A SYSTEMS FRAMEWORK FOR ASSESSING AIR QUALITY IMPACTS OF ITS: APPLICATION TO MEXICO CITY

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ABSTRACT

Intelligent Transportation Systems (ITS) – the application of communications and information technology to surface transportation systems – has the potential to improve transportation along several dimensions, from safety to emissions reductions to travel time and reliability. ITS has become a worldwide technology, and many cities in Latin America are currently deploying ITS, from individual technologies to entire ITS Architectures. While improving mobility is at the core of any ITS deployment, in metropolitan areas from Mexico City to São Paulo, air quality concerns are such that ignoring possible air quality impacts of ITS technologies represents either a failure to leverage ITS for air quality improvements, or even a risk of running counter to air quality management efforts. While there is a growing number of studies evaluating the air quality benefits of ITS, there are important limitations on the extent to which the results of these studies can be used to support planning of ITS in cities in Latin America. First, the challenges involved in modeling ITS air quality benefits mean that they typically focus on only one or two ITS technologies at a time. Second, air quality and mobility conditions vary greatly across cities, meaning that air quality outcomes will also vary widely. Finally, from a planning standpoint, a more system-wide and qualitative framework is needed to generate the kind of dialogue needed between a diverse number of groups – environmental, transportation, public works, public security, and transport operators – to decide how ITS can meet a metropolitan area's needs. In order to address these issues, I develop a systems framework that can encompass a number of ITS technologies and performance measures. Within this systems framework, I look specifically at air quality. Rather than focusing on particular modeling tools, I break down air quality impacts into eight mechanisms that can lead to decreases or increases in mobile source emissions. I will also return briefly to the literature on ITS environmental benefits, to review which mechanisms are included as variables. Finally, I will consider the case of Mexico City, and the interactions between current ITS deployments and air quality.

KEY WORDS: Intelligent Transportation Systems (ITS), Air Quality, Environment

1. INTRODUCTION

In Latin America, there is growing interest in and deployment of Intelligent Transportation Systems (ITS), from small-scale, and relatively isolated applications to entire ITS Architectures. At the same time, many of the cities where the pressure to deploy ITS is felt strongest (often to address congestion in the face of physical, financial and social limits on the ability to "build one's way out" of congestion with more highways), also confront major air quality problems. In light of these issues, this paper addresses the following questions. In what ways can ITS have an impact, whether positive or negative, on mobile source emissions and overall air quality? Which ITS applications have been shown to have an impact on air quality, and how? Are there ITS applications specifically oriented toward the goal of improving air quality or generating fuel savings? When deploying multiple ITS services, how can one unravel the overall air quality impacts? This research presents a systems framework for assessing air quality impacts of ITS, based upon eight mechanisms for changes in emissions from the private vehicle fleet and public transportation. After presenting this framework, the results of applying the framework to Mexico City are briefly highlighted.

2. ITS AND AIR QUALITY

ITS is often deployed to meet a variety of goals related to mobility, public health and safety, and overall quality of life. In order to guide the consistent evaluation of ITS applications, the Joint Program Office of the U.S. DOT developed a set of measures of effectiveness. These measures, often referred to as "A Few Good Measures," include the following (USDOT-JPO, no date):

- *Safety*: Reduction in the overall crash rate, Reduction in the rate of crashes resulting in fatalities, Reduction in the rate of crashes resulting in injuries, and Improvement in surrogate measures.
- *Mobility*: Reduction in travel time delay, Reduction in travel time variability (or improved reliability), Increase in customer satisfaction (including product awareness, expectations of product benefits, product use, response, realization of benefits, assessment of value), and Improvement in surrogate measures.
- *Efficiency*: Increases in effective capacity, and Increases in throughput.
- *Productivity*: Cost savings, measured as the difference in costs before and after ITS implementation, or the difference in costs compared to a traditional transportation improvement.
- *Energy and Environment*: Reduction in emissions, Reduction in fuel consumption.

