Motivation and implementation of traffic management strategies to reduce motor vehicle emissions in Canadian cities

Alexander Y. Bigazzi and Amr Mohamed

Abstract: There is a pressing need to reduce pollution emissions from transportation and consequent negative effects on air quality, public health, and the global climate. Diverse traffic management strategies have been proposed and undertaken with primary or secondary goals of reducing motor vehicle emissions. The objective of this paper is to investigate the motivation and implementation of traffic management strategies to reduce motor vehicle emissions, with a focus on moderate-scale local and regional strategies that are broadly applicable. Public documents from 44 local, regional, and provincial government entities across Canada were reviewed for information regarding the implementation of 22 traffic management strategies. Results show that different levels of government are involved in the implementation of different types of strategies, and with a different mix of traffic, safety, and environmental motivations. Regional governments more frequently cite environmental motivations and appear to be most interested in the two strategies with the strongest empirical evidence of air quality benefits: area road pricing and low emission zones. Strengthening regional transportation planning and better integrating it with municipal and provincial planning could potentially increase the implementation of effective sustainable traffic management strategies in Canada. Additional opportunities exist through emphasizing the potential environmental co-benefits of strategies such as road pricing, speed management, and traffic signal and intersection control improvements.

Key words: traffic management, travel demand management, emissions, air quality, sustainability.

Résumé : Il y a un besoin urgent de réduire les émissions de pollution du transport et leurs conséquences négatives sur la qualité de l'air, la santé publique et le climat mondial. Diverses stratégies de gestion de la circulation ont été proposées et entreprises dans le but principal ou secondaire de réduire les émissions de véhicules automobiles. L'objectif de cette étude est d'examiner la motivation et la mise en œuvre de stratégies de gestion de la circulation visant à réduire les émissions de véhicules automobiles, en portant une attention sur les stratégies locales et régionales d'envergure moyenne qui sont applicables à grande échelle. Des documents publiés de 44 entités publiques locales, régionales et provinciales à travers le Canada ont été passés en revue afin d'obtenir des informations quant à la mise en œuvre de 22 stratégies de gestion de la circulation. Les résultats montrent que les différents niveaux de gouvernement sont engagés dans la réalisation de différents types de stratégies et que leurs motivations en matière de trafic, de sécurité et d'environnement sont différentes. Les gouvernements régionaux évoquent plus fréquemment des motivations environnementales et semblent être les plus intéressés par les deux stratégies dont la preuve de leurs avantages en matière de qualité de l'air a été faite : la tarification routière par secteur et l'établissement de zones à émissions limitées. Assurer la planification de transport régional et une meilleure intégration de celle-ci avec la planification municipale et provinciale pourrait hausser la mise en œuvre de stratégies durables et efficaces de gestion de la circulation au Canada. De nouvelles possibilités existent par la valorisation des retombées environnementales potentielles découlant de stratégies comme la tarification routière, la gestion de la vitesse et les améliorations de la gestion de la circulation aux feux et aux intersections. [Traduit par la Rédaction]

Mots-clés : gestion de la circulation, gestion de la demande en transport, émissions, qualité de l'air, durabilité.

Introduction

Traffic-related air pollution generates significant negative health impacts, as confirmed by a robust body of scientific literature (Brauer et al. 2012; Health Effects Institute 2010). In addition, the transportation sector emits a large and increasing portion of worldwide anthropogenic greenhouse gases, contributing to global climate change (IPCC 2014). Due to the scope and complexity of sustainability issues in the transport sector, multi-pronged, integrated strategy suites are often recommended for mitigating environmental and health impacts (Cambridge Systematics 2009; Hodges and Potter 2010; ICF International 2006; Kalra et al. 2012;

May 2013; U.S. Environmental Protection Agency 2011a). Traffic management is one broad category of strategies for reducing motor vehicle emissions, distinct from technology-based and land-use strategies. Traffic management strategies (TMS) with potential emissions benefits include road pricing, operating restrictions, lane management, speed management, and various trip reduction strategies. The TMS primarily affect emissions through changes in the amount of vehicle kilometers traveled (VKT) and in emission rates (mass per VKT). The VKT is primarily affected by changes in travel activity (the number and distribution of trips) and travel mode, while emission rates are primarily affected by changes in vehicle speeds (including stop-and-go activity in congested urban driving) and the types of vehicles driven.

