Masoud et al. (2017) has concluded that applying fused grid principles will result in more walking and less driving, which obviously would result in reducing GHG emissions, none of the previous research quantified by how much would GHG be reduced and thus quantifying its social benefits.

This research aims at modelling the influence of fused grid design principles on GHG emissions by utilizing a recently developed TRIp-Based Urban Transportation Emissions (TRIBUTE) model (Rahman and Idris, 2017). The paper presents a case study that compares GHG emissions of an existing grid neighbourhood in the City of Kelowna, British Columbia with a theoretically retrofitted model of the same neighbourhood.

Literature Review

Understanding the factors influencing global GHG emissions is key to developing appropriate mitigation strategies. Many previous studies have reported on the environmental impact of global GHG emissions and their intensity (Bristow et al., 2008; Davis and Caldeira, 2010; Jung et al., 2012; Xiangzhao and Ji, 2008). According to the framework for sustainability, introduced by Ehrlich and Holdren (1971), relationship between human activity and its impact can be ascertained by using IPAT identity. IPAT refers to the environmental impact (I) consists of population (P), affluence (A), and technology (T). Further, the application of the IPAT with energy and emissions has led to the Kaya framework (Ramanathan, 2006). According to the Kaya framework, global GHG emissions are influenced by the following four driving factors: global population, gross world product, global energy consumption, and carbon intensity of energy (Kaya, 1990).

Many researchers rely upon the Kaya equation to estimate global as well as national emissions (Mahony, 2013; Raupach et al., 2007; Timilsina and Shrestha, 2009). However, the available models to estimate and forecast transportation-related GHG emissions can be broadly categorized as two groups, which are context specific and vary greatly in complexity and data requirements based on their detail level, application domain, and policy sensitivity. The first group translates the changes in vehicle technology and/or operating characteristics into estimating and forecasting fuel consumptions and subsequently, GHG emissions factors. the U.S. Environmental Protection Agency (EPA)'s Motor Vehicle Emissions Simulator (MOVES) and MOBILE6 are belongs to the first group. On the other hand, the second group focuses on estimating and forecasting GHG emissions from the transportation sector in response to changes in sociodemographic, transportation, and/or land use characteristics (Concas and Winters, 2007; Grant et al., 2008; Winters et al., 2010; Concas and Winters, 2012; Lin, 2014). For instance, Municipal Transportation and Greenhouse Gas (MUNTAG) model was developed by Derrible et al. (2010) to help municipalities estimate their GHG emissions. Further, MUNTAG model was implemented by Sugar and Kennedy (2012) to calculate GHG emissions from private automobiles, buses, streetcar, light rail transit, and subway. However, this model suffered by utilization of the empirical formulas that may not represent local travel behaviour. In addition, MUNTAG is unable to capture land use mix in estimating and forecasting transportation-related emissions. On the other hand, another model, Trip Reduction Impacts for Mobility Management Strategies (TRIMMS), developed by Mahendra et al. (2012) has been used to calculate GHG emissions under various Transportation Control Measures (TCM). However, emissions factors used in this model are retrieved by running the USEPA's MOVES that needs huge amount of data on its detail level. It is apparent that there is no universal model for estimating and forecasting GHG emissions from the transportation sector.

As such, Rahman and Idris (2017) developed a TRIp-Based Urban Transportation Emissions (TRIBUTE) model to address the aforementioned limitations of the available models. TRIBUTE is used to estimate and forecast transportation-related GHG emissions at the macroscopic level to help municipalities evaluate alternative transportation and land use policy scenarios and eventually select the one(s) that help them meet their future GHG emission targets. TRIBUTE model can capture the impacts of transportation and land use planning/TDM policies on travel behavior, and subsequently GHG emissions from passenger transportation. TRIBUTE is directly sensitive to various sociodemographic information, modal level-of-service attributes, and land use factors, making use of HHTS data. Further, TRIBUTE is indirectly sensitive to vehicle technology and fuel efficiency, making use of emissions inventories. Moreover, TRIBUTE is trip-based, which means that emissions are calculated per trip (i.e. not over a link), making it applicable in small municipalities, where a detailed transportation network model is absent.