This paper focuses on air quality impacts, one of the most difficult ITS outcomes to measure. Estimates of emissions changes are usually simulation based, using multiple scenarios with and without ITS services and under different traffic, weather and accident conditions to predict emissions changes. Before and after field data is sometimes used in combination with simulation, for example, GPS-equipped floating cars can be used to gather more detailed speed, stop, and acceleration data as inputs to estimating emissions (Zimmerman et al, 2000, p 5-7). While much progress is being made in developing models integrating demand modeling, traffic network simulation and emissions modeling, there remain many challenges. A review of the state-of-practice of air quality evaluation of ITS outlined some of the following issues: (1) "emissions factors...[fail] to adequately capture the effects of vehicle-operating modes on mobile source emissions," (2) "current travel demand models and traffic flow simulation models are not sufficiently detailed for purposes of ITS evaluation," and (3) these models "also fail to provide the kind of inputs needed for use in modal emissions modeling" (Mehta et al, 2001, p 37). Although these models continue to advance, many cities in Latin America may not have either the necessary data – reliable vehicle registration databases and O-D matrices – or the necessary models – network simulation, travel demand, or emissions models – to do the model interfacing needed to measure the emissions impacts of ITS. While some lessons can be cautiously transferred from one country to another, air quality benefits will be highly sensitive to the each city's conditions, for example, congestion levels, transit use, and fleet composition.

2.1 Identifying the Mechanisms for Air Quality Impacts

Due to the sensitivity of air quality benefits to the conditions of each city and the uncertainty in the current models, rather than focusing on the *magnitude* of the air quality impacts, the framework for evaluation presented here is based upon the *mechanisms* by which emissions reductions are achieved. While earlier assessments (Washington et al, 1994) focus on mechanisms related to trip characteristics of private automobiles – vehicle miles traveled, engine idling, vehicle refueling, and modal activity (acceleration, deceleration, cruising), it has been recognized that this is limited by assumptions that travel behavior, commute distances, vehicle fleets, and mode shares will not change significantly (Mehta et al, 2001, p 13). The eight mechanisms identified and described below are expanded to consider public transportation operations and mode share, as well as the circulation of high emitters within the vehicle fleet.

- *Vehicle Kilometers Traveled (VKT) for Private Autos* directly impacts air quality, since more travel means more emissions. ITS can influence private auto VKT in several ways: shorter trip lengths and better trip chaining through route guidance systems, avoidance of non-essential trips when advised of poor traffic conditions through ATIS, or even increases in trip making due to induced demand from traffic system improvements.
- *Traffic Speed* is an important determinant of emissions on a per kilometer basis. Emissions rates (g/km) vary non-linearly, often in a U-shape, with speed. Therefore, traffic moving either very slowly, or very rapidly, will have the highest emissions rates.
- *Idling, Queuing, & Starts/Stops* focus on the dynamics of the general traffic flow, since using average traffic speeds alone does not allow one to capture the number of stops, acceleration, deceleration, and idling, which is when some of the highest emissions occur.
- *Traffic Volume/Throughput* is tightly linked to traffic speed, since the faster the vehicle flow, the more vehicles can pass during a given time unit. However, using throughput as a measure can also capture the changes in demand that result from improvements in speed and therefore level of service. Throughput is also related to overall VKT, but can be used as a measure on a specific route or corridor that might be a "hot-spot" for high emissions/concentrations of pollutants.
- *Transit Vehicle Dwell/Idling & Starts/Stops* reflects the idling, queuing, and starts/stops like that of general traffic flows, but also captures vehicle dwell times while passengers enter and exit transit vehicles. It is listed as a separate concept from idling, etc. of general traffic flow, since transit vehicles may be allowed signal priority or run along separated guideways.
- *Transit Fleet Management* can include the above operational changes, but also includes more efficient route structure, demand-responsive routing, or the ability to use fewer vehicles, which minimize transit VKT while maintaining the same or better level of service.
- *Mode Share of Public Transit (PT) or NMT* indicates to what extent ITS, and in particular, Advanced Public Transportation Systems (APTS), can lead to a mode shift from low/single

occupancy vehicles to high occupancy vehicles or to non-motorized transportation (NMT) (walking or bicycles), thereby reducing emissions on a per traveler basis. This category can also include mode share shifts favoring "cleaner modes" of public transportation, such as electric or alternative fueled vehicles.

- *Detection of High Emitters* is included under our expanded definition of ITS, described below. The detection of high emitters can influence emissions either through the short-term restriction of the circulation of high-emitting vehicles, or more longer-term by influencing driver's maintenance of the vehicle, and specifically, of the emissions control equipment.

