Potential Emission and Air Quality Impacts of Intelligent Vehicle-Highway Systems

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To the extent that intelligent vehicle-highway systems (IVHSs) improve traffic operations and increase the efficiency of the transportation system, emission benefits are expected. However some policy makers are concerned that by increasing the number of vehicle trips and vehicle miles traveled IVHS may have detrimental emission effects as well. Detrimental effects would partially offset the emission benefits gained from improved traffic operations and a more efficient transportation system. There is little evidence, however, that most IVHS strategies will induce travel to the point that increases in roadway supply brought about by efficiency improvements are quickly and completely absorbed by additional traffic. Air quality problems associated with congestion, poor vehicle maintenance, wasted travel, and too many vehicle trips may be alleviated by an array of IVHS products, user services, and technologies that improve the level of service on highways, promote mode shifts that favor travel on high-occupancy vehicles, and supplement conventional emission control programs such as inspection and maintenance.

The potential effects of intelligent vehicle-highway system (IVHS) strategies on vehicle emissions center on the trade-offs between possible increases in travel demand because of increases in roadway capacity or improvements in level of service, possible decreases in travel demand because of more complete travel information and improvements in public transportation systems, and reduced vehicle emission rates resulting from better traffic management. On the one hand IVHS could increase travel demand as a result of faster travel times that may increase the number and length of trips and shift trips from high-occupancy vehicles to single-occupancy vehicles, the induced travel demand that may be realized through significant improvements in the transportation system, or changes in land use patterns that increase trip length (*1*). On the other hand IVHS could reduce travel demand by increasing the attractiveness of mass transit and ride sharing, convincing travelers to forgo or delay trips during poor traffic conditions, generating shorter trips through route guidance, or reducing wasted travel produced by navigational errors (*2*). IVHS will also enable more efficient use of the existing system infrastructure capacity by reducing recurrent and nonrecurrent congestion and improving traffic flow. In turn smoother traffic flow can reduce a vehicle's emission rates during a given trip.

ANALYTICAL FRAMEWORK

The basis for the timing of IVHS implementation in this paper is technology and system feasibility. This analysis defines the short term to be the years 2000 to 2010 and the long term to be beyond 2010. This definition includes the implementation of first- or second-generation systems in the short term and the implementation of more technologically complex systems in the long term. In addition the geographic scale employed in the analysis focuses on impacts at the regional and corridor levels, although where appropriate effects on high localized emission concentrations are discussed.

It is also important to view the emission impacts of IVHS in light of advancements in vehicle emission control technologies or other mitigation strategies. The eventual penetration of electrically heated catalysts and more advanced combustion control processes into in-use fleets will reduce vehicle emissions. Moreover emphasis on alternative and reformulated fuels in the 1990 Clean Air Act Amendments is evidence of an increasing political preference for different, more effective control strategies. In the long term the emission impacts of IVHS may be negligible under a scenario characterized by an in-use fleet of low-emission vehicles. In the short term, however, evolutionary rather than revolutionary changes in emission control technologies are likely to occur and more concrete projections can be made.

Consideration should also be given to possible changes in the emissions certification process of new vehicles. A recent study by the National Research Council (*3*) concluded that motor vehicles emit two to four times as much hydrocarbon (HC) and carbon monoxide (CO) emissions as estimated by the Environmental Protection Agency (EPA) and the California Air Resources Board. Much of this underestimation may be related to the driving cycle tests used in measuring vehicle emissions, the emissions certification process for new vehicles, and the development of models with existing emission (*1*). The federal test procedure (FTP) is used to certify that new light-duty vehicles and light-duty trucks are in compliance with federal or California emission standards. However this test does not allow for various vehicle operating conditions, such as speeds over 57 mph, accelerations that are greater than 3.3 mph/sec, or sharp decelerations. Activities such as these are believed to be significant contributors to instantaneous vehicle emission rates. In fact a recent report by EPA (*4*) assessed average driving behavior and concluded that driving speeds and acceleration rates are much higher than those represented by the current FTP. EPA will conduct a battery of tests in 1993 to quantify emissions under off-cycle driving patterns (i.e., patterns that are outside the envelope of FTP) (*5*).

Because off-cycle emissions are controlled by new certification processes, emissions under stop-and-go driving conditions will be mitigated. Enrichment and motoring events occur when driving conditions are characterized by congestion. Because possible off-

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cycle emission controls will be geared to reduce emissions under these vehicle operating conditions, the significance of emission benefits associated with IVHS strategies that improve traffic flow may be diminished.

