Evaluating emissions implications of proposed Intelligent Transportation Systems deployments: Canadian experience

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Abstract

This paper proposes general guidelines for integrating environmental impact evaluation in future ITS deployment studies. These guidelines are intended to assist parties undertaking future studies of ITS deployment plans to build environmental impact measures in their studies. The guidelines identify the kinds of analyses, operational indicators and proxies, and direct environmental measures (pre- and post-deployment) that would be recommended in the context of prototypical ITS deployments.
Keywords: emissions, Intelligent Transportation Systems, incident management, traveller information systems.

1 Overview

The transportation sector, being a major source of air pollution, can play a very important role in improving air quality. The challenge lies in improving air quality without adversely affecting the mobility of the nation. In this context, it is important to explore transportation options that may result in potential air quality benefits. Intelligent Transportation Systems (ITS) technologies and operational concepts are increasingly being considered an integral element for improving transportation system operations. For instance, Advanced Traffic Management Systems (ATMS) comprise strategies such as signal optimization and ramp metering, which are aimed at reducing recurrent congestion, and strategies like incident detection and rapid accident response, which are aimed at reducing non-recurrent congestion. Recently, interest has also focused on investigating the emissions implications of various ITS deployments.

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Network performance parameters and total emissions are, in principle, correlated. Poor traffic performance on a network with long queues and delays is typically associated with increased vehicle emissions. Conversely, a better traffic performance on a road network normally results in lower emissions. However, evaluation of air quality, in general, is a complex process. Evaluation of air quality benefits of ITS is further compounded by the fact that deployment of most ITS strategies has been relatively recent, and is largely still in its initial stages. To better understand expected air quality benefits of specific ITS deployments, the relation between ITS technologies and emission-producing activities needs to be clarified. The traffic operational attributes/improvements that are most likely to be impacted by ITS technologies are the following:

Operating Speeds – ATMS, including incident management, are expected to result in improved traffic flow and reduced congestion, which are typically translated into improved operating speeds. For the most part, such improvements in operating speeds translate into reduced emissions in the urban road network.

Vehicle Kilometres Travelled - The primary impact of ITS technologies on vehicle kilometres travelled (VKT) is positive in nature, with better traveller information likely to result in drivers making informed trip decisions in terms of route selection. Nevertheless, the overall impact of information-related ITS technologies on vehicle kilometres travelled (VKT) can be mixed, since additional vehicle trips may be undertaken with improved capacity and travel speeds resulting from advanced traffic management.

Engine Idling - ATMS are likely to reduce delays at intersections. In addition, better information may reduce time spent in congested traffic conditions, thus reducing engine idling.

2 Prototypical ITS deployments

In this paper, specific ITS deployments were identified and are considered as prototypical for the purposes of illustrating approaches for integrating environmental impact evaluation in future ITS deployment studies. The prototypical ITS deployments that were selected fall within three main User Services Bundles in the Canadian ITS Architecture. The prototypical deployments are incident management (Advanced Traffic Management) and pre-trip traveller information (Traveller Information).

3 Relevant Operational Indicators

In evaluating emissions impacts of ITS deployments, there is need to identify specific transport operational improvements that are most indicative of such emissions impacts. For each ITS deployment, the operational improvements that are most closely related to emissions implications need to identified. These are labelled as the “Relevant Operational Indicators” (ROI) and are relied on in further analysis. Table 1 presents a summary of the Relevant Operational Indicators (ROIs) for the three prototypical ITS deployments identified earlier.

Table 1: Relevant Operational Indicators for prototypical ITS deployments.

ITS Deployment	**Anticipated Operational Impacts**	**Relevant Operational Indicator(s) (ROI)***
Incident Management	Reduction in incident duration Reduction in secondary incidents Reduction in delays	Vehicle-kms of travel Average operating speeds Extent of idling delays+
Pre-Trip Traveler Information	Reduction in Average Annual Daily Traffic (AADT)	Vehicle-kms of travel

(*) The ROIs should be estimated for a certain operating period (e.g. peak period) and for both before and after deployment
(+) Vehicle-minutes spent idling (in queue) due to intersection or incident delays.