While there is some overlap – and clearly a strong interdependence – among many of these concepts, this list represents a comprehensive set of mechanisms that allow us to better understand how ITS may lead to changes in emissions and thus, air quality. Using these mechanisms, I will then classify the various studies on air quality impacts of ITS. However, before moving to this classification, I will first reconsider the current taxonomy of ITS applications and services.

2.2 Expanding the Taxonomy: "Environmental ITS"

There are a number of ITS applications specifically oriented toward air quality and vehicle emissions, although they are often not considered within the "traditional" ITS taxonomy. These systems are often based on the identification of gross polluters through on-road emissions remote sensing, with response strategies ranging from simply providing feedback to drivers on their vehicle's emissions levels, to restricting the entry of high-emitting vehicles into specified zones. Other measures include automated enforcement of general vehicle restrictions, intended to control mobile source emissions, or automated speed enforcement to move traffic at speeds characterized by more "desirable" emissions factors. Therefore, I will consider an expanded ITS taxonomy that includes these Environmental ITS technologies, which I refer to as EITS, shown in Figure 1.

Emissions-based Speed Enforcement is based upon similar technologies to regular Automated Speed Enforcement, with speed radar and cameras using license plate recognition (LPR) to identify and fine vehicles exceeding the posted limit. However, the system differs in that the goal is not to avoid speeding as such, but to lower emissions by improving the flow of traffic, avoiding the stop-and-go dynamics that can arise from large variations in vehicles speeds and maintaining traffic speeds within a range at which emissions on a gram/km basis are lowest.[1] These systems should ideally be coupled with monitoring of pollutant concentrations in order to ensure that the "correct" speed limits are set. Emissions-based Speed Enforcement has not been widely implemented, but has shown to be effective (in terms of both emissions reductions and revenue generation through fines) in a deployment along a stretch of highway in the Netherlands (Keuken, 2004).

ITS-based Vehicle Restriction Enforcement is another EITS, which restricts vehicle circulation or entry into specific zones either through Pricing Strategies, License Plate-based Driving Restrictions, or Car Free Days, in which no private vehicles are allowed to circulate. License Plate-based Driving Restrictions are of high interest in Latin America, and different forms of driving restrictions have

[1] As noted earlier, emissions factors (grams of pollutants per km) vary non-linearly with speed, with the lowest emission factors within a speed range of roughly 70-80 kph, although this is highly dependent on the fleet characteristics and the pollutant in question. For example, NOx emissions increase greatly at higher speeds.

been put into place both to deal with air quality problems and to mitigate congestion in many cities. Plate-based restrictions range from one-day-a-week to peak-hour-only, and often aim to meet environmental goals by linking vehicle restrictions (and exemptions) to vehicle age and emissions control equipment. However, few of these schemes have ITS-based technologies for enforcement. Currently, Pricing Strategies are the vehicle restrictions most commonly supported by ITS technologies. Nevertheless, enforcement problems and corruption in many vehicle restriction schemes suggest that automated enforcement, such as cameras and LPR, could be highly beneficial.

Various ITS technologies are used to support Pricing Strategies, and include fixed and mobile cameras, LPR, and payment made possible by telephone, text messaging, Internet, or self-service machines (London). There are exemptions for alternative fuel vehicles, although this is "the only explicitly environmental measure in the [London] scheme" (Hutchinson, 2004a, p 34). Those involved in the London Congestion Pricing scheme assert that above all "this is traffic and congestion management, not an air quality scheme" (Hutchinson, 2004a, p 36), and that while benefits may have been achieved at the local street level, no significant impact on overall air quality could be identified. However, given the growing interest of other cities in using pricing as a possible congestion and air quality management tool, I have included it within this category of EITS.