EMISSION IMPACTS OF IVHS TECHNOLOGY BUNDLES

The distinct characteristics of the technologies and systems that make up IVHS preclude a top-down travel and emission impact analysis that attempts to generalize effects across all systems. Rather emission analyses must focus on individual systems or groups of systems with common transportation network and emission effects. The systems that are likely to have similar effects on the transportation system and on vehicle emission profiles have been grouped into eight technology bundles, which are discussed below.

Traffic and Incident Management Systems

Traffic and incident management systems include systems designed to reduce recurrent and nonrecurrent congestion levels by improving traffic signalization, incident detection, and corridor control.

- *Advanced traffic signalization systems* allow vehicle movements to be controlled, in real time, through time and space segregation, speed control, and advisory messages.
- *Incident detection systems* minimize delays and network inefficiencies caused by nonrecurrent congestion and detect dangerous road conditions.
- *Freeway and corridor control systems* include ramp metering, express lanes, message signs that allow for variable speed control, and corridor control strategies.
- *Real-time changeable message road sign display systems* provide up-to-date information to travelers who use freeways or arterial roadways.
- *Emergency Mayday systems* reduce delays associated with slow response and incident clearing operations through signals sent by a vehicle communication system to the traffic network.
- *Hazardous material information systems* can help to better identify and clear incidents that involve hazardous materials.

First-generation traffic signalization systems, such as optimized vehicle actuation, have proven effective in reducing delays at traffic lights. But technical as well as operational problems still need to be addressed for later-generation systems, including partially or fully adaptive coordination.

In contrast most freeway and corridor control strategies are being widely applied today. Second-generation ramp metering systems that vary continuously as measured ramp and freeway flows are monitored in real time have been implemented in various urban regions across the country. These ramp metering signals now control traffic at 91 locations along various expressways in the Chicago area (*6*). Advanced ramp metering signals are also found on freeways in the Los Angeles metropolitan area, where two-lane ramps have been deployed on Interstate 405. The penetration of most freeway and corridor control systems can be extensive in the short term. Only corridor control strategies that strive to integrate the entire network of freeways and arterial roads may not see significant penetration in the short term.

As advances are made in traffic signalization systems, incident detection systems, freeway and corridor control systems, and variable message signs, the integration of traffic management strategies that are based on real-time traffic conditions may become a reality. In the short term, however, the impacts of systems in this technology bundle on traffic and travel may be limited to those brought about by the implementation of first- and second-generation traffic signalization, incident detection, and corridor and freeway control systems. Since first-generation systems are not responsive to real-time traffic conditions, their effectiveness in reducing delays and improving the level of service along corridors will be compromised.

The short-term effectiveness of traffic management systems will depend on the sophistication of computer algorithms that mimic traffic conditions. The Los Angeles Automated Traffic Surveillance and Control (ATSAC) system, implemented in the Coliseum area in July 1984, brought about improvements in the level of service. The installation involved 118 signalized intersections and 396 detectors covering an area of 4 mi^2. Through partially adaptive coordination systems, automatic adjustments of signal timing plans to reflect changing traffic conditions were deployed. Coupled with incident management systems to detect and manage unusual traffic conditions, such as accidents and special events, ATSAC measured improvements of 13.2 percent in travel time, 14.8 percent in average travel speed, and 35.2 percent in vehicle stops. Models were then employed to translate these level-of-service improvements into potential emission impacts. A 10 percent potential reduction in hydrocarbon (HC) and carbon monoxide (CO) emissions was estimated (*2*). The role of incident management systems is augmented when one considers that more than half the delays that occur on freeways are due to incidents (*2*).

Freeway and corridor control systems can also improve traffic flow along a corridor. The implementation of ramp metering on expressways in the Chicago area was found to reduce peak-period congestion by up to 60 percent and accidents by up to 18 percent. On Houston's Gulf Freeway ramp metering reduced travel times by 25 percent and accidents by 50 percent (*6*).

Although ramp metering does improve traffic flow and the level of service downstream, vehicles may undergo a sharp acceleration as they merge onto the freeway at main line speeds from a full stop. It is not clear whether this enrichment process offsets the corridor-level emission benefits (from smoother traffic flow downstream) that are brought about by ramp metering itself and the other systems in this bundle. The net emission consequences cannot be assessed without a better understanding of modal emissions and other factors that may define this relationship, such as the percentage of vehicles that undergo severe enrichment events relative to the total volume of traffic or the percent increase in the number of these events with and without ramp metering. Given the lack of data and analytic tools the corridor-level emission impacts of traffic and incident reduction systems are uncertain in both the short and long terms.

At the network level the potentially negative emission consequences of ramp meters alone are not likely to offset the potential emission benefits generated by this technology bundle through improved traffic flow and level of service. The combination of traffic signalization systems, incident detection systems, and freeway and corridor control systems is likely to result in higher efficiency gains throughout the network than at the corridor level.