The ROIs in Table 1 reflect the state-of-knowledge conclusion that environmental benefits assessment of ITS generally requires quantifying the vehicle activity parameters such as vehicle speeds, vehicle kilometres travelled (VKT), and/or vehicle hours travelled (VHT). Once these “operational indicators” are estimated for the before- and after-deployment cases, relative changes in emissions resulting from changes in these activity parameters may be estimated as well.

Next, and building on existing knowledge bases stemming from previous studies, the general relationships between operational improvements achieved through ITS strategies and the parameters that affect transport emissions (and air quality in general) are developed.

3.1 ROIs for prototypical ITS deployments

3.1.1 Incident management

Incident detection provides the responsible agency with the capacity to observe incident locations and subsequent congestion. This enables the agency to respond quickly, with likely reductions in incident duration. Further benefits are likely to accrue from subsequent reductions in secondary incidents resulting from the primary incident. The main relevant operational indicator (ROI) which is to be estimated/monitored is the extent of idling delays. Due to the expected reductions in incident duration and in secondary incidents based on the deployment of an incident management system (such as using video-based surveillance), a reduction in total incident-related idling delays would most likely be experienced. Due to re-routing and quicker incident clearance, an incident management program could also result in an improvement in operating speeds. The relevant operational indicators (ROIs) which are to be estimated/monitored include vehicle-kms of travel and average operating speeds.

3.1.2 Pre-trip traveller information

The impact of information-related ITS technologies on trip-making can be mixed. While better information may result in drivers making informed trip decisions in terms of route selection, additional vehicle trips may be undertaken with improved capacity and travel speeds. Nevertheless, some studies have indicated that traveller information systems are expected to result in a reduction in Average Annual Daily Traffic (AADT). The main relevant operational indicator (ROI) which is to be estimated/monitored is the vehicle-kms of travel during the peak period, for instance, on roadway corridors covered by the pre-trip traveller information system.

3.2 General relationships between ROIs and emissions implications

In general, total vehicular emissions on a roadway network (or any part thereof) result from moving vehicles and idling vehicles. These two components are typically computed as follows:

Mobile emissions = vehicle-kms of travel * mobile emission factor (gms/veh-km)
Idling emissions = vehicle-mins of queuing * idle emission factor (gms/veh-min)

It is to be noted that the (mobile) emission factor is a function of vehicular operating speed as well as fleet characteristics, while the idle emission factor is a function of fleet characteristics. As such, the relation between relevant operational indicators (ROIs) above for the prototypical ITS deployments and emissions implications is summarized in Table 2 below. A “direct relation” implies that a reduction in the ROI would imply in principle a similar, equivalent reduction in emissions. On the other hand, the emissions implication of a change in operating speed is not direct or clear-cut. Rather, emission factors for the main pollutants typically drop and then rise again with speed. While the absolute values of the emission factors depend on fleet characteristics (and other issues), Figure 1 presents typical variation in CO, HC, and NOx emission factors with speed.

Table 2: General relationships between ROIs and emissions implication.

Relevant Operational Indicator (ROI)	Emissions Implication
Extent of idling delays (vehicle-mins of queuing)	Direct relation
Vehicle-kms of travel	Direct relation
Average operating speeds	Indirect relation – change in mobile emission factor

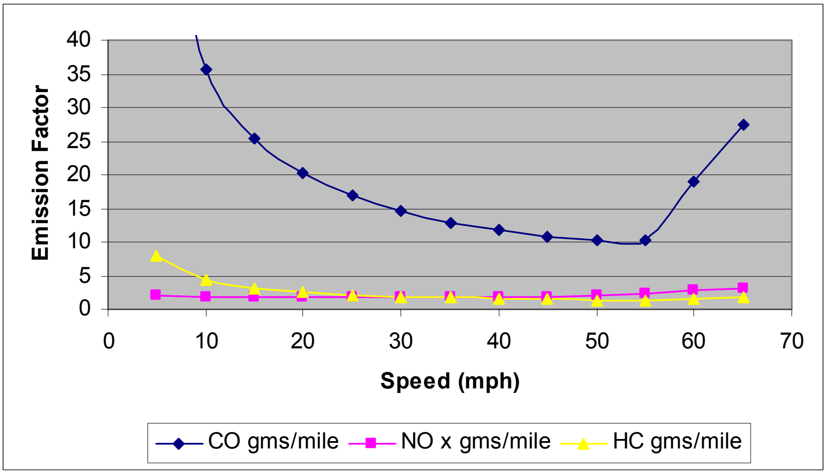

Figure 1: Typical variation in emission factors with operating speed. Source: estimating the effects of urban transportation alternatives. Federal Highway Administration (FHWA), Dec. 1995.