The final bundle of EITS applications is based upon real-time On-road Emissions Sensing. Vehicle Emissions Information Systems (Bishop and Stedman, 2000) integrate highway variable message signs (VMS), drive-by vehicle emissions sensing and LPR. The purpose of these systems is to provide drivers with immediate feedback regarding their emissions status, in order to encourage drivers to take corrective actions for high-emitting vehicles. Another based on remote emissions sensing is that of a "Hybrid" Emissions Testing Program. These systems can take many forms, but include a combination of traditional emissions testing centers and on-road emissions sensing to identify "clean" vehicles that can be exempted from testing or "dirty" vehicles that can be identified and called into the centers (Booz-Allen, 1996). It can also be used for quality control, to verify the validity of test center results. Finally, the most complex (and controversial) system is that of Low Emissions Zones (LEZ) which restrict entry of high emitters into designated areas. In the case of Beijing (Costabile, 2004), the system receives data from air monitoring stations and in cases of high levels of pollution, can authorize traffic restrictions for high emitters. Under these restrictions, traffic-monitoring stations prevent polluting vehicles from entering the restricted areas. The data center can also request that the advanced public transport management system provide extra buses to compensate drivers for the traffic restrictions. Different forms of LEZ have been used in Sweden, and studied for possible application in London (Hutchinson, 2004b, www.london-lez.org).

2.3 ITS Experience in Latin America

A Joint Seminar[2] in January 2004, "Reducing the Impact of Vehicles on Air and Environmental Quality in Cities" provided a unique opportunity to compare the efforts of four Latin American cities to improve air quality through improved transportation systems. Briefly, I summarize the role of ITS in air quality efforts in Bogotá, São Paulo and Santiago, returning later to the case of Mexico City.

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[2] The Joint Seminar represented a collaboration between the International Union of Air Pollution Prevention and Environmental Protection Association (IUAPPA) and the Integrated Program on Urban, Regional and Global Air Pollution (IPURGAP). The report is available at http://eaps.mit.edu/megacities/workshops/IUAPPA/index.html.

Bogotá's Transmilenio Bus Rapid Transit (BRT) system has formed the centerpiece of the city's transportation strategy, with important ITS components supporting Transmilenio's operations including automatic vehicle location (AVL), electronic fare collection systems, and signal priority at certain crossings (Hidalgo, 2004). Bogotá also holds an annual Car Free Day, using a CCTV network and Internet for monitoring and to provide information to the public on alternatives to private autos (WB-MLIT, 2002). Finally, Bogotá has driving limitations (*Pico y Placa*) on 40% of autos during peak traffic periods (Acevedo, 2004).

In Brazil, the most widespread ITS application is electronic toll collection (ETC), driven by private sector participation in highway concessions, with many concessions having also implemented advanced control and communications systems including vehicle monitoring through CCTV, control centers, and incident management (ITS America, 2002). Within *São Paulo* and other urban areas, although ITS has been slower to catch up, congestion and air quality problems are creating pressures for better traffic management, seen as a "viable, low-cost, short-term, and highly effective measure with strong support" (Vasconcellos, 2004, p 10). On the periphery of São Paulo, as well as in Brasilia, Rio de Janeiro and Campinas, radar and cameras for automated speed enforcement, and VMS with detailed traffic and incident information, have been successful (ITS America, 2002). São Paulo also has a vehicle restriction scheme based on license plates.

In *Santiago,* a major focus of air quality and transportation management has centered around the concept of giving priority to public transportation and rationalizing the use of the private automobile. Part of this strategy includes the use of exclusive bus avenues and reversible streets for regular traffic along key axes where flows into and out of the city are highly asymmetrical in the morning and evening. Santiago also has adaptive signal control systems (based on SCOOT) in place, and is working to integrate the traffic control system with signal priority for buses and emergency vehicles. In terms of public transportation, an operation control center monitors bus system operations and provides travel information to users. There is also a focus on supporting seamless intermodal passenger travel. A key component of this is Multivia, a contactless fare card which will allow transfers between the Metro and bus systems, enabling passengers to board more rapidly than earlier mechanical devices for counting change, which should help reduce dwell times (Figueroa, 2004).

In terms of general trends for ITS and air quality in Latin America, one must highlight the growing adoption of ITS-supported Bus Rapid Transit (BRT) systems. Better traffic management through improved traffic signal control is also a near-time goal. Within these four cities, vehicle restrictions are commonly used for congestion and air quality purposes, but with limited ITS enforcement of restrictions. Finally, there is mixed but continued interest in congestion pricing, with some interest in pursuing a congestion pricing-BRT coupling, an idea promoted by ex-Mayor of Bogotá Enrique Peñalosa and Derek Turner, formerly of Transport for London (Golub and Hook, 2003).

