Chapter 8

INTELLIGENT HIGHWAY SYSTEMS (IHS)

1. Summary

Instantaneous adoption of incident management, signal coordination, and ramp meters on all 75 U.S. metropolitan areas' major roads vs. actual 2001 deployment would have reduced wasted time and 5.7 billion gallons of wasted fuel by an incremental 15%. This savings is equivalent to five years' congestion growth, or 0.85 billion gallons of roadway fuel in 2001 [3]. Additionally, an approximate estimate for full deployment to the same metropolitan areas of electronic toll plazas gives another 0.1 billion gallons per year. This estimate is based on an approximate extrapolation of the experience of New Jersey Turnpike [8]. Implementation of a modest amount of advanced routing technologies and of 25% of a set of other technologies would imply a 2001 savings of an additional ~0.5 billion gallons of fuel per year in the conventional technology case.

The total, 1.45 billion gal/y of fuel, agrees very well with both the CEF report [1] and the 10-year plan launched in 2002 by IHS America [6]. Fully implemented, these 1.45 billion gal/y of fuel versus the 2000 EIA *Annual Energy Outlook* (*AEO)* baseline would give 1.68b gal/y in savings versus the EIA *Annual Energy Outlook 2004 with Projections to 2025* (*AEO 2025)* baseline given conventional technology implementation in other highway sectors, alternatively, some 0.98 billion gal/y given *State of the Art* implementation in other non-IHS sectors. Respectively, this equates to some 0.11 Mbbl/d of product (we use product here to mean the same as roadway fuel, i.e., before conversion to crude oil) given conventional non-IHS technologies or 0.06 Mbbl/d of product given *State of the Art* non-IHS savings. Using either baseline, approximately 0.9% of the *AEO 2025* total crude oil consumption would be saved deploying the conventional technologies.

Our *Conventional Wisdom* (*CW*) technology portfolio excludes at least six other major technologies that collectively could save between 17+% and 45+% off a given baseline. These include signal priority modeling for bus rapid transit, intelligent cruise control, very close vehicle spacing, vehicle classifiers, routing algorithms, and agent-based computing infrastructure, all described and referenced in the final section of this chapter, see below. If and when deployed along with the *Conventional Wisdom* technology suite, a subset of these technologies represents our *State of the Art* IHS technology portfolio. Estimating the impact of the *SOA* portfolio in terms of fuel saved and cost is particularly difficult, so rather than go with the summed savings from all of the additional technologies, we have conservatively estimated the impact of any subset to be double the total of the conventional technology portfolio. In actuality, the impact could be manyfold better.

Any estimates, let alone reliable ones, for measure costs are very difficult to come by. Experience indicates that IHS costs are quite low, and we outline a set of four findings that indicate that it is likely that total costs are very low indeed. Because the value of non-fuel related benefits outweigh fuel-related benefit by at least one order of magnitude, saved time being the most important, we have assumed that all IHS investments would be made irrespective of fuel savings. For this reason we assign a zero cost of saved fuel to IHS-related investments across both technology portfolios.

2. Overview of methodology and results

Collectively, Intelligent Highway Systems technologies have the potential to integrate vehicles, systems users, and infrastructure towards more seamless interaction and therefore improve surface transportation safety, efficiency and convenience. IHS technologies include a broad range of wireless, electronic, and automated technologies, most of which facilitate rapid processing and analysis of real-time information for better traffic management. The definition covers both in-vehicle and systems-based technologies. Examples of the former are precision docking for buses, automated guideways, and collision avoidance systems. When IHS technologies are applied to systems-management, they can reduce fuel consumption. This is achieved by enabling one or more features, for example traffic smoothing, route planning and timing, direct congestion reduction, pricing and demand-management, enhancing attractiveness of public transportation mode use, vehicle transmission adaptation to variable conditions and terrain, and facilitation of small platoons of closely spaced vehicles [2].