4 Proposed approaches

This paper suggests alternative approaches for integrating environmental impact evaluation in future ITS deployment. The approaches reflect different levels of analysis sophistication that may be applied selectively, depending on the context and the technical capabilities of the agency undertaking the deployment exercise. The concept of the ROIs is central to the proposed approaches. The ROIs represent an attractive, simple concept that can be quickly grasped since it identifies specific tangible operational measures that are related to emissions impacts. These ROIs are considered as proxies for transport activities and operational measures that are indicative of emissions implications. In addition to the ROIs, three of the proposed approaches require the development of mobile and idle emission factors that can be used to estimate total emissions. Table 3 summarizes the approaches that are discussed in more detail below.

Table 3: Proposed approaches.

Approach	Before/After ROI's	Emission Factors
1. Simplified/Sketch Planning	Estimated	Calculated
2. Simulation	Simulated	Calculated
3. Field - Level A	Measured in field	Calculated
4. Field - Level B	Measure emissions directly in field	

4.1 Development of emission factors

For estimating the levels of pollutants produced by traffic activities, *emission factor models* have been extensively used. Such models include the EPA's MOBILE series of models as well as the EMFAC model developed in California. Total emissions levels are typically computed based on link emission factors (function of link speed, in grams/vehicle-km) and vehicle-kilometres travelled per link. Alternatively, *modal emissions models* represent the relation between vehicle operating modes and emissions directly. For this purpose, emission-producing activities are modelled in detail. Next, the EMFAC model developed by the California Air Resources Board (CARB) is described to illustrate the mechanics and inputs of prototypical emission factor models. Alternatively, MOBILE 5C/6C, the Canadian version of the U.S. EPA's MOBILE model, may be adopted to produce the required emission factors. A brief description of MOBILE 5C/6C is also presented below.

4.1.1 EMFAC [1]

The EMFAC model generates emission factors in terms of grams of pollutant emitted per vehicle activity. Vehicle activity can be in terms of grams per mile or grams per hour, or grams per start, and depends on the emissions process. The emission factors depend on basic scenario data options for month or season. The model calculates a matrix of emission factors at specific values of temperature, relative humidity, and vehicle speed (idle and 1 mph to 65 mph) for each vehicle class/technology combination. The more important concepts/inputs needed in the EMFAC model include vehicle fleet, vehicle class, Fuel, technology group, model year and population

4.1.2 MOBILE 5C/6C [2]

MOBILE 5C/6C is a program adapted for use in Canada from the United States Environmental Protection Agency's MOBILE 5/6 Model. The program calculates emission factors for the purpose of developing national, provincial and regional emission inventories. MOBILE 5C/6C produces estimated NOx, HC (VOC) and CO emission factors in grams per mile for on-road transportation sources from 1985 to 2020. These estimates are given by province for seven different classes of vehicles - light-duty vehicles, light-duty trucks and heavy-duty trucks (both gas and diesel); and motorcycles. Average yearly emission factors account for the rate of emissions of new cars, the deterioration rate of vehicle stock (i.e. a rate in grams per mile which is a measure of the increase in emissions for each 10,000 miles of vehicle use), provincial driving habits and provincial climate and vehicle characteristics. The yearly average emission factor is a weighted average of four seasonal scenarios (winter, summer and two spring/fall scenarios) and two driving speeds (urban and highway).

4.2 Approach 1 – simplified/sketch planning

In this approach, ROIs may be estimated based on simplified/sketch planning techniques similar to SCRITS and IDAS. An overview of these two sketch planning tools for forecasting ITS impacts is provided below. The purpose of this overview is to provide examples of how such impacts are typically estimated.

