Standards for Intelligent Vehicle-Highway System Technologies

JONATHAN L. GIFFORD

Alternative approaches to technological development for intelligent vehicle-highway systems (IVHSs) were investigated by reviewing the standards literature and interviewing key individuals. The standards literature suggested that for certain technologies, market forces can sometimes lead to suboptimal de facto standards, which would support government intervention to protect the public interest. There may be only narrow windows in time during which government or other collective action to establish such standards can be effective at reasonable costs. The greatest power to influence standards setting, however, may come exactly when the information available to inform action is most limited. Market pressure to disseminate a technology sometimes argues for an imperfect standard in a timely fashion over the alternative of no standard at all, but the sheer complexity of technical and marketing issues may confound and extend the duration of the standards-setting process. For automatic vehicle identification (AVI) technologies, concerns about suboptimal de facto standards may be misplaced, because those selecting the technologies are not mass-market end users but large-scale monopoly service providers. However, market pressures from such users to disseminate AVI technology are acute and may overwhelm standards-setting procedures. For other IVHS technologies, concerns about suboptimal de facto standards may also be misplaced, because the more fundamental issue of what end users are willing to pay for remains largely unresolved. Technological and market uncertainty and complexity may severely impede and extend the standards-setting process.

There is a broad consensus among transportation experts that the successful deployment of intelligent vehicle-highway systems (IVHSs) in the United States depends critically on the early development of technological standards and that success is much less dependent on major technological breakthroughs (*1,2*). Systems necessary for various aspects of IVHS are available and currently being pilot-tested in this country. A significant barrier to the dissemination of IVHS in the United States, however, is seen to be the absence of national standards for these existing and developing technologies. The supposition is that such standards must precede deployment and that some consensus-oriented cooperative effort is needed to develop such standards. Debate centers on the appropriate procedures for establishing these consensus standards.

The view that standards are a necessary precursor to the dissemination of IVHS is not self-evident, nor is the view that consensus is the appropriate mechanism for developing standards. Other complex technological systems have developed without early consensus standards. Indeed, there is some cause for concern that early development of IVHS standards may prematurely lock the technology into formats that are inefficient in the long term. Alternative technological development approaches, such as rivalry between competing manufacturers' systems and formats, may yield the greatest consumer benefits.

To investigate alternative approaches to technological development as it applies to IVHS, the author and a research assistant surveyed the literature on IVHS standards and on standards and technological development and interviewed key figures who are active in the development of IVHS standards. This paper reports the results of that research.

Department of Public Affairs, George Mason University, Fairfax, Va. 22030.

DESCRIPTION OF IVHS TECHNOLOGIES

IVHS embraces a broad range of technologies that incorporate advanced communications and control into the operation of highway vehicles and infrastructure. Briefly, the applications fall into several major areas, as indicated, although exact terminology is somewhat fluid.

1. Advanced traffic management systems (ATMSs) focus on traffic control devices such as conventional traffic signals and newer technologies such as changeable message signs as well as vehicle detection and monitoring.
2. Advanced traveler information systems (ATISs) provide drivers or transit users with travel information such as route selection, navigation, congestion, and delay. Transit applications are sometimes referred to as advanced public transportation systems (APTSs).
3. Commercial vehicle operations (CVOs) focus on improving the management of commercial fleets by enhanced vehicle identification and tracking.
4. Advanced vehicle control systems (AVCSs) focus on systems that automate driving, either by enhancing information available to the driver through, for example, radar detection of obstacles in a car's "blind spot," or by replacing driver control with automated control, at least for some portion of a trip.
5. Automatic vehicle identification (AVI) is a system whereby a vehicle carries a small identification device that allows roadside mechanisms to identify each vehicle uniquely. In the highway domain, AVI has been used to identify properly equipped vehicles as they cross certain points on the highway, without requiring action by an observer or the driver. AVI technologies can be used for many transportation applications, including electronic toll collection and vehicle monitoring. (This paper treats AVI as a part of IVHS, although some definitions do not.)

More-detailed descriptions are widely available (*3–5*).