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A recent systematic review of the literature evaluated the empirical evidence for traffic management strategies mitigating air pollutant emissions, air pollutant concentrations, human exposure to air pollutants and health impacts associated with motor vehicle emissions (Bigazzi and Rouleau 2017). Although relationships among motor vehicle traffic, emissions and air quality are well established, the review identified limited empirical evidence of the effectiveness of implemented TMS in reducing emissions and improving air quality. It should be noted that a lack of empirical evidence does not necessarily mean a lack of benefits (van Erp et al. 2012), and many modeling studies support the implementation of TMS to reduce motor vehicle emissions. Among the 22 reviewed TMS, the strongest evidence for air quality benefits exists for area road pricing and low emission zones. The strongest evidence for emissions benefits exists for road pricing, vehicle operating restrictions, lower speed limits, eco-driving, intersection control devices, traffic signal timing, and employer-based programs.

Some sustainable transportation strategies can be implemented through broad policies pursued at high levels of government and industry, such as fuel or carbon pricing, vehicle or fuel technological development, and vehicle or fuel standards and regulations. Other strategies are typically implemented by local or regional governments, particularly those related to traffic management and land use. The scale of application is important because local governments often lack the resources to model the full impacts of proposed projects and policies in detail (Grote et al. 2016). Hence, knowledge gaps about TMS effectiveness are particularly a problem for local and regional strategies.

To better inform decision-making for sustainable transportation, there is a need to improve the body of knowledge regarding the real-world effects of TMS. Additionally, there is a need to better understand how to increase implementation of effective TMS by local and regional governments. As a first step, it is necessary to know the extent to which different TMS are implemented in different municipalities. Furthermore, because air quality and environmental considerations are typically ancillary motivations for transportation projects, it is also important to understand the motivations for those implementations, and the extent to which they include emissions, air quality, and health-related objectives.

The objective of this paper is to summarize the motivation and implementation of traffic management strategies in Canadian cities. The goal is to improve understanding of moderate-scale local and regional traffic management strategies that are broadly applicable. Strategies that rely on extensive capital investment or new vehicle and fuel technology are outside the scope of study, as are sustainable transportation initiatives based on land-use planning and urban form. Publicly available, English-language transportation plans, activity reports, and similar documents were retrieved from multiple levels of government for a sample of small, medium, and large cities across Canada. These documents were reviewed to assess (1) which TMS are being implemented at the municipal, regional, and provincial levels; and (2) whether TMS are being implemented with emissions, air quality, and health-related objectives.

Methods

Scope and categorization of strategies

Traffic management strategies for reducing motor vehicle emissions can be categorized in numerous ways. One main distinction comes from an economic framework, where supply-side and demand-side approaches are separated (ICF International 2006; Noxon Associates Limited and Commuting Solutions 2008), giving rise to Travel Demand Management (TDM) strategies (Litman 2003; Noxon Associates Limited 2011). Other important categorizations come from U.S. environmental policy. Transportation

Control Measures (TCM) are part of the suite of air pollution control strategies sanctioned under the U.S. Clean Air Act (Adler et al. 2012; U.S. Environmental Protection Agency 2011b). Separately, the U.S. Department of Transportation has the long-running Congestion Mitigation and Air Quality Improvement Program (CMAQ) for transportation projects designed to reduce congestion and improve air quality (Federal Highway Administration 2010; Koontz 2012). CMAQ prioritizes TCM and limits funding to projects that do not provide new roadway capacity for single-occupant vehicles. The scope of CMAQ projects is quite broad, although traffic-flow strategies are by far the most-funded type project (Battelle and Texas Transportation Institute 2014).

