Final Report

Smart Highways White Paper

THE ROLE OF THE HIGHWAY NETWORK MANAGER

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THE ROLE OF THE HIGHWAY NETWORK MANAGER

INTRODUCTION

The presence of Smart Highways technology—modern sensors, communications, and control technology—makes it possible for a modern roadway authority to optimize the operational performance of its roadway system. "Optimization" can include maximizing the number of vehicles served, maximizing the revenue generated, minimizing the delays experienced by facility users, or a variety of other agency goals.

Roadway authorities can optimize roadway system performance by

- using modern facility monitoring techniques to determine the current performance of the authority's assets
- combining data on current performance with measures of historical system performance to accurately predict changes in performance in the near future
- analyzing the performance effects of alternative control strategies in response to current and predicted conditions
- selecting and implementing the optimum control strategy or system management plan for those conditions.

These optimization functions happen continuously. As conditions change, operational controls and the management plans that direct them must change. The person in charge of making those control decisions and developing the management plans is the Highway Network Manager (HNM).

The role of the HNM extends beyond simply overseeing key operational decisions. It includes ensuring that the data required to make those decisions are obtained and correctly used; that the facility performance that results from selected control decisions is routinely tracked, and that information is used to both improve future control decisions and direct the resources of the agency; and that the decision criteria used to make those decisions accurately reflect the priorities of the transportation authority. To accomplish this job, the HNM must have access to, and effectively use, a variety of technologies and tools. This paper discusses what it takes to effectively perform such a job.

WHY HAVE A HIGHWAY NETWORK MANAGER?

Until recently, highway operations were almost an afterthought of most highway authorities. Roads were built. Roads were maintained. Operating rules (speed limits, traffic signals, the direction of reversible roadways) were selected, implemented, and enforced. When necessary, resources were expended to clear problems (e.g., accidents) from those roads. Signals were timed and generally left alone until problems with the timing plans were significant enough to be noticed, at which point data on current use were collected and new plans were developed.

This approach to roadways was acceptable when the primary job of the agency was new road construction and repair of existing roads. New construction (capacity expansion) was the primary response to congestion. Alas, new construction is no longer a reasonable response to many congestion problems, especially in urban areas where additional right-of-way is not available. When traditional capacity expansion is no longer a reasonable response to congestion, efficient operation of existing capacity becomes significantly more important to roadway agencies.

Optimizing the operation of a facility requires information on both current conditions and control options. That is, the manager interested in improving operations needs to know that there is a problem (or will soon be a problem) and must have options for addressing that problem. Agencies that implement monitoring systems that tell them when problems occur and that use control/management systems to address those problems will significantly outperform agencies that continue to manage roadways the way they have been managed in the past.

Excellent examples of how active management (i.e., monitoring performance and adjusting management plans in response to reported data) abound in the business world. Wal-Mart, Fed-Ex, and UPS are all companies renowned for use of their operations data to become extremely efficient, reducing costs and increasing revenues while simultaneously improving service to their customers. These companies carefully monitor operational trends in near-real time and then make business decisions that take advantage of those trends. The key is that they have made the collection of data (monitoring performance) and use of those data (active management) part of doing business. They use their data resources to make both day-to-day management decisions and longer term strategic business decisions.

Highway agencies can do the same thing.

Smart Highway technologies provide the data streams and management capabilities that allow the HNM to actually optimize roadway operations. But to gain the ability to optimize their facilities, highway agencies must be willing to build the data systems that make optimization possible, and they must make the utilization of those data systems part of their regular business practice.

HOW THE SMART HIGHWAY IS DIFFERENT

The key difference between a Smart Highway and a traditional roadway is the fact that a Smart Highway can be, and is, actively managed to achieve optimal operational performance. (See Table 1) On a Smart Highway, current operating conditions are always known, and consequently, management decisions can be made whenever they are needed to improve those operating conditions.

Table 1: What Differentiates a Smart Highway

Smart Highway	Conventional Highway
Active Management of Roadway Operations	**Static Operational Plans Based on Average Conditions**
Data Rich Data are collected as part of routine business practice and used for multiple purposes	**Data Inconsistent** Data are collected for single purposes and frequently discarded after use
Information Rich Data are available and analyzed to accurately describe current conditions and the impacts of business decisions (operational plans/actions)	**Information Poor** Little is known about the effects of different business decisions (operational plans/actions)
Prioritizes Roadway Operations User focused	**Roadway Operations are Secondary** Construction focused
Business Outcome Agency Focus	**Business As Usual Agency Focus**

The management decisions that can be made on a major Smart Highway expressway might include changes in

- ramp metering rates
- messages posted on dynamic message signs (DMS) or other information dissemination systems (e.g., the Internet)
- changes in lane control signs (LCS) and/or barriers
- toll rates (for High Occupancy Toll—HOT—lanes and other value priced, managed lanes)
- incident response actions

- requests for enforcement.

If an extensive traffic condition sensing system is combined with active management, a Smart Highway does not need to experience traditional volume-related traffic congestion breakdowns like a conventional roadway. Instead, prior to breakdown, controls are adjusted (metering rates, toll rates, route diversions) that reduce facility demand enough to maintain free flow conditions.

When incidents and other unexpected events occur that do create congestion, active management (fast incident response, traffic diversion and other flow reduction strategies upstream of the unexpected bottleneck) limits the size of the congested area, decreases the time required to remove the capacity constraint, and minimizes the duration of reduced traffic flows and slow speeds.

Traditional traffic management makes use of the same control systems. The difference is that traditional approaches to traffic management tend to use fairly static operational plans, designed with limited traffic volume data and assumptions that often ignore the effects of other traffic disruptions (such as weather). As a result, traditional traffic management plans tend to provide "optimal" results only during periods when actual usage volumes and environmental conditions match the volumes and conditions that were used as inputs to create the traffic management plans.