STANDARDS AND TECHNOLOGICAL DEVELOPMENT

Technology standards have been the subject of research and development for more than a century. During the 19th century, they played an integral role in the development of the American system of manufacture, since standardized parts were essential to mass production (*6*). Since then "private organizations have developed tens of thousands of standards that serve to coordinate the productive efforts of American businesses" (*7*). During the first half of the 20th century, researchers examined the relative impact of standards on the efficiency of production and the social implications of a standardized society (*8–14*). Contemporary research has begun to focus on the relationship between standards and the technological development.

Standards perform a variety of functions: (a) a compatibility function, whereby a standard ensures the compatibility of complementary products from different manufacturers; (b) an informational function, whereby a standard informs the market about the characteristics of a standard product; (c) a quality function, whereby adherence to a standard indicates some level of quality (including a regulatory or safety standard); and (d) a variety-reduction function, whereby a standard allows the reduction in variety of a set of products (e.g., screw sizes) with little or no loss of consumer utility and producer gains in reduced production costs and lower inventory costs (*15*).

Technological standards are typically developed in one of three ways: through a government regulatory process resulting in mandatory standards; through a consensus process undertaken by standards-setting groups resulting in voluntary consensus standards; or through competitive rivalry between different technologies eventually resulting in one or more de facto standards. The U.S. public policy stance on standards, especially in the last decade, has generally been "to avoid mandatory standards, but . . . encourage . . . the formation of widely representative committtees to write voluntary technical standards . . ." (*16,17*).

Standardization is sometimes beneficial because it can lead to "cost savings through economies of scale" and the "lowering of entry barriers." In such cases, early standardization is probably more desirable than late, if the same standard is set (*18*). Early standardization also removes the incentive for potential users of the technology to "wait for the standard to settle down, and thus encourages early adoption of the technology" (*19*).

But there are also reasons to wait to establish standards for existing yet continually advancing technologies. Information on advances will continue to flow, information that may modify the view of the optimal standard to be established. In 1961, for example, IBM promoted its 6-bit computer code as a U.S. standard, but rapid technological change led it to shift its support to an 8-bit code only 4 years later (*20*).

Standards condition the rate and direction of technological development. When the technology is advancing, market forces can cause de facto standards to emerge in the absence of public intervention. Moreoever, historical chance events can exert powerful influences over those de facto standards and give rise to less-than-optimal standards. A striking example is the almost universal "QWERTY" keyboard, which came into predominant use not through any particular technical superiority but instead through a series of historical accidents (*21*).

Such research has developed the notion of "path dependency," which suggests that market forces, left to their own devices, may not yield technically or economically superior de facto standards (*22,23*). Path dependency, as a market failure, provides a rationale for government intervention into market processes in order to protect the public interest.

Two critical policy dilemmas emerge from such conditions. First, public policy interventions to affect standards may be effective or affordable only during a narrow window in time. And second, government's greatest power to influence the path of technological development may come at just the time when the necessary information on which to base such decisions is lacking. But adopting a wait-and-see policy runs the risk of locking into an inappropriate standard (*16*).

These policy dilemmas are central to the topic of this paper, for it is not at all clear whether resolving those dilemmas through consensus-based standards development will produce outcomes superior to those yielded by competitive rivalry. QWERTY is a case in which rivalry yielded lock-in on an inferior technology. But rivalry can also yield tremendous innovation (*24*).

Consider, for example, the competition over the last decade for dominance in the microcomputer market between DOS-based systems (developed by IBM and Microsoft), Apple's Macintosh system, and UNIX. Recent developments suggest that IBM and Apple will now join forces to create a system that synthesizes the benefits of both systems. Further study of this development process is clearly in order, but there appears to be at least an arguable case that competitive rivalry drove both parties to improve their own systems to a greater extent than they would have had the two joined forces in the early 1980s to produce a consensus standard.

What is clear is that both laissez-faire and policy intervention involve risks. Rivalry risks the emergence of de facto standards that are technically inferior. A consensus approach risks diminishing the incentives for innovation.