Consistent with the aforementioned review (Bigazzi and Rouleau 2017), TMS are organized into 22 categories in this study:

1. Operating restrictions and pricing strategies
   a. RCP: Road, congestion, and cordon pricing (tolling, distance pricing, or pricing based on time-of-day or congestion levels)
   b. LEZ: Low or zero emission zones, eco-zones (pricing or restrictions based on emission status of vehicles)
   c. VOR: Vehicle operating and access restrictions (zones, hours, and routes)
   d. PKM: Parking management (supply and pricing)
2. Lane management strategies
   a. HOL: High occupancy vehicle (HOV), high occupancy toll (HOT), and eco-lanes
   b. TBL: Truck and (or) bus lanes
   c. LCC: Lane capacity changes (road diets, peak shoulder running)
3. Speed management strategies
   a. LSL: Lower speed limits
   b. VSL: Variable speed limits
   c. SCD: Speed control devices (traffic calming such as humps, chicanes, micro-roundabouts)
   d. SED: Speed enforcement devices and programs
   e. ED: Eco-driving, eco-routing
4. Flow control strategies
   a. RM: Ramp meters
   b. ETC: Electronic toll collection
   c. IMS: Incident management systems
   d. ICD: Intersection control device (roundabout, signal, stop signs, etc.)
   e. TST: Traffic signal timing (signal coordination, adaptive signal systems, transit signal priority, etc.)
5. Trip reduction strategies
   a. SRP: Shared-ride programs (carpool, vanpool, rideshare programs; incentives; and services)
   b. EP: Employer programs for trip reduction (flex-time, telework)
   c. TI: Transit improvements (pricing, service quality, etc.)
   d. PBF: Pedestrian and bicycle facilities (roadway and trip-end facilities)
   e. OM: Outreach and marketing (to reduce auto use)

Selecting governments for review

The first step was to select the entities (provincial, regional and municipal governments and transport agencies) to review. The location selection criteria were developed in an effort to identify cities of varying size and geography, and with sufficient population to warrant traffic management strategies. Population data were drawn from the 2011 Canadian Census (Statistics Canada 2012). The following entities were included in the review:

1. Provincial governments: provinces and territories with a total population over 500 000,
2. Regional governments: in each selected province, the two largest census metropolitan areas (CMA) with population exceeding 100 000, and

Fig. 1. Locations of reviewed municipalities (map image from Google Maps). [Colour online.]
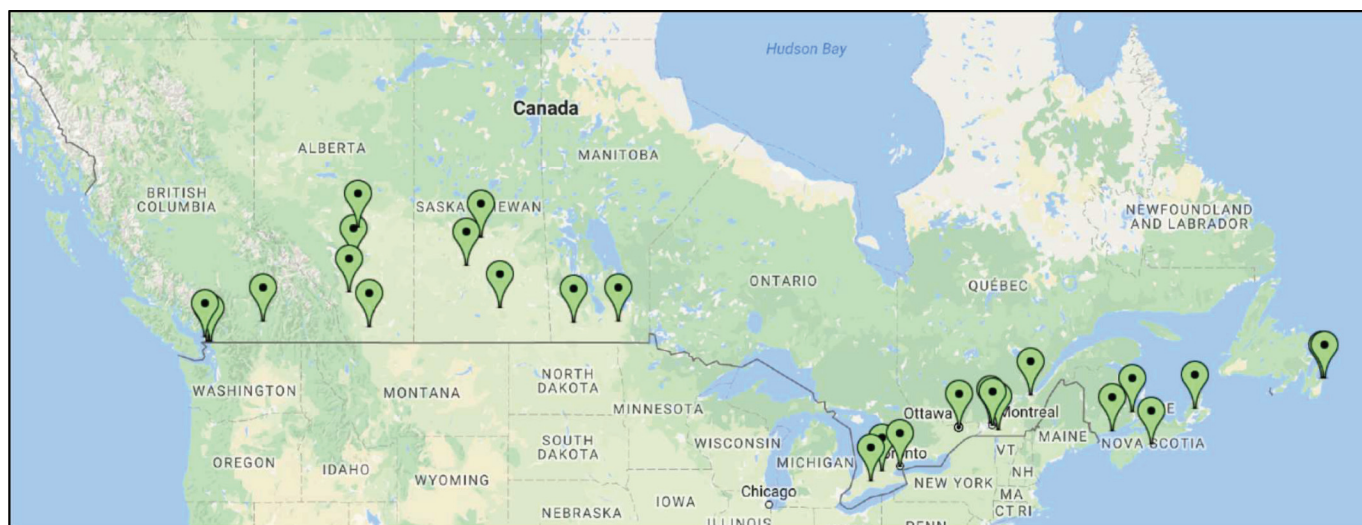
3. Municipal governments: the following municipalities in each selected province (potentially up to four per province):