Unfortunately, when traffic volumes differ from those used to develop the plan (the economy improves and traffic volumes during the peak are higher than they were when the plan was developed) or if the paths used by travelers driving through the signal network changes (e.g., more people now turn left on 1st Street than 2nd Street because of the new timing plan), the traffic management plan frequently produces suboptimal roadway performance. Without robust data collection, analysis, and multiple control options working in near-real time, traditional traffic management systems are simply not capable of maintaining optimal roadway performance.

Classic examples of these "static" plans are traffic signal timing plans applied during defined time periods, such as "peak period," "midday," or "Sundays when there is a football game." This concept of operations makes good sense when traffic surveillance is difficult and costly, when communications are slow and unreliable, and when the computer processing power needed to analyze data and compute or select traffic control plans is not available at an acceptable cost.

The technologies available to create the Smart Highway, however, change all of these conditions. With a variety of new sensors, both roadside and in-vehicle, combined with high bandwidth, lower cost communication systems, operational control decisions do not need to be based on "average volumes and conditions for a given time period;" instead, they can be based on accurate measures of current volumes and operating conditions.

Those same communications capabilities combined with modern computing power enable a far more robust analysis of the available surveillance data, allowing far more complex and capable control algorithms to be designed and built. For example, agencies no longer have to rely on time-of-day ramp metering algorithms; instead, metering rates can be adjusted every 20 seconds to maximize performance of an expressway. Similarly, metering rates can be changed differently at individual ramps to handle the variations in traffic demand occurring in real time at those ramps. (For example, a surge in demand for the 8^{th} Street ramp might be accommodated by increasing the 8^{th} Street ramp meter rate while simultaneously decreasing the metering rates at 4^{th} Street and 12^{th} streets. Thirty minutes later, as demand at 8^{th} subsides, the metering rate at that entrance might be reduced to "normal," allowing the rates at 4^{th} and 12^{th} to also return to normal.) All of these controls can be supplemented by changes in traveler information that divert motorists from ramps serving congested freeway sections to those downstream of blockages, or that shift motorists to uncongested corridors.

This ability to measure the need for (and even anticipate) changing traffic control plans and then respond to the unique conditions of the moment sets the Smart Highway apart from traditional roadways.

WHAT IS NEEDED TO PERFORM HIGHWAY NETWORK MANAGEMENT?

What is needed to realize the promise of the Smart Highway? The simple answer is that operating a Smart Highway starts with traffic control capabilities (signals, pricing, incident response, motorist information). To effectively apply these controls, the Smart Highway requires extensive data collection, data handling, and decision support activities. This means that the Smart Highway requires surveillance systems, communications and software that perform the data collection, data management, analysis, and decision support functions. Although these technologies already exist on many highway systems, the Smart Highway applies them more comprehensively and more actively to maximize the benefits that can be obtained from them.

In addition to the technical requirements discussed above, the Smart Highway needs to be managed like a business. That is, the HNM must be willing and able to apply the control decisions necessary to maximize the agency's goals. For example, if that goal is to maintain maximum flow (avoiding volume induced flow breakdown), the HNM must be able to limit demand for the Smart Highway to flows marginally below those that cause break down. This can be accomplished through any combination of the available control mechanisms (signals, route diversion, and price). Table 2 summaries what is required to create a Smart Highway.

Table 2: What A Smart Highway Requires

Management Controls Traffic control systems for managing traffic flows (e.g., traffic signals, dynamic message signs, variable pricing)
Data Collection Systems Extensive traffic monitoring systems Monitoring of external factors that effect traffic flow (weather, special events, construction events, incident)
Software Tools Traffic surveillance and control Decision support Data archiving and reporting Data analysis (statistical analysis, data mining, traffic simulation)
Business-like Approach to Agency Direction

Each of these subjects is addressed below.

Management (Traffic) Controls

To manage roadway performance, a Smart Highway must have traffic control systems for the HNM to implement. Key business decisions for the Smart Highway agency will be which traffic control mechanisms it implements, and to what extent it is willing to apply those mechanisms, given the political implications of their use. For example, is the agency willing to use price to manage demand? Price has the potential to be an extremely effective traffic management tool, but its application carries significant political ramifications. The HNM must play a significant role in the selection of the traffic control measures used by the Smart Highway agency, as well as in their application on a day-to-day basis.

Traffic control systems the HNM might wish to use include changes in the following:

- ramp metering rates
- messages posted on dynamic message signs (DMS) or other information dissemination systems (e.g., the Internet)
- changes in lane control signs (LCS) and/or barriers
- toll rates (for HOT lanes and other value priced, managed lanes)
- incident response actions
- requests for enforcement.

On freeways and other limited access roads, ramp meters limit the disruption to flow that merging vehicles create and can be used to both divert ramp flows from one ramp to another and to manage the total vehicular demand placed on the roadway during a given period. Unfortunately, ramp meters can only be applied in places where storage space for delayed vehicles exists (or else congestion is created on intersecting roadways) and where storing those vehicles for the required time is politically acceptable.

Route diversion is already practiced informally throughout most U.S. cities during commute periods. "Informal" route diversion takes place whenever radio traffic reporters describe unusual traffic congestion and suggest alternative routes. These are "informal" diversions because little is usually known (by the reporters or the drivers listening to those reporters) about the relative merits of the alternative routes. Rarely (if ever) are scientific analyses undertaken to determine whether traffic flow (for the individual traveler or the corridor as a whole) is more effectively served by diverting traffic to alternative routes, and if so, just how much traffic should be diverted.