This simply follows from an extension of benefits across a wider area. In the long term these systems may allow for an integrated approach to traffic management on the basis of real-time data on congestion, average travel speeds, and the occurrence of incidents. Such an integrated system can lead to regional improvements in the level of service without significant increases in total traffic volumes (beyond those brought about by demographic and economic factors). At the regional level implementation of traffic and incident management systems may reduce CO and HC emissions, but may increase NO_x emissions as average travel speeds increase. Yet without details regarding the number of ramp meters deployed in a specific network and the emissions significance of their deployment, the regional emission impacts of this technology bundle cannot be fully assessed.

Route Guidance Systems

The systems included in the route guidance systems technology bundle are designed to provide motorists with information on highway conditions and route availability to help them decide on the best possible route before or during a trip.

- *Radio data systems* use a radio frequency to broadcast traffic information to motorists.
- *On-board navigation systems* inform motorists about their current location and how it relates to the desired destination, but not on a real-time basis.
- *Electronic route planning and information systems* link minimum-path computer algorithms to highway network data bases, accounting for real-time traffic conditions.
- *Externally linked route guidance systems* provide real-time information on traffic conditions and suggest alternative routes to circumvent congested roads during the route-following stage of the trip.

U.S. vehicle owners have traditionally proven to be price sensitive. Elaborate route guidance systems may be very expensive initially (roughly $3,000), reducing their attractiveness to the general motorist public (*7*). The earliest applications of these systems may be in commercial vehicle operations, where productivity gains from better route guidance will be an important financial consideration to commercial carriers. Penetration may increase as prices decrease and benefits are more widely perceived.

First-generation route guidance systems, such as traffic information broadcasting systems, allow motorists to be better informed in the event of heavy congestion along specific corridors. By providing a motorist with information on his or her current location and how that location relates to the desired destination, on-board navigation systems may enhance the motorist's ability to select an alternative route when heavy congestion is encountered. However these systems are not designed to provide motorists with continuous real-time information on traffic conditions and alternative routes.

More advanced systems, such as externally linked route guidance systems, may reduce vehicle hours of delay and improve level of service along a corridor by roughly 7 to 15 percent by providing dynamic routing information that is fully responsive to traffic conditions on the network (*8*).

By diverting traffic from congested corridors to those with excess capacity, traffic flow will be improved along the corridor. However traffic diversion may result in longer trips as motorists select less direct routes to reach destinations. On the other hand on-board navigation systems have the potential to decrease the amount of wasted travel associated with human navigation errors. The net effect on trip distance, or total vehicle miles traveled, is difficult to assess for either the short term or the long term.

Diverting individual drivers from congested corridors to other routes in the network may also result in a rebound effect whereby additional drivers are attracted to less congested routes, possibly increasing emissions along those routes (*9*). However this claim is not supportable because route guidance systems have the potential to improve level of service in the entire network, and often numerous routes with excess capacity exist between an origin and a destination. At this stage exactly what will be the congestion and emission impacts along alternative routes as a result of route diversion is unclear.

Finally the implementation of route guidance systems may facilitate trip chaining, or the linking of different-purpose trips into one extended trip. As more complete and representative travel information is available to motorists before or during a trip, the satisfaction of different needs through trip chaining becomes feasible. The use of route guidance systems for product and service advertising may have this effect. Trip chaining can, in turn, reduce the number of vehicle miles traveled and eliminate those hot and cold starts associated with separate trips.

The potential travel and emission effects of route guidance systems can be summarized as follows. Improved traffic flow will result in decreases in CO and HC emissions. However NO_x emissions may increase with higher average travel speeds. Potential reductions in the number of vehicle miles traveled and hot or cold starts will translate into reduced CO, HC, and NO_x emissions. The net effect on NO_x emissions is uncertain.

Accident Reduction Systems

Accident reduction systems encompass technologies that provide real-time, on-board warnings to vehicle operators and technologies that automatically assume control of vehicle operations during emergency situations.

- *SmartRamp designs* for commercial vehicles automatically detect the size, weight, and speed of trucks as they approach ramps and advise the driver if there is a rollover hazard.
- *Antilock braking systems* assume control of a vehicle's braking function during moments of excessive braking or severe cornering.
- *Intersection hazard warning systems* prevent accidents that occur when a vehicle enters an intersection and collides with cross traffic that was not visible.
- *Collision avoidance systems* use radar braking and automatic steering control to warn drivers of impending collisions or to automatically assume vehicle control.

On-board warning systems that warn drivers of possible collisions but do not assume vehicle control can be regarded as first-generation accident reduction systems, whereas those systems that automatically control the vehicle to avoid collisions represent second-generation systems. As with other on-board devices, short-term implementation is likely to take place in luxury passenger vehicles and commercial vehicles.