Methodology

This study uses a macroscopic level approach to evaluate the impact of fused grid on GHG emission levels under different neighbourhood street pattern scenarios. The methodology involves:

1. Identify the study area.
2. Develop fused grid design alternatives for the study area
3. Use TRIBUTE to estimate GHG emissions in the existing and alternative scenarios.

Study Area

The selected study area for this research is a 16 hectares neighbourhood located in the South-Central part of Kelowna, British Columbia. The neighbourhood street network is mainly a grid with only one culs-de-sac. This has encouraged traffic to take shortcuts through local roads to reach two major traffic generators located near the neighbourhood including Kelowna General Hospital and Okanagan Lake recreational uses.

Fused Grid Design Alternatives

Two fused grid design alternatives were developed for the neighbourhood, as shown in Figure 1, to examine the impact of fused grid design principles on GHG emissions. Both designs include a series of local road closures to prevent shortcutting through local. The areas that resulted from road closures were preserved to provide green spaces and active transportation corridors in order to maintain high connectivity for pedestrian and cyclists.

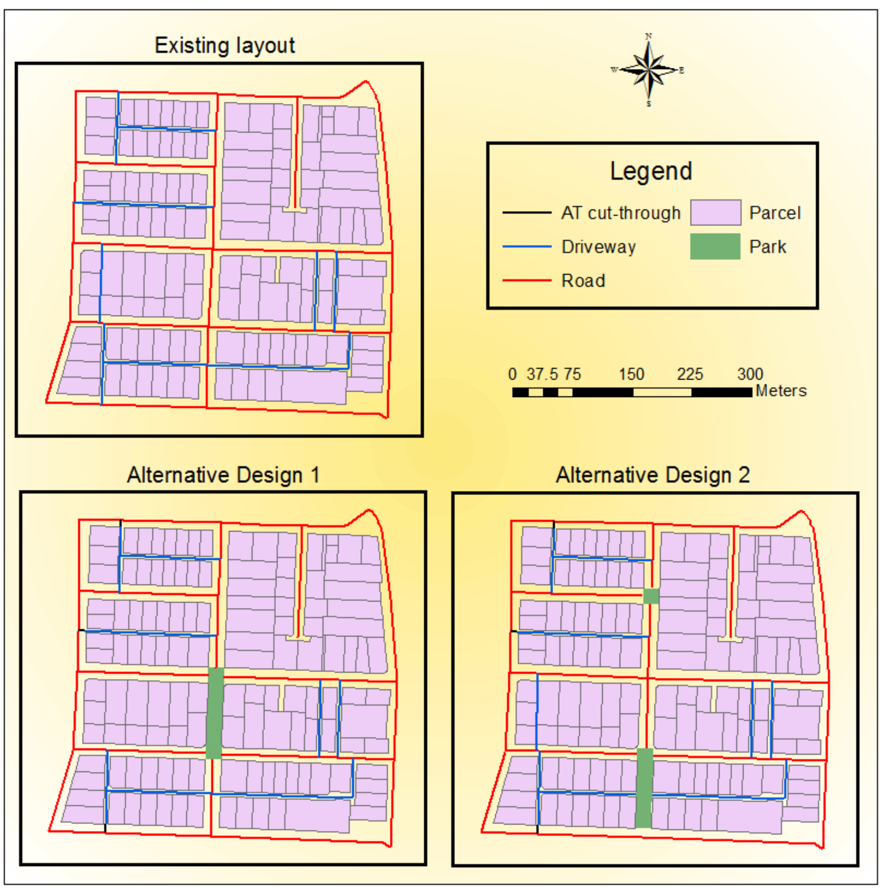

Figure 1. Fused Grid Design Alternatives

TRIBUTE Model
The TRIp-Based Urban Transportation Emissions (TRIBUTE) model was used to quantify the transportation-related emissions from the developed fused grid neighbourhood design alternatives. TRIBUTE deals with the relation between on-road passenger GHG emissions and the total VKT. Since GHG emissions are directly proportional to the total VKT and VKT is affected by several factors (i.e. land use and built environment), increasing land use density, balancing diversity (i.e. land use mix), and improving design can significantly decrease VKT, reduce per capita energy use, and lower GHG emissions (Taylor, 2001).