In cities where ramp metering is a key control function, metering rates are often used as another means of informally changing routing. At ramps where roadway geometry causes traffic volumes to disrupt mainline flow, the metering rates may be set to low (slow) relative to the rates set at nearby, less disruptive ramps. This discourages travelers from using the one ramp and encourages them to use other ramps where ramp merging is less disruptive to mainline flow. This occurs because motorists generally wish to be delayed as little as possible and, therefore, choose to use the ramp with the fastest metering rate. This type of diversion can be further encouraged with signing, but few agencies routinely use diversion signs at ramp meters.

Planned route diversions are practiced in many areas, both as part of traffic mitigation plans during construction activity and as an incident management tool. Traveler information in the form of both static and dynamic message signs is used to route traffic onto alternative routes. In Europe, more extensive use is made of dynamic message signs placed prior to key interchanges to provide travelers with information about which of two alternative routes is the least congested. Where viable alternative routes exist as part of (or in parallel to) Smart Highways, use of dynamic messaging can play a significant role in optimizing traffic flow by shifting traffic between alternative routes.

Price is theoretically the most effective demand management tool. Adjusting prices to manage demand (increasing price to reduce demand, decreasing it to increase demand) is considered by many engineers the most direct way to maintain flow on specific facilities, such as managed lanes. Current HOT lane projects in Minneapolis, San Diego, and Orange County, California, are excellent examples of how price can be used to manage demand while providing travel choices to the traveling public. However, while U.S. citizens are accustomed to the capitalistic notion of balancing supply and demand with price for almost every other commodity in the country, the concept of using price to ration our limited roadway space is only beginning to catch on. The political ramifications of using truly variable pricing to maximize facility performance are significant, even though pricing can maximize use (volume) while maintaining speed.

Finally, effective incident response is a key aspect of a Smart Highway's operation. No matter how sophisticated and technologically advanced the facility and the vehicles that use it are, incidents will occur. And those incidents degrade the performance of the facility, not to mention decrease the facility's safety. The more quickly the appropriate incident response can be brought to bear on an incident, the smaller the impacts of that incident, the more quickly the roadway can be again used to its full potential, and the more quickly a safe operating environment can be restored.

There are two significant problems with managing incident response. The first is that incidents are semi-random events[1], the location and nature of which are unknown prior to the event. This makes it difficult to determine the most cost-effective level of incident response, to position those resources, and to manage those resources to obtain the best possible facility performance. The second problem is that incident response is an ongoing expense, not a one-time capital charge, and as a result, the budget for incident response must be defended each budget cycle.

Both problems are most effectively dealt with by using good management information, and a key attribute of the Smart Highway is that the data needed to manage incident response resources are available. Analysis of past incident histories can be used to determine when and where incident response resources should be on duty. Facility performance monitoring and surveillance efforts quickly detect incidents and allow the most appropriate response to be called

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[1] That is, we can not predict when and where incidents will occur, or what the nature of any given incident will be. However, using statistical analysis, it is possible to predict how frequently incidents will occur along different stretches of road and the nature of those incidents . This information can then be used to determine the most cost-effective responses to those incidents.

to the scene as quickly as possible. The effectiveness of the incident management effort can be reviewed after the fact to determine whether the expected benefits have been achieved, and to determine where improvements can be made to that response. This same information can then be used to describe the benefits obtained through incident response, thus defending its budget.

All of these control measures require data. Real-time data are needed to make control decisions. Archives of those data are needed to feed the analyses that permit the business decisions that continue to improve the operational performance of the Smart Highway and guide the allocation of the available resources that keep the highway working.

Data Collection

The Smart Highway is, to a large extent, a modern business approach to transportation system operation. Operating under sound business practices, the Smart Highway follows the basic business credo of "What gets measured gets managed" and its corollary, "You can't manage it if you don't measure it." Thus, successful operation of a Smart Highway requires the collection and use of extensive data that describe facility performance. This points out a key difference between Smart Highways and conventional highways in that conventional highways are often "data poor."

At a minimum, the following types of data are required to actively manage a Smart Highway:

- facility performance information (vehicle speeds or travel times) for both the Smart Highway and as many connecting and parallel routes as possible
- facility use (volumes, by type of vehicle)
- the availability and use (status) of control systems, including information such as
    - what DMS signs exist and what messages are being displayed

  - what signals exist and how they are being operated
  - what staffing has been deployed and what activities they are performing
  - if pricing mechanisms are being used, what price is currently being charged
- the external events taking place, where those events are located, and what attributes describe them. External events include
  - incidents (when they start, their current status, when they end, whether and how many lanes they block)
  - construction (time and days when road closures take place, number of lanes closed)
  - special events (the existence, size, and location of large cultural activities)
  - environmental conditions (presence and intensity of rain, wind, snow)
- presence and level of all types of enforcement taking place on the facility.

In addition, if the Smart Highway agency is forecasting events (traffic volumes, congestion, weather conditions), collecting and storing those predictions is also important. These predictions are often key variables in the selection of traffic management decisions, and therefore, it is important to understand (and ultimately improve) the accuracy of those predictions.

All of these data need to be collected as part of the Smart Highway agency's routine business process. There is great flexibility in exactly how the data are collected and what they look like, but these basic data needs must be met.

For use in making operational decisions, all of these data need to be "current." That is, the HNM needs to have a near-real time understanding of the current use and performance of the roadway system and all of the factors that are affecting that performance. But these data also need to be retained so that they can be used to examine the historical performance of the roadway system and to compare that performance against the management actions meant to optimize facility use and performance.

Archiving the data described above and then using those data to refine operational strategies; design, build, and test new control systems; and report on system performance allows continued improvement of operational controls and facility management plans. It also provides the key information needed for dealing with users and public decision makers. Finally, it provides the information necessary for the agency to deploy and manage personnel and equipment.