a. Large cities: the two largest municipalities with population exceeding 500 000 and located in different CMA,
b. Medium cities: the largest municipality with a population under 500 000, and
c. Small cities: the largest municipality with a population under 100 000.

Application of these criteria identified 9 provinces, 12 regions, and 27 municipalities for inclusion. Several provinces did not have 2 CMA with population over 100 000, or 2 municipalities with population over 500 000 located in different CMA.

Document search

In November–December 2016, official websites for each entity were searched for documentation related to transportation and traffic management strategies, particularly transportation plans and reports. Retrieved documents were then searched for information related to the TMS as defined above. The exclusion of non-English documents was a limitation in some locations, for which much documentation was in French.

Additional internet searches were performed using the Google search engine for entities lacking relevant information on their public-facing official websites. The search terms used included the TMS names and traffic management, traffic calming, traffic signal, demand management, lane management, pricing, and parking management. The following four regional governments were excluded from the results due to a lack of publicly-available English-language documentation of traffic management: Quebec Metropolitan Community, the metropolitan area of Quebec City, Quebec (2011 population of 765 706); Saskatoon Region, the metropolitan area of Saskatoon, Saskatchewan (2011 population of 260 600); Greater Moncton, the metropolitan area of Moncton, New Brunswick (2011 population of 138 644); and Greater Saint John, the metropolitan area of Saint John, New Brunswick (2011 population of 127 761).

Information coding

Retrieved documents were reviewed and the following coding system was used to summarize the information on implementation of each TMS for each entity:

- A: the strategy is currently **Applied** in the location,
- P: the strategy is not currently applied, but has been **Proposed** in transportation plans, reports, or similar official documentation,

- C: the strategy has not been applied or proposed, but the government or a relevant organization has stated interest and is currently **Considering** or exploring the strategy, and
- NA: no available information on the TMS for the entity.

Note that a designation of "NA" does not necessarily mean that the strategy is not implemented, but rather that no documentation of it was found. This distinction could be relevant for strategies such as intersection control devices that are nearly ubiquitously used but not always mentioned in transportation plans or reports.

In addition to the implementation status of the TMS, the retrieved documents were reviewed to assess the stated motivations for applying or proposing the TMS. The status codes above were suffixed with the following supplementary codes for motivations:

- E: Environment, emissions, exposure, air quality, or health motivations,
- S: Safety motivations such as reducing collisions and fatalities, and
- T: Traffic motivations such as reducing congestion and travel time.

If multiple motivations were stated, their codes were appended in the order of decreasing importance or priority suggested in the documents. For example, if a municipality reported currently applying a TMS and cited expected safety benefits with reduced congestion as a co-benefit, the complete code would be "A-ST".

Results

The TMS implementation results cover 44 entities: 9 provinces, 8 regions, and 27 municipalities. The locations of the 27 reviewed municipalities are shown on the map in Fig. 1, spanning the longitudinal breath of Canada but concentrated, like the population, near the southern border.