Figure 2 demonstrates the conceptual framework of TRIBUTE. TRIBUTE is composed of two main components: a mode choice model and an emissions forecasting model. The first component accounts for the determinants of VKT reduction (i.e. trip length reduction and mode shift). The second component translates the results in terms of GHG emissions. TRIBUTE derives its strength from its behaviorally sound core (i.e. mode choice model) that allows for proper representation of travel behavior and mode shift analysis. The detailed methodology of TRIBUTE can be found in Rahman and Idris (2017).

The step-by-step procedure in estimating and forecasting transportation-related emissions using TRIBUTE can be summarized as follows:

1. Mode choice models were developed by using data from the 2013 Okanagan household-based Travel survey. The developed mode choice models were responsible for estimating the proportion of trips made by each mode of travel (i.e. auto driver, transit rider, and active transportation) in response to changes in personal, modal, and land use attributes
2. Then, the emissions forecasting model started with calculating the total passenger kilometers traveled (PKT) by each mode given the respective average modal PKT (extracted from emissions inventories or HHTS)
3. By running its joint mode choice and emissions forecasting models, TRIBUTE was used to forecast GHG emissions by considering mode shift and reduction in trip length from the different fused grid designs

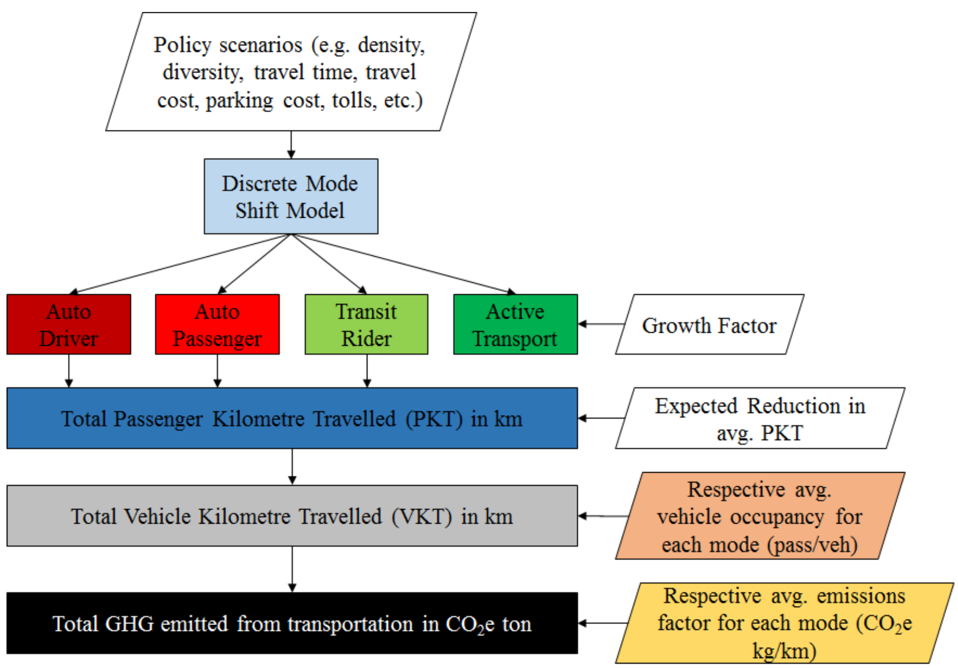

Figure 2. TRIp-Based Urban Transportation Emissions (TRIBUTE) Model (Rahman and Idris, 2017)

Mode choice models

In this study, a couple of mode choice models (i.e. work trip and non-work trip models) were developed to estimate modal shift due to changes in street connectivity only (i.e. travel time and distance). The 2013 Okanagan household travel survey data was used to develop these models. Work trips in the dataset are defined as trips from home to work/school or vice versa, while Non-work trips represent all other trips that were not related to work or school, including trips 1) to restaurants, 2) for recreation, 3) social outing, 4) for personal business, or 5) shopping. The data includes socioeconomic, demographic, and mode choice information of approximately 3,050 households and 25,000 trip records in the Okanagan region. The data was cleaned to include only observations where both trip ends are located in Kelowna, and to exclude observations with missing data. Three utility functions were estimated for each model as follows: 1) automobile, 2) transit, and 3) active transportation.