2.4 Classification of ITS Air Quality Impacts by Mechanisms

Having developed a set of mechanisms to classify emissions and air quality impacts, I now present a review of the literature on reported environmental benefits, drawing largely on the online ITS Benefits-Costs Database (USDOT-JPO, 2004). Because this database primarily lists deployments in the US and Europe, I also augment this list with the ITS deployments in the four Latin American cities. Furthermore, I include an expanded list of ITS applications, incorporating Environmental ITS or EITS. The classification of these ITS applications by mechanisms is contained in Table 1.

3. A SYSTEMS FRAMEWORK

As seen in Table 1, there is a growing body of knowledge regarding the environmental impacts of ITS. Nevertheless, there remains a need for a framework that enables more comprehensive, integrated evaluation of potential air quality and mobility impacts of ITS. Currently, most of the emissions and air quality outcomes of ITS deployments are measured according to individual ITS applications – traveler information, ramp metering, incident management – with a smaller number of studies investigating the air quality impacts of integration of two or more applications. This research will presents a systems framework for analyzing the potential effects of the deployment of multiple ITS subsystems, using a range of performance measures.

This systems framework, primarily qualitative in nature, can be used to identify interactions between ITS *applications* (e.g., traffic information and incident management, advanced signal control, transit signal priority), as well as interactions between *measures of effectiveness* (e.g., emissions, travel time delay and variability, throughput). The framework is deliberately qualitative for various reasons. First, an early focus on quantification may exclude analysts from thinking about important variables that are not easily measured or modeled, such as perceptions of public transit level-of-service (LOS) or driver compliance with instructions on VMS. Second, this framework is intended to be highly inclusive, so that planners, operators, and other decision-makers can use this framework in the early stages of ITS evaluation, in order to explore various combinations of ITS applications and identify opportunities for emissions reductions or synergies between applications. The framework can be used to identify interesting interactions to be further analyzed quantitatively, with detailed modeling or measurements. In this manner, this framework is complementary to efforts to develop integrated transportation and emissions models, by identifying possible areas of interest for future modeling work and/or field measurements.

3.1 Layered Systems Diagrams

The systems framework consists of organizing ITS applications into a series of layered influence diagrams. The diagrams should contain the ITS applications (shown in bold in Figure 2), the measures of effectiveness (reliability, customer perception, etc), the mechanisms for emissions reductions (shown in italics in Figure 2), and other relevant parameters. Diagramming is a manner of decomposing, from the top-down, a variety of ITS applications of interest, while focusing systematically on the goals and measures of effectiveness that are most relevant. As the number and complexity of the systems grows, the diagrams can be "layered" into ITS bundles. Figure 2 shows four different but overlapping ITS bundles: (1) ATMS - signal coordination, (2) APTS - transit signal priority and AVL, (3) EPS - contactless smart card, and (4) EITS - vehicle emissions information systems. The interactions within and between ITS bundles are also shown.

While the diagrams indicate the direction of influence through arrows, these arrows do not show magnitude or whether the influence is positive or negative. While there are some well-established relationships that are consistent across contexts, for example, level-of-service as a function of volume, other relationships depend greatly on the specific context. For example, transit signal priority can have either positive, negative or neutral impacts on the flow of all private vehicular traffic, and increasing vehicle flow speeds can have positive or negative emissions impacts.

3.2 Key System Interactions

This framework intends to enable transportation analysts and planners to map out and better understand the interactions between multiple ITS deployments and their possible impacts on air quality. The eight ITS-air quality mechanisms are key for tracking how these systems can interact to improve air quality or not, and to avoid focusing too much on certain parameters that affect emissions. For example, while traffic speed is a key parameter in emissions, it is important to think systematically about how increases in speed and reductions in travel delays and reliability will increase the LOS along those routes, since over the long-run, as people switch to these improved/faster routes, the volume on those routes will increase until speeds once again fall – an induced demand through ITS-based expansion of effective capacity. This focus on key system interactions can help avoid unforeseen outcomes in actual deployments and guide more comprehensive evaluations in ITS. Emissions changes from transit signal priority provides an interesting example. While some analyses only focus on the queuing times for buses at traffic signals (Lehtonen and Kulmala, 2002), other studies include the effects on all vehicle traffic (Dion et al, 2002). However, most studies fail to include changes in transit ridership/mode share and the subsequent impact on emissions. This framework allows one to highlight frequently omitted interactions. Although it may not be feasible to model or measure these interactions, with this systems framework, at least they are not forgotten.