We use the definitions and categories as classified in [2]. We then briefly review the impact of IHS assumed in The Interlaboratory Working Group 2000 report “Scenarios for Clean Energy Futures” [1] *Advanced* scenario. Next we review the impacts from deploying several technologies looked at by the Texas Transport Institute, [4] and [5]. This review reveals that the number of estimates of impacts on fuel use from IHS technology deployment is low in relation to the number of available technologies. For our conventional technology suite we therefore select those technologies for which we have a reasonably accurate impact estimate. Given the number of unanalyzed technologies and their possible impact, and the relatively modest conventional technology impact, we have simply assumed that the *State of the Art* technology portfolio would, if deployed, double the savings relative to the conventional technology suite.

We then review costs. While the costs are difficult to estimate, it is clear that on average IHS-related technologies would not be particularly expensive and that the value of non-fuel related benefits outweigh fuel-related benefits by at least one order of magnitude. If implemented to the degree stipulated herein, they would be relatively very cost effective. It is also clear that due to the high ratio of non-fuel related benefits to fuel-related benefits IHS technologies would be deployed largely without regard to fuel-related benefits. Based on this, we assume that the two portfolios of IHS related technologies considered here would have an average CSE of zero. For comparison, we also show the all-in cost on a CSE-basis. This cost simply assumes the cost of IHS technologies would be equal to the average CSE of all highway vehicle-based measures. Our results are summarized in Table 7-1.

3. Technologies and impacts

IHS architecture: The U.S. National Intelligent Transportation Architecture (of which IHS would be a subset) has 32 IHS user services bundled into 8 main categories. These eight categories are (1) travel and transportation management, (2) public transportation options, (3) electronic payment, (4) commercial vehicle operations (CVO), (5) emergency management, (6) advance vehicle control and safety systems, (7) information management, and (8) maintenance and construction [2].

The Clean Energy Futures report: This report simulated the effect of increased usage of IHS systems in their *Advanced* scenario by reducing by one percentage point the degradation factor in NEMS. This is the factor that translates EPA values of fuel economy into "on-the-road" values, and it accounts for congestion and other factors that increase fuel usage over the value that would be computed using the EPA values. No figures for the costs of this change were given, nor did the report outline a justification for the magnitude. That said, for degradation factors ranging from 0.75 to 0.85, the net effect of this adjustment is to reduce fuel consumption per mile driven by between 1.19% and 1.35% from any given baseline mpg and VMT (Vehicle Miles Traveled). This is quite similar to our findings for savings that would result from deployment of our *Conventional Wisdom* technology suite. The CEF report does not estimate costs, and we have taken this as another indicator that these costs are quite low.

Impacts are mostly independent of capital cycles: Impacts from systems-based IHS technologies are relatively less dependent on long capital turnover cycles. The importance of this factor is often overlooked in a sector where efficiency improvement is generally heavily dependent on capital turnover. Many of these technologies may therefore relatively very rapidly affect the efficiency of entire substocks of vehicles, e.g., roadway and airway vehicles. Put another way, these technologies may have an adoption-advantage over vehicle-based technologies. Vehicle-based technologies are often not easily suited for retrofit, so their actual impacts tend to correlate closely with the time constants associated with vehicle turnover periods. However, deployment of systems-based IHS technologies will tend to have a nearly immediate impact on the entire existing stock of local vehicles (e.g. London's ring road fee, electronic toll payments, traffic signal synchronization, etc.), thereby avoiding the capital turnover constraint.

Net benefits from and deployment strategies for system-based IHS technologies: In terms of net benefits, systems-based IHS technologies can be very cost-effective as they often involve little hardware, generally low costs, and usually entail multidimensional benefit impacts. A single technology will often contribute to all of congestion reduction, lowered traffic risks, improved safety, and increased vehicle stock average fuel economy.