The modelling results show that travel time is negatively correlated with using the auto mode; however, the impact of trip time on choosing the auto mode for work trips was more pronounced compared to non-work trips. For AT mode, the models show that travel distance is strongly negatively associated with walking and cycling with a similar impact for work and non-work trips.

Results

The results of the mode choice modelling, presented in Table 1, revealed promising results for the impact of fused grid design principles on work trips. It shows that both FG design alternatives were successful in reducing auto use share by 10 percent and 40 percent increase in walking and cycling modes (Table 1). On the other hand, results are not that promising for non-work trips as the reduction in auto use is less that 1 percent and the increase in walking and cycling is approximately 10 percent only. This suggest that other factors, such as land use, might be more important for people when deciding what transportation mode they will use for non-work trips.

Table 1: Modal Shift

	Work Trips			Non-work trips		
	Auto	Transit	AT	Auto	Transit	AT
Existing	79.2%	8.7%	12.0%	93.5%	1.5%	5.0%
Design 1	71.5% (-7.7%)	11.6% (+2.9%)	16.9% (+4.9%)	92.9% (-0.6%)	1.6% (+0.1%)	5.5% (+0.5%)
Design 2	72.1% (-7.1%)	11.4% (+2.7%)	16.5% (+4.5%)	92.9% (-0.6%)	1.6% (+0.1%)	5.5% (+0.5%)

In addition, both FG design alternatives demonstrated higher reduction in trip length for car users. In particular, Design 1 was successful in reducing trip length by 44.34%, on the other hand, there were 37.93% reduction in trip length in Design 2. The reduction in trip length by retrofitting fused grid designs is illustrates in Figure 3.

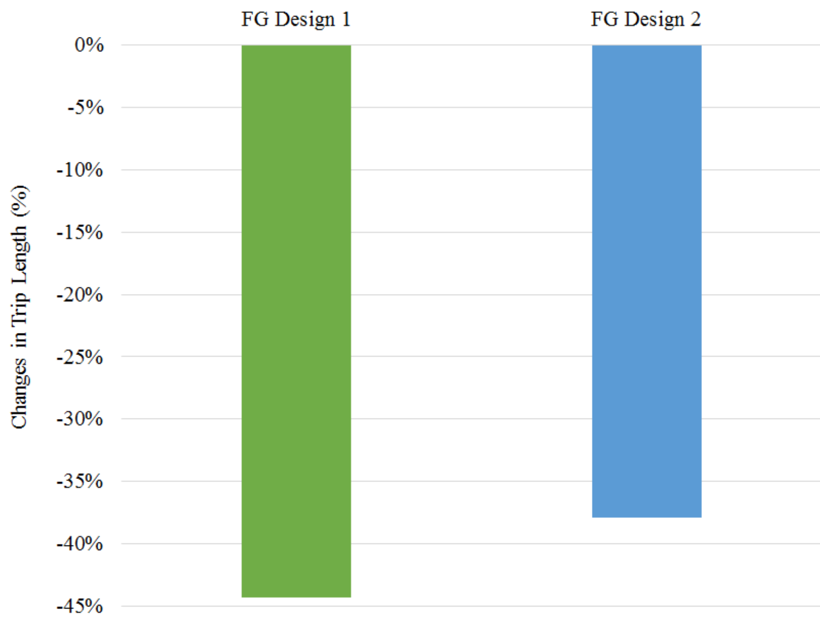

Figure 3: Trip length reduction by retrofitting fused grid neighbourhood designs

By running mode choice and emissions forecasting components of the TRIBUTE model, GHG emissions from fused grid alternatives were estimated by considering corresponding mode shift and trip length reduction from the different alternatives. As shown in Figure 4, that the implementation of fused grid design alternatives leads to substantial reduction in GHG emissions from the transportation sector. Specifically, there is 44.6% reduction in GHG emissions from FG Design 1, due to the higher reduction in trip length as well as greater mode shift towards active transportation. On the other hand, FG Design 2 showed 38.5% reduction in transportation-related GHG emissions. Both fused grid designs demonstrated very promising reduction in emissions.