For operational purposes, a data archive of roadway performance, combined with a record of the traffic control strategies used and an archive of the external factors that affect roadway performance (e.g., incident data, weather data, construction activities), provides the knowledge base for understanding the causes of performance problems, which leads to improved management plans when those events reoccur.

Software Tools

A piece of data, by itself, does not equal information, let alone knowledge and action. Therefore, the Smart Highway agency needs a series of software tools to manage, evaluate, apply, and learn from the data it collects. Four sets of software tools are needed by the HNM to collect and utilize the data described above. These tools sets are

- surveillance and control system software
- real-time decision support software
- data archive and reporting software
- analytical software for operational planning and research purposes.

Figure 1 shows how each of these software efforts interact with the data being collected, the control decisions being made, and the performance reports being generated to manage the Smart Highway. Each of these types of software is explored below.

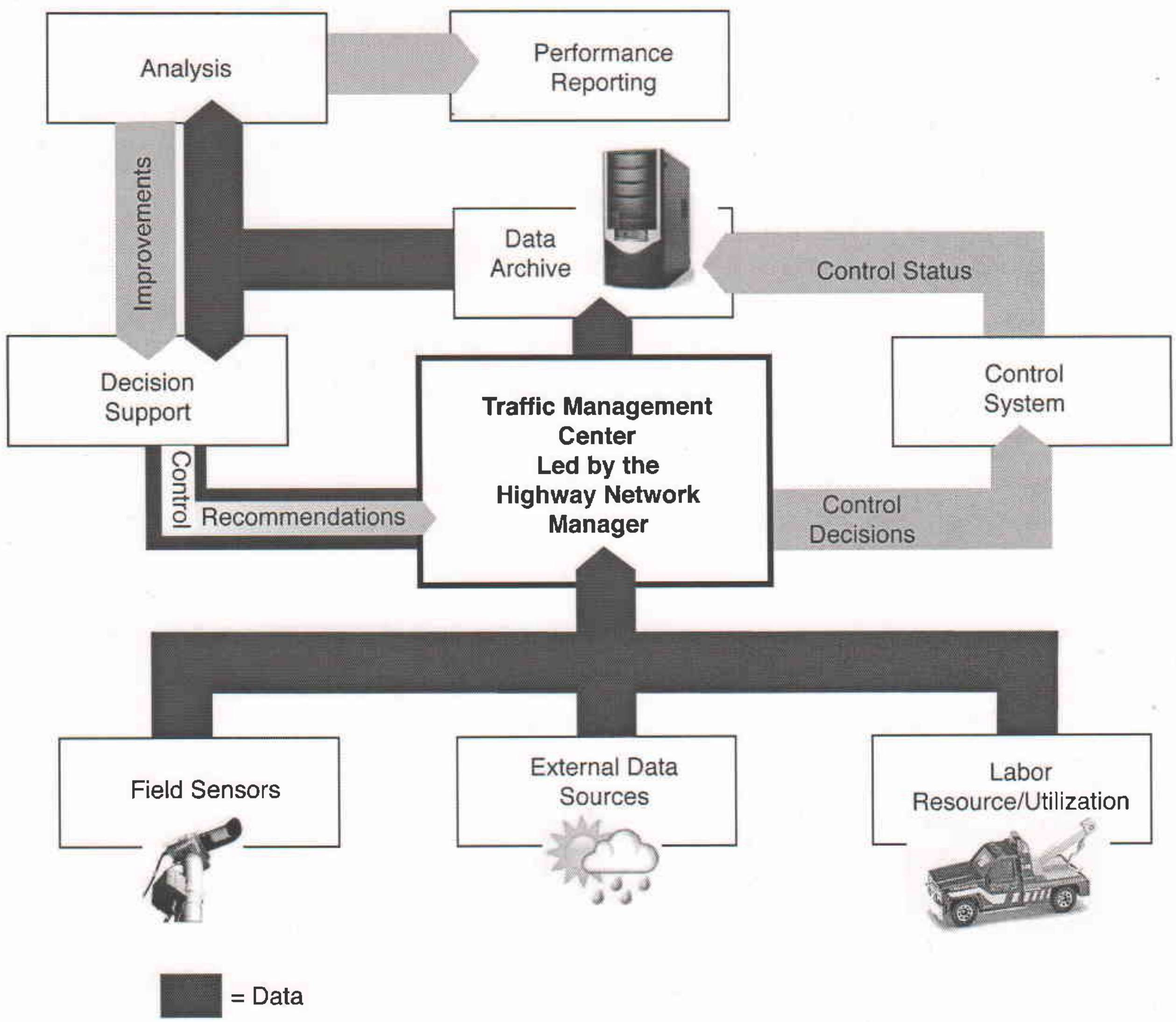

Figure 1: Operational Data and Information Flow Within The Smart Highway

Surveillance and Control Software

The first of these tools consists of the basic surveillance and control system software packages needed to monitor current system performance and operate the control systems available to the HNM. These generally consist of specialized software built into devices in the field that feed data to and instructions from an integrated traffic management center (TMC). The specific functionality provided includes such tasks as

- electronic toll collection
- automated toll enforcement
- traffic signal control and timing
- traffic volume (and classification) counting
- vehicle speed measurement and reporting
- ramp meter control (and metering rate calculation)
- CCTV control software
- DMS control and message selection software
- computer aided dispatch (CAD) software for police and service patrol staff
- other control system software.

Not all roadway systems have all of these control components, and even when they are present, the actual algorithms used by individual components can vary dramatically between traffic control centers. The software used for even something simple like "traffic volume counting" varies, depending on the type of data collection sensor used, the exact measurements produced by that sensor, and the frequency with which the traffic control system wishes to have that sensor report data (e.g., every time a vehicle passes, or data summaries describing the last 20 or 30 seconds).