TMS implementation status

Figure 2 summarizes the status of all 22 studied TMS in terms of the number of entities (out of 44) reporting that the strategy is applied, proposed, or considered. The results show wide implementation of many of the TMS. The most commonly identified strategies (applied, proposed, or considered), decreasing from most frequent, are transit improvements, pedestrian and bicycle facilities, parking management, lower speed limits, shared-ride programs, and intersection control devices. The least commonly identified strategies, increasing from least frequent, are low emission zones, outreach and marketing, ramp meters, variable speed

Fig. 2. Status of TMS implementation among 44 reviewed entities. [Colour online.]
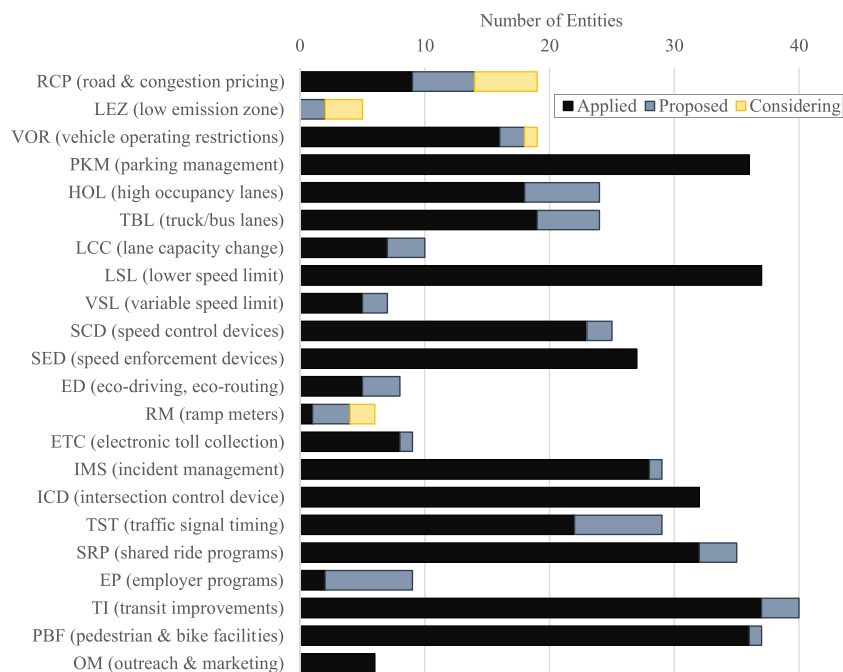
limits, and eco-driving. Four strategies are more often proposed and considered than applied, potentially indicating growth in these areas: low emission zones, employer programs, ramp meters, and road and congestion pricing.

Figure 3 shows the percent of each type of entity reporting applied, proposed or considered implementation of each TMS. On average, TMS are being implemented or considered in 51% of provinces, 49% of municipalities, and 45% of regions. The relative balance among the three levels of government suggests that all three levels would be appropriate targets for initiatives promoting implementation of TMS. Regional governments appear to be the entities most interested in low emission zones, whereas provincial and municipal governments are more focussed on speed, parking and incident management, and intersection control devices.

Figure 4 shows the number of TMS applied, proposed, or considered in each of the 27 municipalities versus population (log scale), along with the province in which the municipalities are located. Medium and large cities across Canada are implementing or considering many of the TMS. All 8 "large" cities with population over 500 000 are implementing or considering at least half of the 22 TMS. The number of reported TMS increases with city size, as could be expected by both needs and resources for implementation. However, these results could also be affected by the resources available in each city for providing public documentation of traffic management strategies. In other words, larger cities could be implementing more TMS and also providing more public documentation of their traffic management efforts. Some of the TMS likely have threshold effects, meaning they would only be justified in cities large enough to have significant traffic congestion problems. Other strategies are basic municipal functions (parking, speed limits, intersection controls), and so could be implemented by any municipal government.