4.2.1 SCRITS [3]

SCRITS (SCReening for ITS) is a "spreadsheet analysis tool for estimating the user benefits of ITS, developed in response to the need for simplified estimates in the early stages of ITS related planning, in the context of either a focused ITS analysis, a corridor/sub-area transportation study, or a regional planning analysis." As discussed above, environmental benefits assessment of ITS will generally require quantifying the vehicle activity parameters such as vehicle speeds, Vehicle Kilometres Travelled (VKT) or Vehicle Miles Travelled (VMT), Vehicle Hours Travelled (VHT). Once these parameters have been quantified, the emissions resulting from these activity parameters have to be estimated. SCRITS uses a series of look-up tables to perform the analysis of both the activity parameters and the emission estimation. SCRITS estimates energy and environment benefits for only three ITS strategies, namely, Closed Circuit Television (CCTV), freeway traffic detection, and information and traffic signal systems. In analyzing the environmental benefits of this strategy, SCRITS assumes that deploying this strategy will lead to an increase in the average system speed. The emissions factors for before and after improvement are taken from the look-up tables. The difference in these estimates are the benefits of the ITS deployment.

4.2.2 IDAS [4]

The ITS Deployment Analysis System (IDAS) is software developed by the Federal Highway Administration that can be used in planning for Intelligent Transportation System (ITS) deployments. State, regional, and local planners can use the IDAS benefits module to estimate impacts resulting from the deployment of ITS components. These impacts are quantified using various performance measures of travel time, travel time reliability, throughput, safety, emissions, energy consumption and noise. The benefits module uses the updated data set representing the ITS option and the unmodified data set representing the control alternative, to perform a series of analyses to generate the difference in performance between the two scenarios. The IDAS benefits module is comprised of a travel time/throughput submodule, an environment submodule, a safety submodule, and a travel time reliability submodule. The environment submodule estimates changes in mobile source emissions, energy consumption, and noise impacts of ITS strategies. Using the performance statistics generated from the travel time/throughput submodule, the environment submodule estimates environmental performance measures by using a series of detailed look-up tables that consider emissions and energy consumption rates by specific network volume and traffic operating characteristics.

4.3 Approach 2 – simulation of ROIs

Different approaches have been proposed to evaluate implications of ITS deployments based on the underlying traffic simulation models. Static models typically focus on peak hour or peak period traffic conditions and are useful for developing emissions inventories in a certain area. On the other hand, dynamic traffic simulation-assignment models can represent spatial and temporal variation of travel times, stopped times, speeds, queues, and travel distances over very short simulation intervals (e.g. 30 seconds). This type of output is more representative of the operational impacts of ITS interventions.

Washington *et al.* [5] have described the current emission estimation practice in the following five steps:

Step 1. Quantifying emission-producing vehicle activities or ROIs (e.g. number of trips, VKT, idling delay, operating speeds) through a traffic simulation model;

Step 2. Providing data on vehicle, fuel, operating, and environmental characteristics to the emission factor model;

Step 3. Running the emission factor model to predict activity-specific emission rates for the given vehicle, fuel, operating, and environmental characteristics;

Step 4. Multiplying each activity estimate by its appropriate activity-specific emission rate; and,

Step 5. Summing the estimated emission for all the activities.

In this approach, ROIs (representing emission-producing vehicle activities) need be developed using either microscopic models like TRAF-NETSIM or CORSIM, or macroscopic models like FREFLO and TRANSYT-7F. Newer simulation models like INTEGRATION, DYNAMIT, and DYNASMART are better suited for simulating various ITS scenarios.

4.3.1 Example – simulation using static traffic model

A paper by Sbayti *et al.* [6] investigates the effect of roadway network aggregation, on emission inventories. A traffic model and an emission factor model were integrated to determine total emissions in the future Beirut Central District area for these three modelling approaches. The modelling consists of three consecutive steps. EMME/2 (by INRO Consultants Inc.), a widely used static traffic model, is often interfaced with pollutant emissions/dispersion models to simulate the effect of changes in land use, traffic fleet characteristics, roadway network, and lane configurations on emission estimates. MOBILE5B, developed by the US Environmental Protection Agency, uses average speeds, vehicle fleet characteristics, ambient conditions, and trip duration distribution to estimate emission factors. Three levels of detail are used to estimate the total emissions, the macro-, meso and micro-scales. At the macro-scale, the average network speed was used to calculate an average emission factor for the whole network. Total emissions are estimated by multiplying total vehicle miles travelled (VMT) by the average emission factor. For the meso-scale approach, an average emission factor for every roadway functional class is determined. The contribution of each roadway functional class to pollutant emissions is then aggregated to yield total emissions. In the micro-scale method, link speeds are used to obtain emission factors for every link. Link VMT is multiplied by the corresponding link emission factors and summed over all links to obtain total emissions.