Collision avoidance systems that rely on technologies like radar braking and automatic steering control are still in the development stage. Short-term implementation of the systems in this technology bundle may be limited to SmartRamp designs and first-generation collision warning systems. In the long term advances in radar braking and automatic steering control systems will facilitate the penetration of collision avoidance systems that automatically assume vehicle control during emergency situations.

Traffic accidents directly contribute to nonrecurrent congestion on roadways across the country. By reducing the likelihood of traffic accidents, accident reduction systems can potentially reduce delays associated with nonrecurrent congestion and improve level of service at the corridor and regional levels. Studies suggest that approximately 7 percent of all road accidents could have been prevented if antilock braking systems had been fitted to the involved vehicles (*6*). In the long term collision avoidance systems and intersection hazard warning systems that automatically assume control of the vehicle in emergency situations have the potential to eliminate those accidents that occur because of the inability of drivers to judge speeds and distances correctly.

The implementation of accident reduction systems may translate into reduced HC and CO emissions and increased NO_x emissions as traffic flow is improved and roadways provide higher levels of service. These emission impacts are expected to be greater in the long term with the penetration of systems that assume vehicle control during emergency situations.

Vehicle Control Systems

Systems in the vehicle control systems technology bundle will allow those vehicles traveling on an appropriately equipped roadway to operate at closer driving distances and at more constant speeds.

- *Radar braking systems* are designed to brake vehicles automatically when predetermined speed and distance relationships are violated.
- *Vehicle speed control systems* include conventional cruise control, speed governors, and variable speed control.
- *Automatic headway control systems* use vehicle sensors to maintain constant distances (brake and speed control) between vehicles traveling on a particular lane of a roadway.
- *Automatic steering control systems* automate the steering process of vehicle operation and allow vehicles to follow a predetermined path along dedicated highway lanes.
- *Automatic highway systems* combine vehicle control strategies with other IVHS products to produce highways on which vehicles drive themselves.

Various technical problems associated with radar braking need to be resolved. These include false alarms that can be caused by roadside obstacles; blinding, which occurs when radar signals from vehicles traveling in the opposite direction block out the return signals from potential obstacles; and problems caused by poor weather conditions, such as backscatter from rainwater (*6*).

The penetration of variable speed control systems may depend on economic factors and vehicle turnover rates, and thus may be significant in the short term. Adaptive cruise control systems are being designed and tested in various programs around the world, including PATH (Partners for Advanced Transit and Highways) and PROMETHEUS (Program for European Traffic with Highest Efficiency and Unprecedented Safety). These systems may be available on some vehicle lines within the new few years.

As a result of the expected staged implementation of the systems included in this bundle, it is possible that short-term and long-term travel and emission impacts may differ. Short-term penetration of vehicle speed control systems may result in smoother traffic flow and improved levels of service on freeways. Vehicle speed control systems, especially adaptive cruise control, may damp out flow disturbances by reducing speed differentials and minimizing the frequency of vehicle stops. The resulting smoother traffic flow should reduce delays, improve energy efficiency, and reduce CO and HC emissions. (NO_x emissions may increase as average speeds increase on a particular freeway). An added benefit may be the reduction of rear-end collisions, with accompanying nonrecurrent congestion relief, that sometimes occur from the propagation of flow disturbances (*2*).

In the long term radar braking systems, automatic steering control systems, automatic headway control systems, and automated highway systems may be implemented, potentially removing the human element from the vehicle operation process. Such applications could double or triple the capacity of a freeway lane (*2,7*).

If the effect of implementing these systems on one existing lane of a freeway is comparable to the effect of adding one or two new lanes, then congestion on the freeway can be replaced by freer-flowing traffic. However if arterial routes in the immediate area of the freeway are also congested, then the new freeway capacity and corresponding improved level of service may cause some of the traffic on parallel routes to be diverted onto the freeway. This diversion may diminish the benefits to freeway users, but may improve level of service on parallel routes (*2*). Therefore potential capacity improvements at the corridor level may also have regional impacts.

Large capacity increases may induce traffic at both the corridor and regional levels as people decide to take trips that they formerly would have forgone because of excessive congestion on the affected freeway or on parallel roads. Results from a recent study conducted by the Institute of Transportation Studies (ITS), University of California at Berkeley, show that capacity expansion induces traffic on the expanded facility, but that this effect occurs over an extended period of at least two decades (*10*). More important the study shows that even after 20 years the traffic induced by expansion falls well short of what would be required to produce the same volume-capacity ratios in the absence of a capacity enhancement project. Therefore capacity expansion will improve the level of service on the expanded facility. This improved level of service will be realized shortly after the project is finalized and is likely to continue for many years. This finding refutes the notion that additions to roadway capacity are quickly and completely absorbed by additional traffic. Increased roadway capacity is not likely to result in a system with equal congestion and more vehicles. The proposition that traffic builds to fill capacity may be true 20 or 30 years after the completion of a project, but this is of little relevance.