Included in this category of software are all of the communications needed between the TMC (where the HNM is located) and all the devices in the field. In some cases, this communications software follows defined standards such as the NTCIP communication protocols being constructed and adopted by the intelligent transportation systems (ITS) community. In other cases, the data and communications follow proprietary protocols supplied by vendors that build the sensor or control systems.

In some cases, devices in the field actually report to data centers elsewhere in the region or country, and those data centers feed information to the TMC. The specific communications path can vary as much as the sensors and computer systems on either end of that communications path. What matters is that the devices in the field communicate to the TMC their observations and how they are currently functioning, and the TMC communicates back to those devices if some change to a device is required.

Once the data exist at the TMC, the next piece of software comes into play, the traffic management decision support software. This software is discussed in the next section, although in many cases, "decision support" is actually "automated control" and is part of an integrated surveillance, control, and driver information system (SC&DI) software package. Even when this is the case, the decision support task (e.g., how fast should the ramp meter at the NE 45th St. on-ramp be operating?) must be modular so that it can be replaced as more capable control systems are developed. And regardless of the decision support/control system algorithm used, the end result must be communications to the devices (and individuals) in the field that change the actions those devices (individuals) are taking.

Decision Support Software

The second set of software tools needed to allow the Smart Highway to achieve its potential is the decision support software that helps the agency, led by the HNM, decide exactly which controls (metering, price, diversion) should be applied and how they should be applied to optimize facility performance. Decision support software takes the data describing current conditions, computes one or more control responses, and recommends (or implements) the best of those alternative strategies.

The role of this software is, as its name implies, to assist the HNM in the selection of the best operational decisions. In some cases, these decisions are made automatically. In other cases, they are made subject to the HNM's intervention, and in still other instances, they are only made by the HNM. Some decision support software is integral to the operation of a single control system, whereas other decision support systems offer insight into decisions that cross multiple control systems.

An example of a traditional, automated, single system decision support system is the most common form of adaptive traffic signal control. In this case, algorithms built into the logic of the traffic signal control use current roadway performance information, combined with data on current levels of travel demand, to adjust signal control plans (e.g., metering rates or traffic signal phase lengths) in real time.

In almost all cases, these plans can be overridden by traffic management center operators. Manual overrides are performed when operations personnel have access to knowledge not available to the automated control system or the "correct" control decision depends on factors not contained in the automated algorithms. For example, a ramp metering algorithm might notify the operations control staff that a ramp queue is getting too large. It might then recommend that the metering rate be increased. The control system operator can then choose to accept the newly recommended metering rate, keep the current rate, or select an entirely different rate. This level of decision support (partial automation) is often used when the control system algorithm has incomplete knowledge about the conditions surrounding the network. (In this last example, the control algorithm may have incomplete knowledge about conditions on the intersecting arterial, and the job of the operator may be to use a CCTV camera to check current arterial congestion levels before adopting the suggested metering rate or selecting an alternative rate.)

This level of semi-automated decision support easily transforms into the next level of support, a system that is divorced from the actual operational controls and only makes suggestions about possible control strategies in response to automated or operator input. This type of decision support is now often performed "informally" and is frequently based on the working relationships and knowledge of specific individuals and the defined communications protocols of agencies working together for their common good.

A good example of decision support occurring outside of the direct control system computations is when a significant accident occurs on a roadway that runs parallel to a controlled facility. A phone call (or some other notification system) informs the operations staff of the controlled facility that an accident has taken place. On the basis of previous experience and perhaps planning studies, the operator consults his list of available timing plans and implements a new signal timing plan that anticipates traffic rerouting to avoid the accident.

Considerable improvements are needed in the decision support software currently available to most highway agencies for the HNM to achieve the operational goals of the Smart Highway agency. Most available decision support systems lack extensive roadway condition monitoring systems. This lack of data limits the sophistication and completeness of the planning and analysis efforts that the decision support system can perform . The lack of data and planning/analysis capabilities also limits the sophistication of the control systems and strategies that can be applied. Finally, this lack of information and analysis makes it difficult for roadway agencies to work cooperatively with agencies and jurisdictions that operate connecting and parallel facilities.

The results are sub-optimal operating decisions.

The current state-of-the-art in decision support algorithms for traffic system controls is also not advanced in comparison to those used by other network control systems (computer network traffic, phone networks, pipeline networks[2]). In large part this is because maximizing the operational efficiency of our roadway systems has only recently begun to receive widespread attention and increasing prioritization. Another result of the historical lack of importance of optimized roadway performance is that most traditional roadway systems have relatively little of the infrastructure necessary to provide the data necessary to develop or run such decision support systems.

This same lack of data means that the roadway community does not currently understand many of the fundamental relationships that are important to a decision support system. For example, if the roadway agency actually measured and knew that the DMS message "Major Accident Ahead, Use Alternative Route" resulted in a 20 percent diversion to the parallel arterial, whereas the message "Accident Ahead: 30 Minute Delay. Use Route 120 to Save 15 Minutes" resulted in a 50 percent diversion, the agency could use that knowledge to select the optimal message on the basis of the level of diversion it wished to achieve. The need for a more complete understanding of these fundamental relationships is the reason that the analytical software, discussed later, is necessary.

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2 Traffic control systems can borrow from control theory and systems developed for these related subject areas, but care must be taken when doing so because travelers behave very differently than the electrons and water molecules directed by these systems. Drivers decide on the basis of what they believe is best for them, not necessarily what is best for the network.