Motivations for TMS implementation

Figure 5 summarizes the stated motivations (environment, safety, and traffic) for applied, proposed, or considered TMS. Mitigating traffic congestion is the dominant stated motivation for half of the TMS. Environmental concerns are the dominant stated motivation for shared-ride programs, pedestrian and bicycle facil-

ities, eco-driving, and low emission zones. Safety is the dominant stated motivation for intersection control devices and four of the speed-management strategies (lower speed limits, variable speed limits, speed enforcement devices, and speed control devices). On average, environment, safety, and traffic motivations are expressed for 20%, 26%, and 34%, respectively, of the implemented or considered TMS. These results suggest that diverse benefits are being considered in TMS implementation. Enhanced messaging about co-benefits could potentially encourage further application.
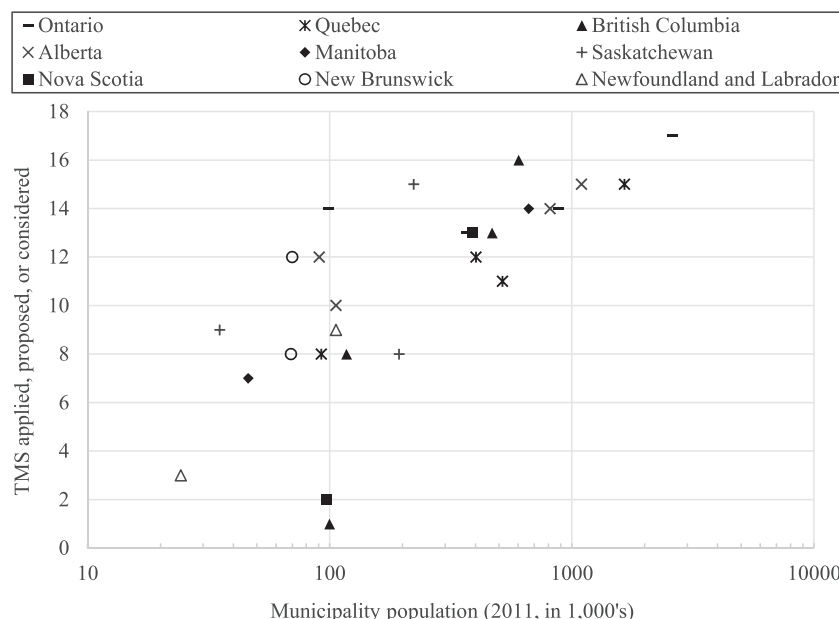
Figure 6 shows the average number of TMS, per entity, with each type of stated motivation. Traffic improvement is the most frequently-cited motivation for municipal and regional governments, while safety is the most frequently-cited motivation for provincial governments. Environmental motivations appear in all three entity types, most frequently for regional governments, which could reflect the important role of regional governments in urban air quality management. These results suggest that environmental messaging is a potentially effective motivator for TMS at all three levels of government.

Comparison with TMS effectiveness

Several interesting findings emerge when the implementation results are put into context of the recent review of TMS effectiveness (Bigazzi and Rouleau 2017). Firstly, regarding the state of evidence, existing literature on TMS suffers from a lack of ex-post analysis of implemented strategies. That shortcoming is understandable for strategies such as ramp meters and variable speed limits that have received ample attention in the literature but little implementation in Canada. Conversely, many of the TMS are widely implemented, providing numerous opportunities for before-and-after studies of emissions and air quality effects.

Regarding TMS implementation, only two strategies in the literature review had empirical evidence of generating air quality benefits: low emission zones and area road pricing. Unfortunately, these strategies are not currently implemented in Canada, and are only being considered in a few locations — which is a stark contrast to Europe (Croci 2016; Holman et al. 2015). Of the seven strategies identified in the review as having empirical evidence of emissions benefits, only three are broadly applied or proposed in Canadian cities: lower speed limits, intersection con-

Fig. 3. Percent of entities by type implementing or considering each TMS. [Colour online.]

Fig. 4. Number of TMS (out of 22) applied, proposed or considered in each municipality.

trol devices, and traffic signal timing. Thus, there are opportunities to increase implementation of some of the more effective TMS in cities and regions across Canada.