Another major avenue of research inquiry has been in health and safety standards, specifically in the appropriate role for government in setting standards and the extent to which the public interest is served by reliance on private voluntary standards. Beginning in the mid-1960s, private voluntary standards in several industries came under intense scrutiny. In the automobile industry, they were prompted by Nader's *Unsafe at Any Speed* (*25*), which led to the National Traffic and Automotive Safety Act in 1966. Similar concerns led to the Gas Pipeline Safety Act of 1968 and the formation of the Consumer Product Safety Commission in 1967. Research in this area has focused on how to conjoin the democratically motivated consideration of the public interest—especially the interests of consumers, workers, and small businesses—with the experience and expertise provided by the private standards-writing organizations, which governmental agencies cannot readily duplicate (*7,26–28*).

These concerns have raised the level of interest in standards as a general area of inquiry (*29*). Researchers have also focused on investigations of standards in various substantive areas, including communications and computers (*20,30*), housing (*31,32*), highway design (*33,34*), land surveying and ownership (*35*), agricultural technology (*36*), and electrical supply (*37*).

These case studies contain some particularly relevant conclusions and generalizations for inquiry into IVHS. For packet switching standards for computer communications, economic and competitive pressures were forcing the rapid implementation of computer networks, with or without standards. As a result, if standards were going to contribute to the technology, they had to be developed on a compatible time scale. In such cases, the study concluded, an imperfect standard developed in a timely fashion is better than no standard at all, and the best time to develop a standard "appears to be during a very narrow window" after there has been some operating experience with a particular technology and "when there has been a commitment by other organizations to enter the field, but before these same organizations" commit themselves to divergent approaches (*20*).

In the standardization of computerized local-area networks (LANs), the "sheer complexity of the issues" surrounding the development of LAN strategies and standards meant that few engineers, if any, understood all the technical and marketing issues involved. Most of the participants in the standards-setting group conceded they were "there to learn rather than support any particular position." But even though there was a desire to reach a standard, the process became lengthy as group members struggled to understand the issues and the various arguments being presented. The LAN situation also indicated that a standard adopted before the technology has gained significant market experience leads to very lengthy standards that attempt to accommodate many options, because it is not clear ex ante what functions and formats will satisfy market preferences (*30*, p. 20).

The difficulty, then, lies in treading the narrow path between developing standards that adequately serve the public interest—soon enough to effect dissemination of the technology, but not so soon as to lock into inferior technology—all the while working in a domain that is fraught with complex technological and marketing issues that themselves are highly uncertain, indeed most uncertain, at the time the decision should be made.

IVHS STANDARDS

An abundance of literature addresses potential IVHS technological applications such as AVI, route guidance systems, and vehicle sensing and control strategies, but little material focuses specifically on IVHS standardization and technological compatibility issues. Much of the literature acknowledges the importance of system and technology standards and protocols for successful implementation, but, with few exceptions (*38*), most does not focus on standardization specifically (*39–41*).

The central standardization issues fall into three categories: timing, content, and process and participation. The timing issue turns on when it is appropriate to establish standards. "Standardization needs to be viewed in the context of an overall process of system design," and even the most mature IVHS application, ATMS, "has not yet reached the stage in its development that the system design trade-offs are understood." It is not advisable to wait until all "system implications" are understood and all "technical uncertainties are resolved" to initiate the standards development process, but it is necessary to determine the physical media and network topologies for the IVHS functions before establishing comprehensive standards (*42*, p. 15).

The content of standards obviously varies for each technology application, such as AVI. One general content issue is the question of performance versus design standards. Generally, design standards are seen to be inferior to performance standards since they tend to be more restrictive to innovation, but they are more difficult to develop (*43*). A more difficult aspect of the technical content of standards is the speed of events as of this writing. Multiple committees are meeting, establishing scopes and charges, creating task forces, and such. A general report on where matters stand would therefore be outdated almost immediately, and a more detailed discussion of the technical content issues for each standards-setting effort is beyond the paper's scope. Hence, this paper does not focus on technical content.