The good news is that roadway decision support (and control) systems can take advantage of many of the theoretical advances that have been made in the monitoring and control of other network environments. These technologies do require adaptation to the roadway environment, which is unique because roadway networks are subject to the vagaries of human decision making; That is, travelers don't simply go where they are told. It is easy for an operator of a network of water pipes to use a series of values to direct just the right amount of water into each pipe. The water does not think for itself; it goes where it is directed. Alas, drivers attempt to optimize their own travel behavior, and they perform that optimization strictly for their own benefit.

A classic example of how driver behavior affects the efficiency of roadway operations derives from traffic signal networks. A signal engineer may collect a large quantity of data on traffic patterns (volumes and turning movements at each intersection in the network grid, origin and destination patterns) and create a new optimum timing plan based on those data. As soon as the new timing plan is implemented, however, drivers realize that their old travel patterns are not working as expected, and many begin to experiment with new paths through the network. Soon, they find new paths that work better for them, and the result is a different traffic pattern than was assumed for "optimal" network flow. The result is that few timing plans remain "optimal" very long unless they are built specifically to adapt to changing traffic patterns.

The traffic monitoring aspects of the Smart Highway mean that enough data can be collected to feed a modern control system. But to actually achieve optimal traffic flow, considerable development work (including basic research) is likely to be needed to construct, test, and refine the decision support systems that create that optimization. Modern control system technology features decision support systems that constantly "learn" from observed behavior (neural networks) to provide continuously updated decision support. These types of control algorithms are beginning to appear in modern traffic control systems, and the Smart Highway system needs to be aware of, and foster the development of, advances in traffic control system capabilities based on the capabilities found in other networks.[3]

Smart Highway technology also makes it possible to use price as a very effective control mechanism. While price is a key variable in the demand/supply equation, it has not been a variable that the roadway industry has been able or willing to apply as a control measure. The advent of electronic tolling gives Smart Highway agencies the technical ability to use dynamic pricing to optimize roadway use. Changes in the political climate may soon give Smart Highway agencies the approval to apply these techniques. True congestion pricing is currently being tested in several HOT lane trials in the U.S. Its success in those tests is expected to result in its increased application elsewhere in the country.

However, while price may be the most effective traffic control measure yet applied, the control algorithms that support real-time pricing decisions likely need additional development. First, the marginal price sensitivity of motorists is not well known. Second, the control (pricing) algorithms currently used in the facilities that are experimenting with this control technology are crude, as are the mechanisms used to communicate current prices to the motorists who need to make decisions about using those facilities. Third, far more complex pricing schedules may be needed than are currently available, as prices will probably need to be set very differently depending on whether the agency's goal is to maximize revenue, maximize profit, maximize vehicle throughput, maximize person throughput, or some combination of those goals. And the

[3] The development of these capabilities is the reason the Smart Highway needs a data archive and sophisticated analysis software. And the HNM, as the primary customer of that work, must help lead this development effort.

intention of the "optimization" scheme applied by any one agency may change from day –to day or even from one time of day to the next.

Regardless of the goal selected for the basic pricing scheme, selecting and building the decision support system that sets the current price on a variable pricing system is likely to require fairly robust data sets that compare levels of use against toll rates and external conditions. Thus the development and application of key decision support tools are interconnected to the data collected and the software analysis tools described elsewhere in this paper. And the person who needs to lead this work is the HNM.

Lastly, decision support systems are likely to need frequent tuning (or will need to be self tuning) to adapt to the changing environment within which all roads exist (i.e., driver behavior changes in response to growth in the region, changes in the economy, alterations in the transportation facilities that intersect or are parallel to the Smart Highway, and more).

Data Archive Software

The third set of software tools important to the HNM provides the data archiving and reporting capabilities necessary to report on the performance of the roadway system and to serve the analysis requirements mentioned above and elsewhere in this paper. While real-time performance measures are vital to operational decision making, "after the fact" analysis and reporting of performance are necessary to judge the long-term effectiveness of the facility management decisions and to provide the data needed to refine those management decisions. Therefore, "current" data need to be stored, summarized, and reported to provide the management information necessary to continually refine (manage) the facility.

The phrase "continuous process improvement" is no longer in vogue in the business world, but the basic concept of continuously reviewing both the performance of a business as a whole and the performance of various aspects of that business is necessary for the company (agency) to obtain and then maintain optimum performance levels.

Wal-Mart succeeds not just because the company's store managers understand when they are running out of a specific inventory item in time to reorder it. The company succeeds as a whole because it uses those same data in multiple ways to make good business decisions. Wal-Mart studies the accumulated sales data of groups of stores, as well as all stores it operates. These studies cover both short-term trends and longer periods. These analyses provide the company with an understanding of the changing needs and desires of its customers. The same data are used to describe the performance of its suppliers so that Wal-Mart can continuously adapt its business practices to changing performance levels.

Sales data are not the only data Wal-Mart uses. The company uses all kinds of operational data. Sales data describe which items are "hot," but a more complete picture of potential profit comes from combining sales statistics with data on which items are returned to the stores. Merchandise returns cost money and require staffing, and understanding that a given brand/manufacturer is supplying poor quality goods may cause Wal-Mart to change suppliers both to make customers happy and to decrease labor expenses. Wal-Mart also combines sales data with direct cost data and advertising data to determine net profits being generated by specific items.

This proactive, global view of how to use all of the available operating data is a major key to the success of many businesses. It is not a custom of any public roadway agency in the U.S. For most roadway agencies, data tend to be viewed as a "necessary evil," required to make a control system function or to meet federal and state reporting requirements. Rarely are data viewed as key management assets that facilitate significant operational and business improvements. And consequently, operations data are rarely used for these purposes.

So what should a Smart Highway agency be reporting routinely from its data archives? Like Wal-Mart, it should be routinely reporting performance statistics. Examples of these types of statistics include the following:

- the level of facility use and how is it changing
- how often the roadway is congested
- when and where that congestion takes place and how long it lasts
- how many incidents/accidents take place, where they are located, and their nature.