The ITS study found that the estimated demand-capacity elasticity 4 years after a capacity expansion ranges from under 0.1 to over 0.3, whereas 10 years after completion the range becomes 0.2 to 0.4. Therefore a 1 percent increase in capacity is expected to result in a 0.1 to 0.3 percent increase in traffic 4 years after the capacity enhancement project is completed. Similarly this 1 percent increase in capacity is expected to result in a 0.2 to 0.4

percent increase in traffic 10 years after project completion. Sixteen years after project completion the demand-capacity elasticity range is estimated to be 0.22 to 0.55. Although capacity-demand elasticity depends on the specific project under consideration, the magnitude of the induced traffic effect resulting from capacity enhancement projects is relatively low, since traffic will not expand to fill capacity until roughly 20 or more years after the capacity enhancement project has been completed.

Similarly results from the ITS study at the regional level indicate that road expansion generates traffic. The study estimates a 0.5 intraregional elasticity and a 0.2 interregional elasticity of vehicle miles traveled on California highways with respect to changes in capacity (lane-miles) in urban regions. However other factors such as population and income have larger effects than road expansion on the generation of traffic. The study indicates that population elasticities range from 0.7 to 0.8, whereas income elasticities are in the range of 0.4 to 0.9.

Because the capacity elasticities are less than unity, highway expansion is also expected to lead to reduced congestion at the regional level. Moreover the study finds that as a result of larger population elasticities and faster population growth, population contributed considerably more than lane-mile growth to the vehicle mile traveled increases in the study region in the past two decades.

Although the focus of the ITS study is on lane-mile additions, many of the results apply to other types of capacity enhancements as well, including those brought about by IVHS. Within the context of this technology bundle, implementation of the systems that may influence roadway capacity probably will not occur until the long term. Even if these systems lead to induced traffic the ITS report shows that capacity expansion reduces volume-capacity ratios, increasing level of service over an extended period of time. Therefore the notion that IVHS will result in a system of equal congestion and more vehicles is not supportable. Moreover satisfaction of latent travel demand confers a societal benefit in terms of increased mobility and potential contributions to economic activity.

In the long term the implementation of vehicle control systems may generate new land use patterns that can lead to increased trip-making and trip distances. If the effective speed on an automated corridor is twice that on the existing congested corridor, people may locate up to twice as far from workplaces without increasing the durations of their commutes (*2*). However the emission effects of the longer trips that may result from changes in land use are difficult to assess. For example if the longer trip takes place on a freely flowing highway, trip emissions could decrease.

Although the short-term emission repercussions of vehicle speed control systems can be assessed given expectations regarding traffic operations and travel, the complex nature of the relationships between improved traffic flow, induced traffic, and potential land use changes makes it difficult to assess the emission repercussions of vehicle control systems with any degree of certainty.

Commercial Vehicle Inspection Systems

Commercial vehicle inspection systems increase the productivity of those vehicles engaged in the movement of goods and services and simplify the regulation of commercial vehicles. Only weigh-in-motion and automated safety inspection systems are expected to have an impact on vehicle emissions by reducing congestion at weigh stations and by reducing the number of hot starts.

- *Weigh-in-motion* systems use sensors that can automatically weigh vehicles at main line speeds.
- *Automated safety inspection* systems involve on-board diagnostic systems, scanners, and road-to-highway communication systems situated at safety inspection stations that interrogate vehicles at main line speeds for the condition of safety systems.

Weigh-in-motion stations have been successfully tested, most notably in the California Heavy Vehicle Electronic License Plate Crescent program, and full-scale short-term implementation may be solely constrained by regulatory and institutional barriers. The implementation of weigh-in-motion systems may directly influence congestion at weigh stations. These systems may also eliminate weigh station truck queues that back up onto the highway.

Similarly congestion at roadside inspection stations and along the supporting highway may potentially be eliminated through systems that allow automated safety inspections to be conducted at main line speeds. Roadside safety inspections must be conducted under engine-off conditions. By eliminating the engine-off requirement, automated safety inspection systems can eliminate those emissions associated with hot starts during the inspection process.

Trip Guidance and Public Transportation Systems

By improving their attractiveness and accessibility to travelers, trip guidance and public transportation systems encourage the use of transit and ride-share facilities, increase the efficiency of high-occupancy modes of travel, and reduce operational costs while offering higher levels of service to the public.