4. ITS DEPLOYMENT IN MEXICO CITY

We now turn briefly to the situation in Mexico City. Mexico City has a growing Adaptive Signal Control network with 1,246 computerized signals and plans to expand the system with 700 additional signals. In addition, there are approximately 20 VMS (Setravi, 2002), which remain underutilized in terms of providing information and instructions to drivers. A program has also been developed to provide roaming motorist assistance (Radares Viales) for accidents or mechanical failures. These units also serve as information sources for ATIS. Currently, there are several sources of advanced traveler information for major routes in the city. While radio continues to be a key source of information on traffic conditions, an increasing number of Internet sites for traffic information are appearing, including sites developed by the Secretaries of Transportation (Setravi) and Public Security (SSP), and online newspapers that integrate information from several sources, including Setravi and SSP. There is also a phone-based system (Setravi's Apoyo Vial) for detailed information and alternate route suggestions provided by live operators. One of the limitations seems to be the lack of public information regarding the availability of these phone and internet-based resources, meaning that the impact on traffic conditions is likely minimal.

Little APTS infrastructure currently exists in Mexico City. Some applications that have been considered include the combined use of "panic buttons" and AVL to provide emergency police assistance to public transit vehicles (primarily microbuses). Another system that may be on the near-term agenda is the deployment of a contactless Smart Card for an integrated fare payment system. These cards are being considered for a pilot program in the Metro, with the intention of extending it to the traditional government bus services and the Bus Rapid Transit (BRT) corridors currently in the design phase for two important avenues. The BRT system will also likely make use of AVL systems to control frequency and headways, although the design has not been fully specified. The deployment of Smart Cards could be an important step in moving toward a more intermodal public transit system, allowing more diverse, differentiated fare policies, including transfers and discounts.

Application of the systems framework to analyze these ITS applications has indicated that there are many opportunities to leverage these systems for air quality improvements. Due to space constraints, the full systems diagrams are not presented here, but the findings with regards to possible impacts on the eight air quality mechanisms are summarized in Table 2. Currently there is little of the integration among the various systems necessary to generate substantial impacts, and in isolation the impacts of individual systems are likely to remain small. The analysis also shows that current ITS deployments could be augmented with several EITS applications in order to more effectively reduce emissions, for example, by building upon current vehicle restriction schemes.

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Table 1: Classification of ITS Applications by Air Quality Mechanisms

ITS Application	Deployment/Study Location - Reference	Mechanisms for Air Quality Impacts: Private Vehicle Fleet Emissions					PT Fleet Emissions		
		Detection of High Emitters	VKT for Private Autos	Traffic Speed	Traffic Volume/ Throughput	Idling, Queing, & Starts/Stops	Transit Vehicle Dwell/Idling & Starts/Stops	Transit Fleet Management	Mode Share of PT (or NMT)
APTS (Advanced Public Transportation Systems)									
Transit Signal Priority	Helsinki - Lehtonen & Kulmala (2002)			(X)	(X)	(X)	X	(X)	(X)
Transit Signal Priority	Arlington, VA - Dion et al (2002)			X	X	X	X	(X)	(X)
Automatic Vehicle Location (AVL)	--							(X)	(X)
In-Vehicle Information	Helsinki - Lehtonen & Kulmala (2002)						(X)		(X)
Wayside Information	Helsinki - Lehtonen & Kulmala (2002)						(X)		(X)
ATIS (Advanced Traveler Information Systems)									
Traveler Information (Phone-based)	Boston, MA - Tech Environmental (1993)		X	X	X	(X)			X
Pre-trip Information (Re: Incident)	Beirut - Kaysi et al (2004)		X	X	X	X			(X)
In-Vehicle Information (Re: Incident)	Beirut - Kaysi et al (2004)		X	X	X	X			
Multi-modal Traveler Info (Internet)	--		(X)						(X)
ATMS (Advanced Transportation Management Systems)*									
Motorist Assistance Patrols	San Francisco, CA - USDOT (1996)			X	X	X			
Incident Mobililization & Response	San Antonio, TX - Henk & Molina (1997)			X		X			
Adaptive Signal Control	Toronto - Greenough & Kelman (1999)		(X)	X		X			
Coordinated Signal Control	Phoenix, AZ - Zimmerman et al (2000)		(X)	X		X			
Reversible Lanes	Santiago - Figueroa (2004)		(X)	X	X	(X)			
Ramp Metering	Minneapolis-St. Paul, MN - Hourdakis & Michalopoulos (2002)			X	X	X			
EPS (Electronic Payment Systems)									
Electronic Toll Collection	Orlando, Florida - Klondzinski et al (1998) New Jersey - Wilbur Smith Assoc. (2001)			X	X	X			
Smart Cards - Metro	London, Santiago, Washington								(X)
Smart Cards - Buses (incl. BRT)	Santiago - Figueroa (2004) Hong Kong, Bogotá						(X)	(X)	(X)
EITS (Environmental Intelligent Transportation Systems)									
Emissions-based Speed Enforcement	Netherlands - Keuken (2004)			X	X	X			
Pricing Strategies	London, Singapore - Hutchinson (2004a)		X	X	X	X			X
License Plate Driving Restrict (w/ ITS)	--	(X)	(X)	(X)	(X)	(X)			(X)
Car Free Days	Bogotá - WB-MLIT (2002)		X		X				X
Vehicle Emissions Feedback Signs	Denver, CO - Bishop & Stedman (2000)	X							
High Emitter Restrictions/LEZ	Beijing - Costabile (2004) London - Hutchinson (2004b)	X	X		X				X