The agency should also routinely examine the effects of its management actions: For example,

- How does the congestion frequency/location/duration described above change as new traffic management actions are taken?
- How quickly are incidents cleared?
- Are specific staff more effective than others at clearing incidents?
- How do volumes and speeds change once specific message signs are placed?
- How large are queues at ramp meters?
- Are road maintenance contractors getting in and out of the right-of-way at the designated times, and are their traffic control strategies effectively mitigating congestion at the construction location?

The agency also needs to know who its customers are and how they are reacting to agency policies. For example,

- How has demand changed when the pricing structure (for managed lanes) is changed (total demand, and patterns of use)?

- Does the new pricing structure result in an improvement in revenue/usage/congestion relief?
- What changes in behavior take place when a specific enforcement action is implemented, and how long does that effect last?

To cost effectively produce these statistics and thus obtain the benefits of active management, the data that describe the performance of the roadways system, how the control system is being operated, and the external factors that affect roadway performance (weather, special events, incidents) must be

- automatically collected, quality assured, stored and summarized
- consistently reported in ways that are used for management purposes
- accessible to a wide variety of analysts outside of that basic management process
- flexibly retrieved, in that new uses for data will constantly be invented
- marketed throughout the agency (so that staff with information needs know about the data and can access them).

An interesting fact about data is that the more data are used, the higher their quality becomes, then even more uses are found for them, and more value is placed on those data by the agency.

Successful businesses understand these aspects of data archiving. For example, every time Fed Ex picks up a package, the act of picking up the package is recorded electronically. The data about that package is automatically transmitted to an archive and stored. All interactions with that package are automatically recorded. The data are accessible in real time for operational purposes within Fed Ex (Where is this package going? What action do I take with this package now? How much is owed and by whom for this transaction?), as well as in "planning time" for customer relationship management and business planning. (How many packages does this customer normally ship? When do they ship them? How does that information change the number of trucks I send to that part of town? What are the sizes of my origin/destination city pairs and how does that change the distribution and use of my equipment assets?) The same basic package data are also available to its customers in both real time (Where is my package? Will it get delivered on time?) and planning time (How much do I owe? What are my monthly shipping expenses?).

Volume and roadway performance data are the Smart Highway's version of basic package data. Volume data are the key statistic for managing demand: Is room available for more vehicles? Are there too many vehicles? What happened to demand when changes were made to the traffic management system? Roadway performance data complete the picture of roadway operations. They describe the "health" of the roadway. Such information, like information about package delivery status, is needed by both operators and customers. For example, the Smart Highway operator needs to know that travel times are increasing in order to know that a problem is occurring and to determine whether the "fixes" to that problem are working. The roadway user needs to know this same information to make his own, independent travel decisions.

Operational data can be matched with all kinds of the other data for a variety of business practices. Fed-Ex matches basic package data with labor deployment information, truck scheduling and routing information, and customer requests, complaints, and compliments to provide immensely valuable business information. (Which routes/services are profitable? Which are not? Which customers are particularly important, and what is necessary to keep them as customers? How can available labor be more efficiently deployed and managed? How are equipment needs changing, and how can the equipment already owned be more efficiently deployed?)

The Smart Highway agency should treat operational data the same way. Matching operational results with other statistics (control decisions made, prices charged, incident response resources made available) provides the basic business information necessary to judge the worth of traffic management and other business practices that the Smart Highway performs.

Analytical Software

Once the archive of operational data exists, the final task is to convert those data into useful business intelligence / knowledge. Archived data by themselves are not useful. Archives are useful when the data in the archive are effectively analyzed and reported. Therefore, the fourth category of software required by a HNM includes the analytical suites needed to convert the archived data into useful business intelligence. If the analyses that provide that business intelligence become routine, those analyses are frequently converted into decision support software[4]

Analytical software comes in a variety of forms. For the sake of discussion, analytical applications are divided into three basic categories that highlight both the types of analytical software that are useful to the HNM and the functionality that must be built into the archive itself. These three categories of analysis software include

- database queries of the archive that provide management outputs

[4] The big difference here is the ease of performing these analyses. "Analysis software" tends to be very flexible but more cumbersome to use., whereas "decision support software" is easy to use but generally only performs previously defined analyses.

- offline research software, where *ad hoc* data sets are extracted from the archive to feed specialized analytical tools; these analytical tools include both specialized transportation analysis software and more generalized statistical analysis tools
- parallel control system and management applications that use "streaming" exports of the archive data as an input data source (e.g., current performance of the roadway might be compared in near real-time with historical roadway performance data extracted from the archive to predict future conditions as an input to the HNM's roadway management decisions).

Many of the performance reports needed for management purposes come from simple queries and summaries of the data stored in the archive. Some of these interactions with the archive are routinely performed, even to the extent of being fully automated (e.g., some routine performance reports used for management purposes are run automatically each month). Other interactions are routine but run "as needed." Other queries are performed on an *ad hoc* basis to meet specific needs. Therefore, the archive needs a usable interface that includes both access to "canned reports" and the ability to allow users to create their own queries.

All modern database software systems come with these analytical capabilities. The issue here is rarely the capability of the database software itself. Rather, it is having sufficient knowledge of how to structure queries so that the output of those queries produce the management statistics described in the previous section on archive functionality. While it is necessary to have expert software engineers to help write those queries, the key to successful development of these analytical applications is having transportation engineers who understand <u>how</u> the data need to be manipulated and who can translate those ideas into instructions that the software engineers can code.