- *Ride-sharing information systems* include on-line computers in business centers, shopping malls, homes, or smart kiosks that tie into a real-time central data base where ride-sharing matches can be identified.
- *Traveler information and service systems* provide travelers with real-time schedule and fare information, pretrip planning information, trip reservation and payment services, and ride-share participant selection and location information.
- *Traffic management systems* give priority to high-occupancy vehicles through traffic signal priority, dedicated highway lanes, ramp controls, and toll strategies.
- *Transit and fleet management systems* better track transit vehicles during service and improve scheduling, ticketing, and planning operations.

From a technological perspective the operational reliabilities of these systems are virtually assured, given that current communications and computer systems are well suited to handle the interface between centralized information clearinghouses and travelers (particularly for work-related trips). For example experimental transit preferential signal priority schemes have been installed in Kent, Ohio; Louisville, Kentucky, and Washington, D.C. These schemes employ automatic vehicle identification technology to identify transit or other types of high-occupancy vehicles when approaching the specially equipped intersection. The penetration of the systems included in this technology bundle may be accelerated by the 1990 Clean Air Act Amendments, which emphasize transportation control measures such as ride sharing as a means of reducing impacts of transportation activities on air quality.

The travel impacts of trip guidance and public transportation systems may be fewer vehicle trips and vehicle miles traveled as a result of person-trip shifts from single-occupancy vehicle modes to high-occupancy vehicle modes. Although the number of person-trips may not decrease, reductions in the total number of vehicle trips and total vehicle miles traveled will result in overall reduced levels of congestion and improved levels of service at both the corridor and network levels. Real-time information on traffic conditions at the route level can also induce motorists to delay trips to those times when congestion levels are low.

Under a scenario of full system implementation the potential traffic operation impacts of this technology bundle may translate into reduced CO, HC, and NO_x emissions at both the corridor and regional levels. Although improvements in level of service may increase average speeds and thereby increase NO_x emission rates, total NO_x emission levels may be reduced as the number of vehicle miles traveled and the number of vehicle trips fall. However the effect on NO_x emissions will depend on the types of systems and the extent of their implementation.

Enabling Technologies for Travel Fees

Examples of IVHS enabling technologies for road pricing programs include automatic vehicle identification, location, and classification technologies, electronic toll collection, and smart cards.

- *Automatic vehicle identification* technologies use transponders, roadside readers, and computers that automatically and uniquely identify vehicles as they pass through specially equipped points on the system network.
- *Automatic vehicle location* technologies provide real-time vehicle location information to a control center by means of on-board computers or sensors.
- *Automatic vehicle classification* systems classify vehicles according to type, gross vehicle weight designation, or other attributes.
- *Electronic toll collection* allows toll collection without vehicle stops.
- *Smart cards* store personalized identification codes linked to centralized data bases.

The enabling technologies included in this IVHS bundle can increase the effectiveness of roadway pricing by minimizing the substitution effect and maximizing the income effect of changes in travel costs. The substitution effect represents the potential increase in congestion on local roads that results from pricing programs implemented on freeways, main lines, or other major corridors in a particular urban area. Automatic vehicle identification and location systems may facilitate the implementation of roadway pricing at the local or regional level, so that travelers are charged appropriate travel fees for using any portion of the transportation network. Strategies can be designed to minimize travel decisions associated with preferential routes on the basis of significant price differentials. In this way the substitution on the part of travelers away from main lines to local roads that may not be equipped for high traffic volumes can be minimized, whereas the increase in travel cost at the network level (i.e., the income effect) may shift trips to alternative modes or delay trips to off-peak periods.

However these strategies are likely to be unavailable in the short term as technological, institutional, legal, ethical, and political barriers inhibit the implementation of local or regional schemes. In the short term those urban areas that implement road pricing programs are likely to do so only at the corridor level. As a result the short-term travel and emission effects of corridor-level projects are uncertain when considered from the perspective of the entire region or transportation network. In the long term, however, the potential does exist for significant travel and emission effects at both the corridor and regional levels.

The short-term corridor-level impact on mode shift may be positive because of the use of high-occupancy vehicle buy-in lanes. On a per-vehicle basis NO_x emissions may increase as reduced congestion facilitates faster travel speeds. However because travel fees may have the effect of reducing the total number of vehicle trips, it is difficult to determine how overall NO_x emissions will change in the short term. In the long term significant changes in the number of vehicle trips may decrease total NO_x emissions at both the corridor and regional levels.

Emission Control-Enabling Technologies

The emission control-enabling technology bundle includes those devices and systems that have the potential to mitigate mobile source emissions directly by complementing conventional emission control strategies, such as inspection and maintenance programs.