For rigorous benefit quantification of some mainly congestion-oriented systems-based IHS technologies we have mainly relied on work done by the Texas Transport Institute (TTI). TTI finds that traffic congestion in the 75 largest (of 400) U.S. urban areas in 2001 cost $69.5b by wasting 3.5 billion hours (lost productivity) and 5.7 billion fuel gallons [2]. This is therefore the size of the reduction potential. The potential is up from $8b in 1982 [3, Exhibit 12, p. 24]. This estimate relies in part on abatement measures analysis in

[4] and method in [5]. Regarding lowering congestion, a key TTI conclusion is that the best solution entails a portfolio of options:

> It is clear that adding roadway at about the same rate as traffic grows will slow the growth of congestion. It is equally clear, however, that only five of the 75 areas studied were able to accomplish that rate. There must be a broader set of solutions applied to the problem, as well as more of each solution than has been implemented in the past, if more areas are to move into the "maintaining conditions or making progress on mobility" category… This analysis shows that it would be almost impossible to attempt to maintain a constant congestion level with road construction only. Over the past 2 decades, only about 50 percent of the needed mileage was actually added. This means that it would require at least twice the level of current-day road expansion funding to attempt this road construction strategy. An even larger problem would be to find suitable roads that can be widened, or areas where roads can be added, year after year. Most urban areas are pursuing a range of congestion management strategies, with road widening or construction being one of them.
>
> [3, p. 31 and p. 34. See also Exhibit 17, p. 33]

See [6] for updated information on metropolitan area progress in IHS deployment. Current understanding of the potential impact of IHS on fuel consumption is still limited.

The 10-year plan launched in 2002 by IHS America has a goal of saving at least 1 billion gallons per year. This plan has four programmatic themes, two of which could result in significant energy consumption reductions in the future, advanced crash avoidance, and advanced transportation management. We discuss these next.

<u>Savings from Advanced Crash Avoidance and Route Guidance Technology</u>: Technologies for advanced crash avoidance include adaptive in-vehicle electronics, which is forecast to reduce fuel consumption by acceleration and deceleration smoothing, automatic response in stop-and-go driving, anticipatory throttle and transmission adjustment in varying road and terrain conditions, and enabling safe movement of platoons of tightly spaced trucks and cars [2]. We do not have estimates of savings nor costs in conjunction with this category, and have excluded it from our total IHS potential savings.

In addition to advanced crash avoidance, deployment of route guidance technologies to reduce miles wasted from erroneous route choices and traffic delays will make an impact, e.g., in the trucking industry. This product has been accounted for in the trucking section, and it is clear it could reduce total VMT by reduction of out-of-route miles across all vehicle classes. Eliminating these would amount to gross fuel savings in the form of lower VMT. Here the potential is large, as between 3% and 10% of trucking miles driven are wasted due to poor route-planning [7]. As light vehicles travel a large fraction of their VMT on familiar routes during commuting, we have used a potential of 0.25% VMT reduction for light vehicles.

<u>Savings from Advanced transportation management</u>: The advanced transportation management theme is also forecast to have significant effect on vehicle energy use via tools to manage vehicle flows adaptively, within the physical infrastructure and across jurisdictions and modes. This relies on area-wide surveillance and detection, real-time

data capture and analysis of traffic flow data, and predictive capabilities. Highlights of the better-understood opportunities now follow.

Traffic signal control has been around for a long time, and has recently become a significant component of IHS. Studies reveal fuel efficiency benefits ranging between 1.6 and 50%, with most results less than 20% [2]. However, it is not clear whether these percentages would be applicable against national fuel consumption figures, although it is probably reasonable that the lower figure could be. While it is again not clear what the costs are, traffic signal installation would likely have very small costs on a CSE basis.

Improved incident management, via surveillance, verification, better emergency dispatch, changeable message signs, and early notification to upstream drivers, decreases fuel consumption by reducing the delay and congestion associated with blocked traffic. It isn't clear by how much, but it is clear it could be important. For a limited initiative, Maryland calculated fuel savings of 4.1 million gallons per year.