Although still somewhat fluid, process and participation issues appear to be stable enough to merit description. There is wide recognition of the need for a process to establish and coordinate national, and potentially international, IVHS standards and protocols (*44*). In separate studies recently completed for Congress by the General Accounting Office and the U.S. Department of Transportion (DOT), both agencies recommended the development of a national cooperative effort for the identification of technical standards (*1*,*45*). DOT's report also indicated that this effort should provide the forum not only for identifying the areas in need of technical standards, but also for deciding on the necessary standards and protocols as well. But the exact relationship between the public and private sectors is still in question (*40*), and even within the public sector, there is substantial disagreement over the respective roles of local, state, and federal governments (*46–49*).

There also appears to be relatively wide agreement that such a process be based on a voluntary consensus approach. A communications standards workshop held in June 1990 identified as its highest-priority action item the establishment of an IVHS Standards Oversight Committee with accreditation from the American National Standards Institute (ANSI). ANSI accreditation would ensure adherence to such various procedural protocols as open meetings and dispute handling (*50*). "[T]his Committee would observe, track, and coordinate all IVHS standards activities in the U.S., regardless of the originating organization. . . ." Workshop participants also recommended that IVHS standards be developed by existing standards-making organizations and coordinated by a newly established oversight committee (*2*, p. 13).

The Intelligent Vehicle Highway Society of America (IVHS AMERICA), incorporated in July 1990 as a nonprofit, public/private association, was a response to the desire for an organization to direct, coordinate, and provide structure for all IVHS efforts in North America, including standards-setting. It is anticipated that DOT will use it as a formal advisory committee on IVHS matters (subject to the provisions of the Federal Advisory Committee Act, 5 U.S.C. App.). As one of its organizational responsibilities, IVHS AMERICA will help identify needed standards, specifications, and protocols.

IVHS AMERICA has created a Standards and Protocols Committee, which will act in an oversight and coordinating capacity for all U.S. IVHS standards activities. It will function as a "clearinghouse between requirements and standards-developing organizations" to identify areas in which technological standards are needed and to enlist the help of the appropriate voluntary standards-making organizations. It will not operate as a standards-setting group but will work to become ANSI-sanctioned (R. Weiland, author's files, 1991).

The actual development of the standards in the United States appears to be falling to four organizations: SAE, IEEE, AASHTO, and ASTM (G. Euler, W. D. Toohey, R. Weiland; personal communication; 1991).

SAE will most likely develop IVHS vehicle and human factors standards. Currently, SAE has a Database Standards Task Group working as a part of its Navigation Aids Subcommittee. This group has been working toward map data base standards for in-vehicle navigation systems for about 1 year. In addition, SAE recently formed an IVHS division under its existing Standards Board, which will "provide for the development and maintenance of SAE Standards, Recommended Practices, and Information Reports so as to aid the manufacturer in design consistency of vehicles and equipment that fall within the scope of the IVHS Division and to provide guidance and input to the IVHS AMERICA Standards Committee to coordinate harmonized national and international IVHS standards, protocols, and systems" (W. D. Toohey, personal communication, June 1991).

IEEE will focus on developing communications and electromagnetic technology standards. IEEE recently created a Standards Coordinating Committee, which will cooperate closely with the Standards and Protocols Committee of IVHS AMERICA to write standards in the communications and electromagnetic technology areas in response to requests from IVHS AMERICA (J. May, personal communication, July 1991).

AASHTO will most likely become involved in standards for technologies that affect highway facilities and the overall highway infrastructure. The AASHTO committees that developed the current roadside, geometric, and pavement design standards will have a substantial interest in the standards-setting process for IVHS technologies that will affect existing highway infrastructure standards. AASHTO currently has a temporary Special Committee on Transportation Systems Operations, which, among other responsibilities, tracks IVHS activities and the potential needs for infrastructure standards. This special committee, which reports to the Standing Committee for Highways, was established in December 1988 and has a 5-year temporary charter. As IVHS systems and technologies mature, AASHTO will make more permanent organizational decisions in terms of how to handle standards development in its areas of expertise (D. J. Hensing, personal communication, July 1991).