- *Remote sensing devices* measure the concentration of pollutants in the exhaust plumes of vehicles as they pass a roadside monitoring station.
- *Vehicle diagnostic systems* monitor the fuel consumption and exhaust emissions of vehicles and advise drivers on appropriate maintenance practices.

Section 205 of the 1990 Clean Air Act Amendments promulgates regulations requiring manufacturers of light-duty vehicles and light-duty trucks to install emission diagnostic systems beginning in model year 1994. The California Air Resources Board has promulgated similar regulations that require vehicle manufacturers to install on-board diagnostic devices that monitor the performance of catalytic converters. Therefore the short-term penetration of on-board emission diagnostic systems may be accelerated by these statutes, and penetration rates may be constrained only by vehicle turnover rates.

The use of remote sensing devices as an alternative to scheduled, periodic inspection and maintenance programs has several major shortcomings related to the inability of remote sensing devices to obtain readings on all vehicles; to measure evaporative, crankcase, and NO_x emissions; to detect problems with systems designed to control emissions during engine warm-up operation; and to distinguish vehicles with moderately high HC and CO emissions from those that are free from defects.

However as a supplement to conventional inspection and maintenance programs, remote sensing offers two potential advantages.

- Remote sensing can provide a deterrent to the tampering or maladjustment of emission control devices by a vehicle owner that

TABLE 1 Potential Short-Term, Corridor-Level Impacts of Technology Bundles

	Traffic Flow	Vehicle Trips	Trip Distance	Mode Shifts	HC Emissions	CO Emissions	NOx Emissions
Traffic and Incident Management Systems	Positive	Insignificant	Insignificant	Insignificant	Uncertain	Uncertain	Uncertain
Route Guidance Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Uncertain
Accident Reduction Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Vehicle Control Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Commercial Vehicle Inspection Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive
Trip Guidance and Public Transportation Systems	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Enabling Technologies for Travel Fees	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Emission Control Enabling Technologies	Insignificant	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive

Key:

- The short term is defined in this study to be from 2000 to 2010.
- Positive impacts reflect improvements in traffic flow, reductions in vehicle trips or trip distance, or mode shifts from single occupancy vehicles to high occupancy vehicles.
- Negative impacts reflect increases in congestion, vehicle trips or trip distance, and those impacts that reflect mode shifts from high occupancy vehicles to single occupancy vehicles.
- Insignificant impacts reflect no changes (or small changes) in traffic flow, the number of vehicle trips, trip distance, or mode shifts.
- Uncertain impacts are those for which changes in traffic flow, tripmaking, trip distance, or mode cannot be even qualitatively assessed given the current state of knowledge.

TABLE 2 Potential Short-Term, Regional-Level Impacts of Technology Bundles

	Traffic Flow	Vehicle Trips	Trip Distance	Mode Shifts	HC Emissions	CO Emissions	NOx Emissions
Traffic and Incident Management Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Route Guidance Systems	Positive	Positive	Uncertain	Insignificant	Positive	Positive	Uncertain
Accident Reduction Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Vehicle Control Systems	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Commercial Vehicle Inspection Systems	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Trip Guidance and Public Transportation Systems	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Enabling Technologies for Travel Fees	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain
Emission Control Enabling Technologies	Insignificant	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive

Key:

- The short term is defined in this study to be from 2000 to 2010.
- Positive impacts reflect improvements in traffic flow, reductions in vehicle trips or trip distance, or mode shifts from single occupancy vehicles to high occupancy vehicles.
- Negative impacts reflect increases in congestion, vehicle trips or trip distance, and those impacts that reflect mode shifts from high occupancy vehicles to single occupancy vehicles.
- Insignificant impacts reflect no changes (or small changes) in traffic flow, the number of vehicle trips, trip distance, or mode shifts.
- Uncertain impacts are those for which changes in traffic flow, tripmaking, trip distance, or mode cannot be even qualitatively assessed given the current state of knowledge.

TABLE 3 Potential Long-Term, Corridor-Level Impacts of Technology Bundles

	Traffic Flow	Vehicle Trips	Trip Distance	Mode Shifts	HC Emissions	CO Emissions	NOx Emissions
Traffic and Incident Management Systems	Positive	Insignificant	Insignificant	Insignificant	Uncertain	Uncertain	Uncertain
Route Guidance Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Uncertain
Accident Reduction Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Vehicle Control Systems	Positive	Insignificant	Negative	Insignificant	Uncertain	Uncertain	Uncertain
Commercial Vehicle Inspection Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive
Trip Guidance and Public Transportation Systems	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Enabling Technologies for Travel Fees	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Emission Control Enabling Technologies	Insignificant	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive

Key:
- The short term is defined in this study to be from 2000 to 2010.
- Positive impacts reflect improvements in traffic flow, reductions in vehicle trips or trip distance, or mode shifts from single occupancy vehicles to high occupancy vehicles.
- Negative impacts reflect increases in congestion, vehicle trips or trip distance, and those impacts that reflect mode shifts from high occupancy vehicles to single occupancy vehicles.
- Insignificant impacts reflect no changes (or small changes) in traffic flow, the number of vehicle trips, trip distance, or mode shifts.
- Uncertain impacts are those for which changes in traffic flow, tripmaking, trip distance, or mode cannot be even qualitatively assessed given the current state of knowledge.