Ramp metering is a technology that safely spaces vehicles margining onto a highway while minimizing speed disruptions to existing flows, with the most significant benefit being time savings and with a mixed fuel consumption impact since ramp metering causes vehicles on ramps to stop and go, which increases fuel consumption, while it causes smoother flow on the freeway, resulting in consumption reduction [2]. It appears more detailed studies are needed to understand how the effects interact and how fuel consumption is affected [2].

For the three technologies above, TTI simulated full adoption—incident management, signal coordination, and ramp meters—on all 75 cities' major roads vs. actual 2001 deployment. The 2001 actual deployment ranged from 0% to ~60%, depending on what measure and where. Full deployment would have reduced the wasted time and fuel by an incremental 15%, equivalent to five years' congestion growth or 0.85 billion gallons of roadway fuel in 2001. This full implementation equates to 1.69 billion gallons per year in savings versus the *AEO 2025* baseline, or some 0.11 Mbbl/day, i.e., 0.4% of the *AEO 2025* total crude consumption. While the benefits of HOV and bus lanes and of public transport are also quantified in [4], we have generally excluded mode switching from our impact estimates in this section and elsewhere. Of course, if such a switch involves greater convenience for the user, this exclusion becomes a clear conservatism.

Electronic toll collection (ETC) saves time and reduces stop-and-go traffic, with analyses showing that fuel savings offset operating costs, with ETC systems moving five times as many vehicles as conventional toll lanes, and ETC systems significantly lowering toll plaza operational costs and reducing delay by 85% [8]. While the following data from New Jersey Turnpike ETC build-out does not permit a complete net benefits analysis, they are worth noting. 1.2 million gallons were saved per year at NJTP at the 27 toll plazas employing ETC. Moreover, $2.7 million were saved from reduced handling costs of fare media, and revenues were increased by 12% after automated fare collection implementation [8]. If capital costs were of this order, the CSE would be approximately zero. The study evaluated NJTP's E-ZPass electronic toll collection system by measuring traffic counts, queue lengths, lane configurations, and transaction times during peak periods at 27 toll locations. Field observations were evaluated against toll collection records and 24-hour total queue length and average vehicle-class delay before and after E-ZPass deployment at each station were generated. Toll plaza delay was reduced by approximately 85% for a total savings of 2,091,000 vehicle-hours per year. Passenger car delay was reduced by 1.8 million hours per year; truck delay was reduced by 291,000 hours per year; and E-ZPass user delay was reduced by 1,344,000 hours per year. User cost savings as a result of delay reductions were estimated at $19.0 million per year for passenger cars and $6.1 million per year for trucks for a total annual savings of $25.1 million. User cost savings related to fuel consumption were estimated at $1.5 million for passenger cars, and $400,000 for trucks.

One could estimate the impact of nationwide ETC if the following data were available: NJTP relative traffic density and fraction of traffic, fraction of NJTP plazas involved in the specific savings, and what fraction of nationwide plazas with what traffic densities have ETC today. Unfortunately these data are not easy to come by. The NJTP is 148 miles in length, but it is unclear what IHS lane-mile-count is or how long it is and what its relative traffic density is per lane-mile. Alternatively, if we assume there are about as many toll collection points that could benefit from this initiative in the rest of the 75 major metropolitan areas in mainland U.S. as along the 27 toll collection points, that these points are not yet built out, and that the average benefits would be approximately the same as for the 27, it would appear that some 1.2M gal/y x 75 ~ 100 million additional gallons could be saved from E-ZPass introduction nationwide if at the density seen with the NJTP.