AVI STANDARDS

One component of IVHS—AVI, which is used in toll collection—uses a technology that extends well beyond IVHS and overlaps with standards-setting activities in several other areas. The U.S. Department of Defense is developing an accounting application of this technology for identifying aircraft during refueling and for freight container identification. In the refueling application, for example, a fuel truck could identify an aircraft during refueling for a potentially paperless transaction (J. Carnes, personal communication, July 1991). Working on a much smaller scale, Hughes has developed a ⅜-in. long by ¹⁄₁₆-in. diameter transponder for injection into fingerling salmon. The transponder allows the unique identification of each fish that returns upriver to spawn (D. S. Fleming, personal communication, Aug. 1991).

Standards for this technology are developing rapidly on several fronts. IVHS AMERICA's Committee on Standards and Protocols has established a subcommittee for AVI, and SAE's IVHS division has established a committee on AVI. Also, the trucking industry is experiencing rapid and extensive innovation and experimentation with communications technologies that may overlap with the development of AVI (*51*).

At the subnational level, several states are developing or have developed specifications for procurements that include the technology. California is developing compatibility specifications for AVI systems for electronic toll collection in the state. Several state agencies anticipate using the technology, including the Department of Transportation, which operates several toll roads; the Golden Gate Bridge Authority; and the Transportation Corridor Agencies (which are developing three toll roads in Orange County). The specifications define the "compatibility requirements for AVI equipment to insure that one transponder will operate at all future AVI facilities" in California. Once developed, the state intends to promulgate the specifications as administrative regulations (L. Kubel, personal communication, 1991).

The Virginia Department of Transportation (VDOT) has also established AVI specifications for toll collection. The specifications are not for statewide systems; they are part of a procurement process for an automatic toll system on the Dulles Toll Road in Northern Virginia. VDOT sees the Dulles Toll Road project in part as a proving ground for automated toll technology in the state. If the system operates successfully, it will more than likely be implemented elsewhere in Virginia (*52*). Several other state-level efforts are under way, as well as a coalition of New York and New Jersey that has agreed to use compatible AVI technology (L. Kubel, L. F. Yermack, personal communication, 1991–1992). One recent study identified operational or expected AVI activities in 22 locations (*53*).

With respect to non-IVHS applications, the Computer and Business Equipment Manufacturers Association recently created an ANSI-accredited standards committee for Non-Contact Information Systems Interface (called X3T6). Its purpose is to develop a non-contact interface between computer devices for the transfer of information. The committee will review "current technology in radio frequency data/communication, infrared and similar non-contact data transfer technologies with the objective of standardizing the interface between like devices." Although the technical committee will develop the standard for U.S. activities, the committee eventually intends to submit it to ANSI for approval as an international standard. The committee is open to all potential identification device applications (J. Carnes, 1991; author's files, March 1991).

The International Standards Organization is also developing standards for identification devices and recently adopted International Standard 10374, Automatic Equipment Identification (M. Bohlman, author's files, May 1991). Although it was not developed specifically for highway applications in potential AVI systems, it may well influence the groups now aligning themselves to undertake AVI standards efforts and those firms that develop and implement automatic identification devices.

As of this writing, attempts to coordinate these various parties are moving forward. IVHS AMERICA's Committee on Standards and Protocols convened a special coordinating meeting on AVI standards in October 1991 intended to coordinate the development of specifications for North America and to "encourage restraint regarding the implementation of standards with less than continental scope . . ." (author's files, Oct. 1991). ASTM appears to be leading the effort for AVI standards, although some concern has emerged over whether it would adequately incorporate the views of trucking interests. At the same time, Virginia, California, and the New York–New Jersey coalition all have issued or will soon issue such specifications.

The case of AVI standards is interesting not only on its own merits, but also insofar as it can enlighten consideration of standards for other IVHS technologies. Two scenarios for the development of AVI standards capture the range of possibilities. Under the first, the laissez-faire scenario, states and operating agencies would promulgate specifications for their jurisdictions along the lines of ongoing efforts in California and Virginia or in multistate coalitions, as in New York and New Jersey. In all likelihood, these specifications would be incompatible, so that participating vehicles would require separate transponders for each jurisdiction in which they routinely operated. Standards-setting efforts, under the auspices of IVHS AMERICA or another organization, would likely produce a standard somewhat later, perhaps in 2 years. Such a standard would be informed by the experience of the lead states, and states implementing systems after the standard was available would likely adhere to it. Further, lead states might procure equipment consistent with the standard in a later replacement of their original equipment, or "gateway technologies" might be developed that would allow lead states' equipment to read standard transponders.