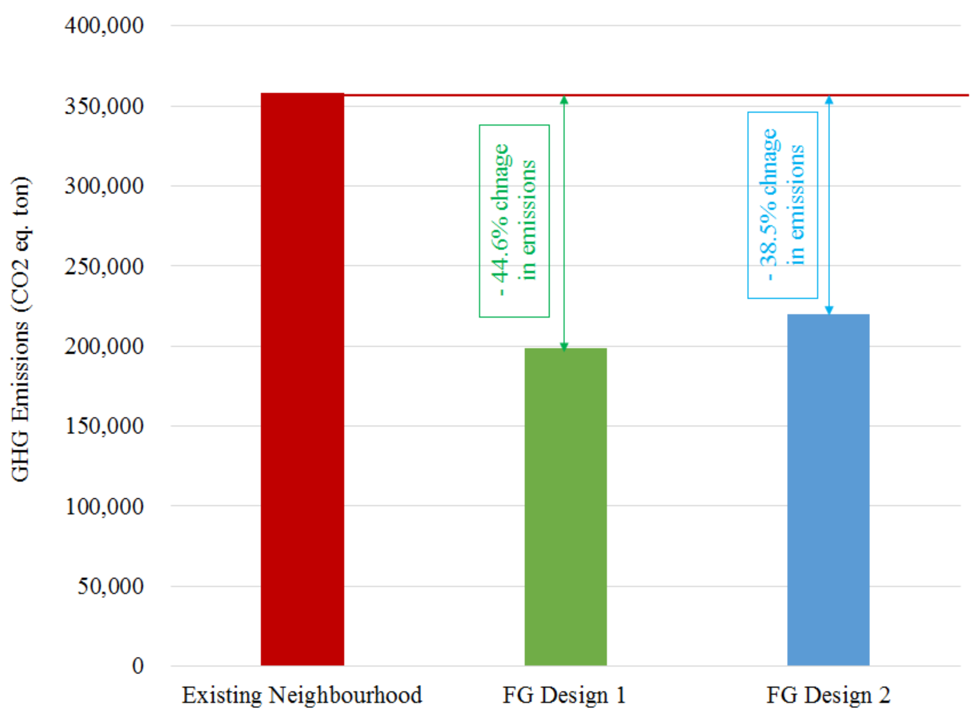

Figure 4: GHG emissions from fused grid neighbourhood designs

Conclusions

Fused Grid Neighborhood Design Principles combine the best characteristics of the conventional culs-de-sac and traditional grid neighborhood patterns, and features many design elements including compact higher density and mixed land uses, car-free cores and central greens, and ubiquitous convenient smaller green spaces for restorative play/rest areas and social interaction opportunities. Different aspects of fused grid design principles, such as safety, traffic performance, walkability, and mode shift were quantified before; however, no one quantified GHG emissions from different fused grid design. This study focused on quantifying transportation-related emissions from different FG design alternatives by utilizing a novel trip-based emissions model, TRIBUTE.

Fused grid neighbourhood design principles showed a promising modal shift towards active transportation from car driving as well as a large reduction in trip length for those who keep driving. By combining these two aspects of fused grid design principles (i.e. mode shift and trip length reduction), TRIBUTE shows a significant amount of GHG emissions reduction that can be achieved by retrofitting fused grid design. In particular, a maximum of about 45% reduction in GHG emissions can be achieved by implementing fused grid design principles.

This study only considered the street connectivity aspects of fused grid design principles. However, this research can be extended by considering all other characteristics of fused grid, such as population density and land use. Furthermore, it would be interesting to include a third aggressive scenario that include acquiring access to private land, thus examining the full potential of the fused grid design principles without being restricted to the existing conditions of the neighbourhood.

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