<u>Savings from other measures:</u> Several other measures that are not easily quantifiable are now listed. Given the magnitude of the potential savings, we believe some of these will make an impact in our *SOA* technology suite. We estimate that these will, together with the conventional technology suite, amount to approximately 0.12M bbl saved per day in 2025. The measures include *signal priority modeling* for bus rapid transit, saving ~5% of IHS fuel [2]. Simulations for *intelligent cruise control* show 8.528.5% fuel savings when 10% of vehicles in a lane have intelligent cruise control [2]. *Very close vehicle spacing* simulations show very close headways produce drafting effects that can save 515% of fuel [2]. Another technology is a *vehicle classifier* [9]. This is connected to a PC, and detects when a vehicle, particularly for trucks, approaches an intersection, then relays that detection to the PC, which in turn delays a light change from green to red to give the truck time to clear the intersection safely and without the energy expenditure of stopping. The literature indicates that each truck stop consumes one-third of a gallon of fuel, a direct saving of this system where deployed, indicating a system payback from counting just two (saved time and fuel, the former worth about four times the value of the fuel) of five benefits at a typical intersection of just under two years [9, p. 8]. Further development in *routing algorithms* as a result of operations research applied to the ‘traveling salesman problem’ will no doubt lead to further efficiencies by eliminating backtracking and overlapping routes. For example, Waste Management, Inc., recently eliminated 761 trucks (or, we estimate from their 10-K, between 5% and 10% of IHS fleet of trucks) and $91M in annual operating costs by deploying an optimization

algorithm to reroute IHS fleet [10]. DARPA-derived technologies for *agent-based computing infrastructure* (the Agent based Logistics (ALP) protocol) may also contribute significantly to this area [11].

Costs of Savings from IHS: Little data exists on the costs of savings. Nevertheless, Table 7-1 has estimated such a cost, but on a fuel basis *only*. While little data exists on costs of systems-based IHS, there are four reasons for why we believe a carefully implemented set of IHS technologies would be very cost effective overall and that the costs related to the energy savings are insignificant and, unlike the fuel-based estimates in the Table of 3345¢/gal of fuel, approximately zero.

This first reason does not relate to energy savings, but to the value of the time that is wasted during congestion. Reducing this waste of time more than pays for the investment in the technology. In other words, irrespective of fuel savings, investment in IHS R&D and deployment is something that will occur anyways due to the value of the saved time. Of TTI's ~$70b in congestion-related waste, ~$63b is time, so the 15% saving that reduced fuel burn by 1.2b gallons, or some $1.6b, reduces wasted time by another order of magnitude, or about $10b. For this reason, we ascribe zero cost of energy saving—as long as wasted time from congestion is reduced, IHS investments will be made irrespective of any energy savings made. The NJTP experience is another indicator of high cost effectiveness without regard to fuel, as a 12% revenue boost was seen from ETC alone.

Second, the majority of the measures are quite simple installations that are largely fixed and involve few physical installations relative to the number of vehicles influenced; only a small fraction is vehicle-based technologies (which would imply a large number of installations). A small number of relatively low-cost installations affecting an entire stock of vehicles are likely to be cost effective.

Third, because these fixed technologies involve relatively little hardware, and mostly involve automated and IT-centric systems with a relatively low embedded R&D cost, they are likely to have relatively low up-front cost. For a given savings impact, this factor tends to reduce amortized costs relative to hardware-heavy and vehicle-based technologies.

Finally, IHS technologies generally influence operational fuel burn for entire vehicle fleets in a given location. Because this influence is exerted on groups of technologies that are already installed (i.e. existing vehicles), it does not involve changes in existing infrastructure nor vehicles. It is therefore quite plausible that average implementation costs would be quite small per gallon saved for this category relative to vehicle-based technologies.