**An "X" indicates the observed/modeled/measured presence of a mechanism, an "(X)" indicates additional possible mechanisms.*

***The presence of a mechanism does not necessarily mean that there were air quality benefits.*

****We include Arterial, Freeway and Incident Management Systems under the general heading of Advanced Transportation Management Systems (ATMS)*

Table 2: ITS Deployments (Existing and Planned/Under Study) in Mexico City and Projected Links to Air Quality Mechanisms

	Deployed Systems	Planned/ Under Study	Private Vehicle Fleet: *Detection of High Emitters*	*VKT for Private Autos*	*Traffic Speed*	*Traffic Volume/ Throughput*	*Idling, Queing, & Starts/Stops*	Public Transport: *Transit Vehicle Dwell/Idling/S/S*	*Transit Fleet Management*	*Mode Share of PT (or NMT)*
ATMS										
Traffic and Incident Surveillance (Video)	X									
Adaptive Signal Control	X			X	X	X	X			
Dynamic Message Signs	X			X	X	X	X			
Motorist Assistance Patrols	X				X		X			
APTS										
In-Vehicle Surveillance (Microbuses)		X								X
Facility Surveillance (Metro)	X									X
AVL for BRT		X							X	X
Transit Signal Priority		X			X	X	X	X	X	X
ATIS										
Internet (information by route)	X			X	X	X	X			X
Internet (information by incident/congestion)	X			X	X	X	X			X
Telephone (Pre-trip and en-route by cellular)	X			X	X	X	X			X
Radio (Pre-trip and en-route)	X			X	X	X	X			X
APTS										
Smart Card (Metro, BRT, Buses)		X						X		X

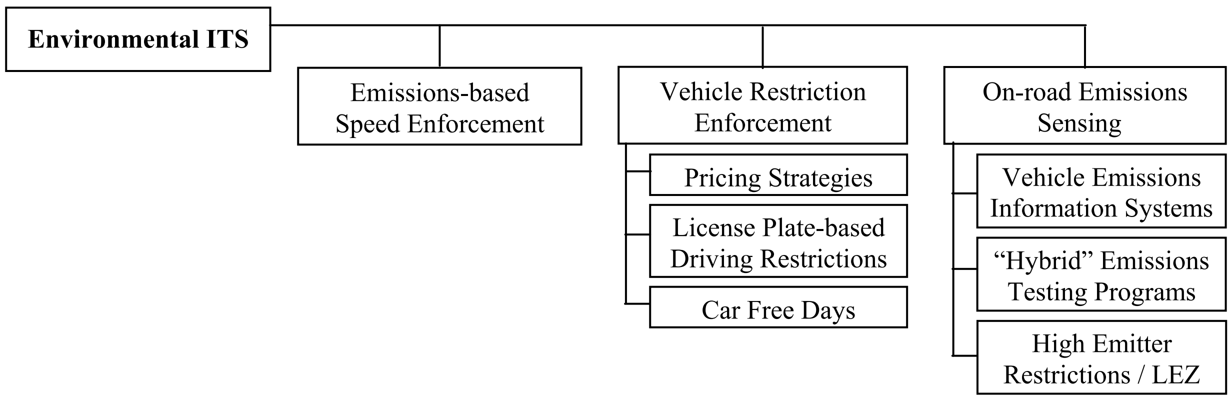

Figure 1: Expansion of the ITS Taxonomy: “Environment ITS”