Under this scenario, lead states would reap the benefits of the technology while the standard was being developed, benefits that would be entirely foregone if they waited for the standard before implementing their systems. Popular estimates suggest payoff periods of less than a year, so that lead states' equipment would have paid for itself before the standard was even ready. Further, lead states would reap benefits even if the standards-setting process became bogged down and did not yield a standard for several years. On the other hand, lead states might resist converting their equipment to be consistent with the subsequently developed standard, thereby raising costs for multijurisdictional users.

Under a second scenario, operating agencies would defer procurements and specifications and participate in a consensus standards-setting process. Once the standard was developed, lead states would move forward to deploy systems consistent with the standard. Under this scenario, a single transponder would suffice for all jurisdictions, and users would be presented with the lowest costs. On the other hand, the standards-setting process would probably require approximately 2 years according to popular estimates, perhaps longer. In the meantime, no benefits of the technology would accrue, and such benefits would be permanently foregone—they could not be recaptured later.

From the standpoint of AVI, the laissez-faire scenario appears to be materializing, as several states issue their own specifications. The success of standards-setting efforts remains to be seen, but the ASTM initiative is promising. From the more general standpoint of IVHS, however, some conclusions are clear.

CONCLUDING REMARKS: ALTERNATIVE IVHS DEVELOPMENT PATHS

From the information collected in this research, a clear framework for the development of IVHS technologies appears to be emerging. IVHS AMERICA's Committee on Standards and Protocols will seek to coordinate the efforts of private standards-developing organizations such as IEEE, SAE, AASHTO, and ASTM. This framework is quite distinct from its major alternatives, rivalry among competing firms and government development of standards. The exception is AVI, for which many applications of the technology are moving forward rapidly and coordination efforts only recently have begun to emerge.

The standardization literature review identified several policy issues: (a) there may only be narrow windows in time during which collective action can be effective at reasonable costs; (b) the greatest power to influence may come at exactly the time when the information available to inform its action is most limited; (c) market pressure to disseminate a technology might argue for an imperfect standard in a timely fashion over the alternative of no standard at all; and (d) the sheer complexity of issues may confound and extend the duration of the standards-setting process.

The first two of these policy issues are not strictly applicable to the AVI case, since agencies operating highway facilities are not firms in a competitive market but monopoly or near-monopoly providers of road services. End users may choose to participate or not through the purchase of transponders, but they probably cannot choose between competing formats in the same way that consumers choose, say, between VHS and Beta videocassette recorders. The agencies can act to modify transponders at their will, and end users cannot elect another technology. Thus, the window in time during which a collectively determined standard can be effective may be much longer.

The third issue—the preference for imperfect standards over no standard at all—seems particularly apt for AVI. Market pressure for implementing systems is intense at present, and agencies are going it alone in the absence of a standard. Although agencies may later elect to convert to a standard system, or implement "gateways" or converters, some coordination to make such gateways technically feasible might be beneficial.

Finally, the complexity of the AVI derives both from its technical content and, perhaps more significantly, from marketing and implementation issues such as privacy and confidentiality of data and the use of transponders for law enforcement.

As for IVHS standards, the concerns over the timing of standards and the information on which standards decision can be based are more applicable. IVHS technologies that will rely on individual consumer choices between competing formats may be at risk for the emergence of suboptimal de facto standards. Technologies whose formats are dictated by the decisions of monopoly operating agencies, on the other hand, may be less at risk.

All IVHS technologies would appear to suffer from uncertainty and poor information on which to base standards decisions. These are new technologies, and consumer preferences and willingness to pay for various services are simply not knowable at this time.

Unlike AVI, market pressures for other IVHS technologies have not yet become acute, suggesting that the choice may not be between an imperfect standard and no standard at all and that efforts to facilitate standards development will be fruitful. And finally, the issues of technological and market complexity are perhaps more acute for other IVHS technologies than for AVI, which may extend the duration of the standards-setting process.

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