TABLE 4 Potential Long-Term, Regional-Level Impacts of Technology Bundles

	Traffic Flow	Vehicle Trips	Trip Distance	Mode Shifts	HC Emissions	CO Emissions	NOx Emissions
Traffic and Incident Management Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Route Guidance Systems	Positive	Positive	Uncertain	Insignificant	Positive	Positive	Uncertain
Accident Reduction Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Vehicle Control Systems	Positive	Insignificant	Negative	Insignificant	Uncertain	Uncertain	Uncertain
Commercial Vehicle Inspection Systems	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Trip Guidance and Public Transportation Systems	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Enabling Technologies for Travel Fees	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Emission Control Enabling Technologies	Insignificant	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive

Key:
- The short term is defined in this study to be from 2000 to 2010.
- Positive impacts reflect improvements in traffic flow, reductions in vehicle trips or trip distance, or mode shifts from single occupancy vehicles to high occupancy vehicles.
- Negative impacts reflect increases in congestion, vehicle trips or trip distance, and those impacts that reflect mode shifts from high occupancy vehicles to single occupancy vehicles.
- Insignificant impacts reflect no changes (or small changes) in traffic flow, the number of vehicle trips, trip distance, or mode shifts.
- Uncertain impacts are those for which changes in traffic flow, tripmaking, trip distance, or mode cannot be even qualitatively assessed given the current state of knowledge.

might occur after successful completion of a periodic inspection and maintenance test, and

- Remote sensing allows for early detection of emissions-related vehicular defects unrelated to tampering that can occur between periodic inspections.

Similarly the penetration of on-board emission diagnostic systems has the potential to improve the identification, by vehicle owners, of emission control system malfunctions. Whether vehicle owners who are alerted to malfunctions will repair their vehicles in a timely fashion depends on many factors unrelated to the reliability of on-board diagnostic systems. It is important to combine strategies that facilitate the identification of system malfunctions, such as on-board diagnostic systems, with those that accelerate repair practices and deter tampering with emission control devices, such as remote sensing devices and inspection maintenance programs.

An integrated emissions identification, inspection, and maintenance approach may significantly reduce in-use emissions from motor vehicles. In the short term the benefits may be constrained by vehicle turnover rates and operational deficiencies. In the long term the impact of this technology bundle on in-use emissions will be more significant as all in-use motor vehicles use on-board emission diagnostic systems and the operational reliability of remote sensing devices is improved.

Summary of Potential Emission Impacts of IVHS

The impact of IVHS on emissions is directly a function of the staged implementation of technologies and systems and the resulting travel and traffic repercussions. Most technologies and systems will lead to improvements in level of service at both the corridor and network levels. These improvements are likely to be measured in small percentage terms rather than in orders of magnitude, and level-of-service improvements are not expected to induce significant amounts of travel. Therefore some IVHS strategies can potentially decrease emissions by improving traffic flow, whereas others can reduce the number of vehicle trips (and the number of cold and hot starts) by promoting travel in high-occupancy vehicles and on public transit systems.

Although better control of off-cycle emissions will reduce the magnitude of the emission benefits that result from improved traffic flow, the emission impacts of most IVHS actions may still be positive. When combined with remote sensing devices, on-board diagnostic systems, and travel fees, IVHS strategies that improve traffic flow and the level of service on roadways have the potential to alleviate air quality problems associated with congestion, poor vehicle maintenance, wasted travel, and too many vehicle trips. Emission benefits may be realized without compromising economic development and the public's need and desire for mobility.

Vehicle control systems have the potential to induce traffic as a result of significant increases in roadway capacity. But it is unlikely that the induced traffic generated by these systems will result in a transportation system characterized by the same level of congestion and more vehicles. Moreover the implementation of those vehicle control systems that can significantly increase capacity, such as automated highways, probably will not occur until the long term. In the long term emissions from motor vehicles may be much lower than current levels, as fuel specifications change (e.g., reformulated fuels) and advanced emission control technologies (e.g., electrically heated catalysts) become feasible.

The potential emission impacts of each IVHS technology bundle are summarized in Tables 1 through 4.

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