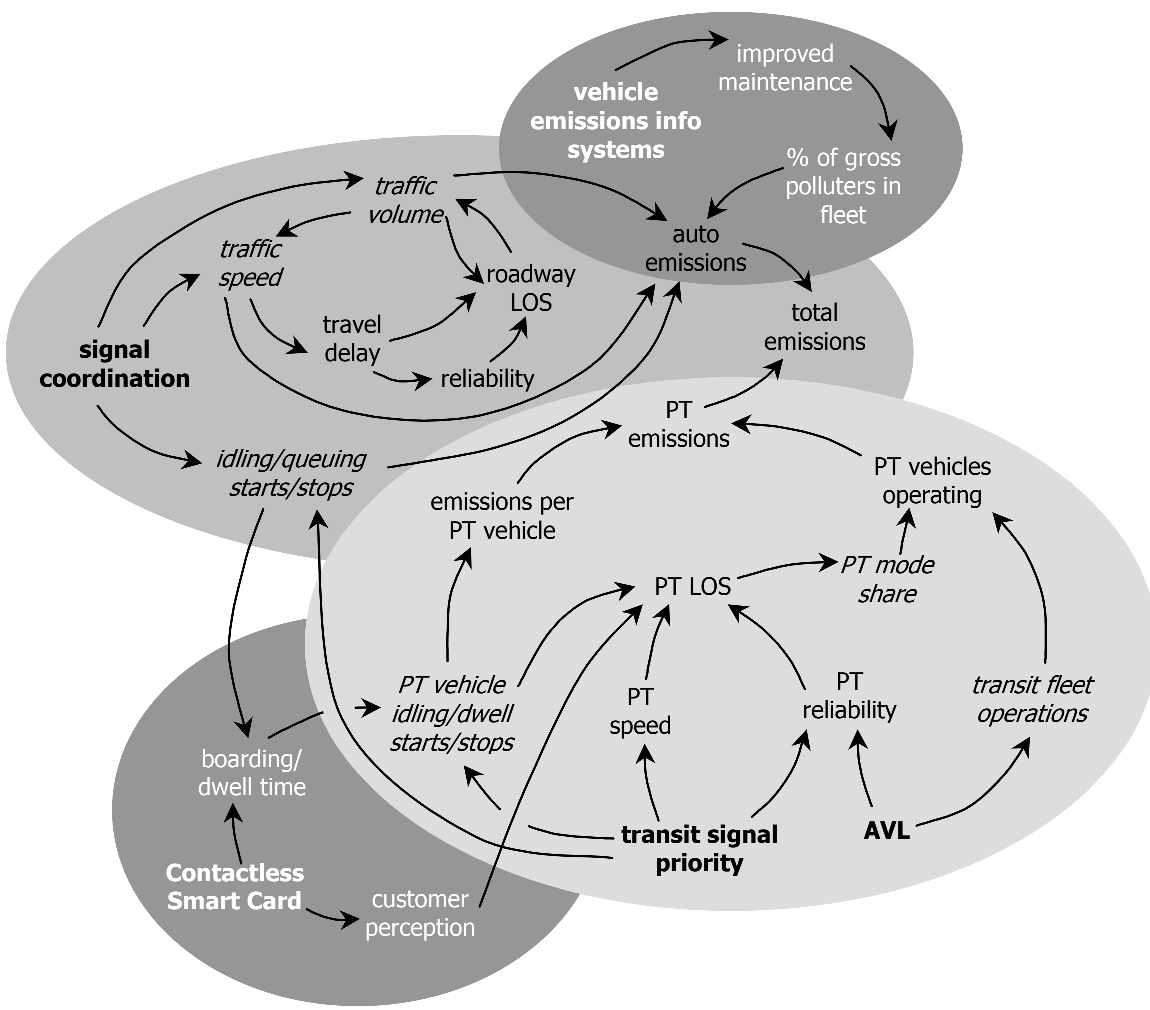

Figure 2: Example Systems Framework for Multiple ITS Applications