Regarding motivations, road pricing has good potential for generating emissions and air quality benefits, but that is not currently a stated motivation for reviewed Canadian governments. Similarly, vehicle operating restrictions and lower speed limits can potentially generate emissions benefits, but those benefits appear not to be a strong motivating factor in Canadian cities.

Environmental motivations are also uncommon for intersection control devices and traffic signal timing strategies, for both of which there is some empirical evidence in the literature of potential emissions benefits. These discrepancies present opportunities to encourage TMS implementation by emphasizing the potential environmental co-benefits for strategies primarily pursued for safety and congestion reasons. Environmental benefits are a stated motivation for several strategies for which existing literature provides insufficient empirical support, including shared

Fig. 5. Stated motivations for TMS implementation among 44 reviewed entities. [Colour online.]
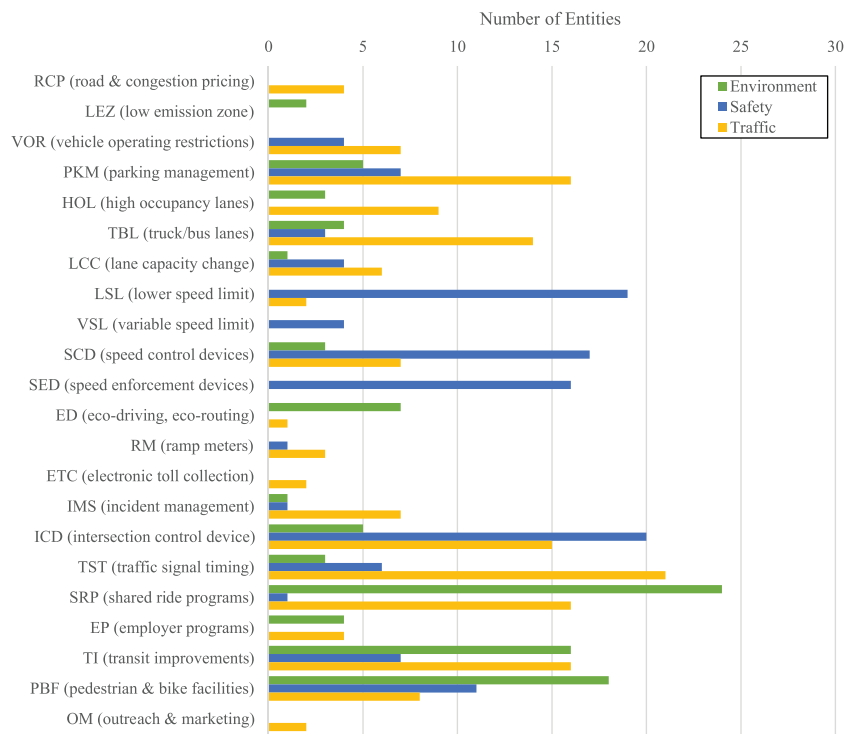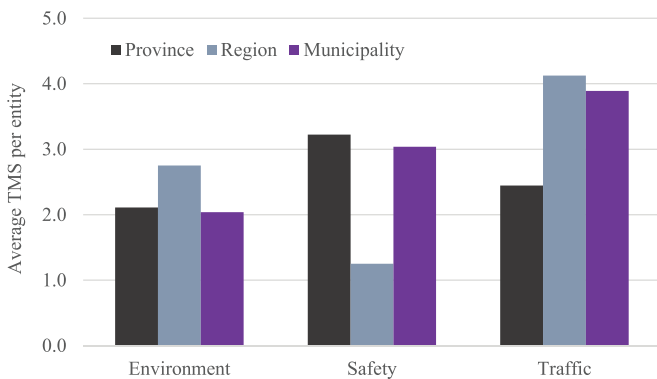

Fig. 6. Average number of TMS per entity with each type of stated motivation. [Colour online.]

ride programs and transit improvements. These strategies can yield emissions and air quality benefits, as modeling suggests, and should be pursued, but implementation should be coupled with robust ex-post analysis of real-world effects to strengthen the environmental case for further implementations.