REFERENCES

1 Interlaboratory Working Group. 2000. Scenarios for a Clean Energy Future (Oak Ridge, TN: Oak Ridge National Laboratory and Berkeley, CA: Lawrence Berkeley National Laboratory), ORNL/CON-476 and LBNL-44029, November. Available online at http://www.ornl.gov/sci/eere/cef/

2 Shaheen, S.A. and Finason, R., “Intelligent Transportation Systems,” in *Encyclopedia of Energy*, pp. 487-496, vol. 3, 2004

3 David Schrank and Tim Lomax, “2003 Urban Mobility Report,” Texas Transportation Institute, The Texas A&M University System, September 2003. Available online at http://mobility.tamu.edu/ums/report/

4 David Schrank and Tim Lomax, “2003 Urban Mobility Report, Volume 2: Five Congestion Reduction Strategies and Their Effects on Mobility,” Texas Transportation Institute, The Texas A&M University System, September 2003. Available online at http://mobility.tamu.edu/ums

5 David Schrank and Tim Lomax, “APPENDIX B, Methodology for 2003 Urban Mobility Report, Volume 2: Five Congestion Reduction Strategies and Their Effects on Mobility,” Texas Transportation Institute, The Texas A&M University System, September 2003. Available online at http://mobility.tamu.edu/ums

6 See http://IHSdeployment2.ed.ornl.gov/IHS2002/default.asp

7 Kenworth Truck Company, “White Paper on Fuel Economy”, October 2001, downloadable at www.kenworth.com/Kenworth_White_Paper.pdf.

8 US DOT, “New Jersey: Intelligent Transportation Systems,” FHWA, section on IHS Benefit Data, excerpt online at http://www.IHS.dot.gov/staterpt/NJ.HTM

9 Srinivasa R. Sunkari, Hassan A. Charara, and Thomas Urbanik II, "Reducing Truck Stops at High-Speed Isolated Traffic Signals," Texas Transportation Institute, September 2000. Available online at http://tti.tamu.edu/product/catalog/reports/1439-8.pdf Also in Texas Transportation Researcher, Volume 37, Number 2 (2001), Available online at http://tti.tamu.edu/researcher/

10 Sharon Begley, “Did You Hear the One About the Salesman Who Traveled Better?”, *The Wall Street Journal*, 23 April 2004.

11 Sherry Marcus *et. al.*, “Predictive Assessment in the Advanced Logistics Project” Final Status Report, Defense Advanced Research Projects Agency (DARPA), order G531, Available online at http://cougaar.org/docman/view.php/16/30/Predictive_Assessment_Final_Report.pdf

Table 7–1: ESTIMATED HIGHWAY FUEL SAVINGS FROM INTELLIGENT HIGHWAY SYSTEMS

Selected Technologies

	Current 2000	*CW* 2025	*SOA* 2025	
Baseline data				
Calculated non-ITS redct'n		27%	58%	Percent of truck, lt truck, & auto use saved, 2025
Total Highway fuel use	20,444	23,747	13,783	T Btu/yr
Implied 25-yr change		1.162	0.674	ratio
SOA/CW savings ratio			2.0	ratio
Estimated savings				
Subtotal, TTI figs (*)	0.85	0.99	1.15	b gal/y
ETC	0.10	0.12	0.13	b gal/y
Adv Routing (**)	0.30	0.35	0.40	b gal/y
Other	0.20	0.23	0.27	b gal/y
Total savings (various units)	1.45	1.68	1.95	BN gal/yr
	181	210	244	T Btu/yr
	34.5	40.1	46.5	M bbl/y
	0.09	0.11	0.13	M bbl/d
Percent reduction, ITS	0.89%	0.89%	1.77%	% of 2025
Estimated costs				
All-in cost of saved energy (***)		$14.01	$ 18.73	$/bbl product
		$ 0.33	$ 0.45	$/gal product
Energy-related CSE		$0	$0	$/bbl
		$0	$0	$/gal

(*) These include: incident management, signal coordination, ramp meters

(**) Advanced Routing Assumptions:

	0.25%	0.25%	0.25%	Percent VMT rduct'n light vehicles
Total non-truck	14,978	11,750	10,893	T Btu/yr
	119.8	94.0	87.1	b gal/y

(***) All-in costs here assumed equal to avg non-IHS highway transport CSE.