4.3.2 Example – simulation using dynamic traffic model

Kaysi *et al.* [7] developed a framework for assessing the potential of Intelligent Transportation Systems (ITS) in alleviating non-recurring traffic congestion and to estimate the resulting implications for vehicle-induced emissions in a congested city in a developing country. A series of simulation scenarios were conducted using dynamic traffic simulation-assignment methodology, and resulting emissions were estimated using an emission factor model. DYNASMART and MVEI/EMFAC were the traffic and emission factor models used in this research (Figure 2). The scenarios were used to evaluate the impact of different ITS deployment parameters - such as type of information provision (pre-trip, and in-vehicle) and driver compliance - on network performance and resulting emissions. Network performance measures such as travel and stop times were developed, and corresponding vehicle emissions are estimated using CO, NOx, and TOC as indicators for each scenario. The experimental factors considered in defining simulation scenarios were information provision technique, market penetration/driver response, and incident duration which accounts for the time required for detection, response, and clearance.

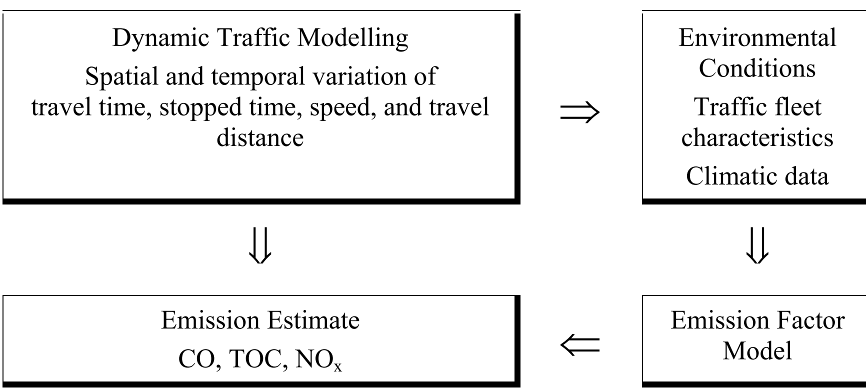

Figure 2: Simulation sequence under dynamic traffic and emissions modelling.

4.4 Approach 3 - Field Level A

This approach is very similar to Approach 2 except that quantification of the emission-producing vehicle activities or ROIs will be field-measured or obtained empirically under before/after ITS deployment conditions instead of being simulated using a traffic model.

4.5 Approach 4 – Field Level B

In this approach, emissions need to be measured directly in the field instead of computing them based on estimated, simulated, or measured ROIs and emission factors. Conclusions from an NCHRP study indicate that air quality monitoring to observe the impacts of ITS deployments is technically feasible for primary pollutants, such as CO, VOCs, and NOx [8]. Measurements of upwind concentrations can be subtracted from the downwind values as a means for characterizing the contribution of a roadway facility to ambient downwind concentrations. Experiments need to be conducted both prior to and subsequent to deploying an ITS project. It is important to note, however, that observing ITS deployment effects is feasible only if they exceed a certain threshold value. For primary pollutants, this is on the order of 2 percent. Direct observation of ITS deployment effects on secondary pollutants is considerably more difficult. Moreover, monitoring over a large geographic area to determine the effects of area wide ITS deployment programs is inherently more difficult than monitoring on a location- or facility-specific basis [8].

5 Conclusions

This paper has proposed general guidelines for integrating environmental impact evaluation in future ITS deployment studies. The proposed guidelines are intended to assist parties undertaking future studies of ITS deployment plans to build environmental impact measures in their studies. The guidelines identify the kinds of analyses, operational indicators and proxies, and direct environmental measures (pre- and post-deployment) that would be recommended in the context of prototypical ITS deployments.

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