Conclusions

This study reviewed public documentation of 22 potential traffic management strategies for reducing motor vehicle emissions in 44 local, regional, and provincial government entities across Canada. Many of the TMS are broadly implemented, with a mix of traffic, safety, and environmental objectives. Additional opportunities exist and could be encouraged by emphasizing the potential environmental co-benefits of strategies such as road pricing, speed management, and traffic signal and intersection control improvements. Other TMS are rarely implemented, including the two strategies with the most empirical evidence of air quality benefits: area road pricing and low emission zones. These are also two of only four strategies that are more often proposed and considered than actually implemented. These two strategies, in

particular, should be given more serious consideration in efforts to improve air quality and reduce the carbon footprint of Canadian cities.

Municipal, regional, and provincial governments all have a role in the implementation of TMS, with different strategies more relevant to different levels of government. Regional governments appear to be most interested in road pricing and low emission zones, and also most frequently cite environmental motivations for implementing TMS. Thus, regional governments are the most likely avenue to introduce the types of ambitious TMS that have been shown to yield significant air quality benefits.

The governance model for transportation in Canada, however, is not conducive to implementing regional transportation projects with environmental objectives. A previous survey of transportation planning across Canada noted "weakened regional visions within most urban areas" and "clashes between municipal and provincial visions" (Hatzopoulou and Miller 2008), both of which can hinder implementation of ambitious traffic management strategies such as road pricing and low emission zones. Similar governance issues were noted in a study of efforts to increase water conservation in Canadian municipalities (Furlong and Bakker 2011). As a comparator, the Metropolitan Planning Organization (MPO) model in the United States has the advantage of a statutory requirement for joint transportation and air quality analysis and planning in regions with poor air quality through the "transportation conformity" process (Zhang et al. 2014). Statutory requirements for regional governments in Canada are weaker. Strengthening regional transportation planning and better integrating with municipal and provincial planning could potentially increase the implementation of sustainable traffic management strategies in Canada.

This paper provides a summary of TMS implementation across Canada, but with several notable limitations. One limitation is the exclusive use of publicly available, English-language documents. Direct, bilingual questioning of decision-makers could reveal additional information about TMS motivations and implementations. In future work, it would be useful to investigate further details of implementation (scope, cost, etc.) for a smaller set of

strategies. The role of TMS within the broader scope of environmental mitigation strategies should also be investigated, including transportation strategies outside the scope of this review (vehicle and fuel technology, new transit lines, land use and urban form, etc.) and strategies in other sectors (building efficiency, waste stream technologies, etc.). In particular, connections between travel (mode choice, VKT, energy consumption, etc.) and the built environment (land use, urban form, etc.) have been closely examined, with lower per capita emissions generally associated with more compact and mixed-use development (Cambridge Systematics 2009; Ewing and Cervero 2010; Hong and Goodchild 2014; Liu and Shen 2011). Although land-use strategies are outside the scope of this paper, they could influence TMS implementation and effectiveness, and future work should examine synergistic and antagonistic interaction effects between traffic management and land-use strategies.

In addition to the need to improve our understanding of TMS impacts on environmental outcomes, there is a need to better understand how evidence of TMS impacts can be effectively used to influence transportation decision-making. The results in this paper indicate some misalignments between the evidence base and implementations. Further investigation of the TMS implementation process could seek to identify the most effective methods of providing information about emissions and air quality impacts to the public and decision-makers. This information could be used to better target intervention efforts aimed at increasing the consideration of emissions and air quality in project development and decisions. Important questions include how public perception of traffic-related air quality issues impacts the implementation and acceptance of TMS, and how public understanding of these issues can be improved. Public acceptance is a particularly important question for implementing area road pricing and low emission zones, which are uncommon in North America (Currier 2008; Holman et al. 2015).

Acknowledgements

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