Some of the knowledge that those transportation engineers need will come from continuing analysis of the operations data collected and stored in the archive. Therefore, the second set of analytical tools required are tools for improving knowledge of the causes and effects of various traffic disruptions and the outcomes that can be expected from various management actions. The programs that help supply these insights into traffic flow relationships include (but are not limited to)

- traffic simulation and optimization software used to develop and test new control algorithms and control strategies
- statistical analysis software packages, including sophisticated new data mining software, used to research and refine the HNM's understanding of the interrelationships of various events/occurrences and roadway performance
- specifically coded analytical tools created from high level programming languages (C++, C#, Java).

While many of these applications can be purchased from vendors, some applications must be developed in-house. And even applications purchased from vendors will need careful set-up, calibration, and validation before they can be used extensively.

This is especially true for traffic simulation and optimization software, which attempts to replicate the performance of the monitored roadway system so that alternative control strategies can be developed and tested. These software packages are particularly important for testing the outcome of various new Smart Highway control strategies before their implementation in the field. Once they have been implemented, the statistical software is used to determine how effectively the control systems actually work and whether the simulation and optimization programs are correctly predicting the performance outcomes.

The good news is that the archive itself provides the vast majority of the data needed to run these models, as well as calibrate and validate the outcomes from those programs. In fact, the robust data available from the Smart Highway makes the use of sophisticated modeling tools for planning and policy analysis far more cost effective, simply because the data needed to run the programs are readily available.

The archive may also be a key real-time tool for selecting optimized traffic management plans. One frequently suggested control technique predict future conditions by comparing current conditions against historical data with various pattern matching techniques . Those predictions are then used to select optimum control strategies. This is a good example of the third type of archive application software: control system software that retrieves data from the archive in real time.

To date, this basic approach has not been widely adopted for roadway control systems, although some limited applications of the technique do exist as adaptive traffic signal control algorithms. Historically, the major constraints have been an inability to collect sufficient input data and a lack of sufficient computer processing power. Both of these constraints are becoming less relevant as a result of the technological improvements that underlie the Smart Highway system.

Key tasks for the HNM will be to build, calibrate, and operate these programs.

A Business Approach to Agency Actions

For the HNM to be effective, the Smart Highway agency needs to adopt a corporate culture in which the agency places very high importance on improving operational performance. Such a culture uses objectively collected and analyzed data to determine whether agency policies are being achieved and whether staff are performing their jobs effectively. It sets clear goals aimed at improving performance and is willing to supply the resources that work cost effectively toward meeting those goals. Such an approach is also willing to change policies when the data show that the policies are not achieving the desired outcomes.

While such an approach makes good business sense, it is unusual in the current U.S. roadway industry.

THE ROLE OF THE HIGHWAY NETWORK MANAGER

In many ways, the HNM is the key to gaining the benefits of the Smart Highway. In addition to being responsible for selecting the actual operational control decisions being made, the HNM (and his/her staff) must perform other key tasks that are essential for converting the data from the Smart Highway into business decisions that improve the performance of the roadway agency. To do this, the HNM must help in the following efforts (which are also summarized in Table 3):

- cost effectively collect the data that modern technology can make available
- direct the analytical efforts needed to
    - develop and report those statistics that allow more effective management and operation of the roadway system and gather the resources used to direct that operation
    - improve understanding of the relationship between traffic demand and the available control mechanisms
    - design the new control algorithms that take advantage of that improved understanding
- build the software systems needed to make use of those data

- facilitate the use of the collected data by all groups within the Smart Highway agency.

This last point is a key attribute that helps differentiate a Smart Highway agency from a conventional roadway agency. In the Smart Highway agency, data collected once are used for a wide variety of applications across multiple disciplines and are available for use by other agencies. The multitude of uses both reduces data collection costs and increases the agency's ability to make good business decisions.

Table 3: The Highway Network Manager's Duties

Make Operational Control Decisions
Direct Data Collection Decisions Hardware selection Hardware placement Software selection Purchase of data from external vendors (e.g., cell phone probe data)
Direct Operations Data Analysis Performance reporting Staffing and resource allocations Operations research Development of new traffic management plans
Direct Software Development Operations/management/surveillance control systems Decision support Data archiving and reporting Analytical suites
Facilitate Use of Operational Data by Others in the Agency

Unfortunately, the concept of "collect once, use multiple times" is far easier to state than to implement. Therefore, a key role of the HNM and his/her staff is to facilitate these multiple uses. To do that, they must maintain an understanding of data locations, the attributes of those data, and ways they can be accessed by others within the Smart Highway agency. Having this knowledge in a single location facilitates the use of these data for a variety of other business purposes.

It is quite possible that the availability of these data for other Smart Highway business purposes may result in savings (or revenue enhancements) to the agency that exceed the value gained from their use in optimizing operational performance of the roadways. For example, data on facility use by type of use (cars versus trucks, commuters versus recreational travel) and the nature of changes in that use to varying levels of roadway performance (congestion and price) can yield extremely valuable information for the areas of pavement and bridge design, safety analyses, and facility planning.

Pavement and bridge construction and maintenance are the largest expenses of most roadway agencies. Considerable room for reducing costs and increasing revenue (for toll facilities and managed lanes) exists in these areas. Not only can pavement maintenance and rehabilitation be optimized to match actual traffic loads, but for toll facilities, more precise tolling structures can be developed and applied that accurately reflect the costs that different vehicles impose on the roadway. Accurate (and legally defensible) operations data on truck volumes and weights can help in enforcing pavement and bridge warrantee contracts, safeguarding the performance benefits that the warrantee program is designed to provide and leading to enormous potential savings. . This same information will lead to more accurate pavement maintenance and rehabilitation designs when that pavement is ready for such treatments because actual traffic loads will be well known.

Safety improvements should also result because good facility performance information (vehicle speed, the location and timing of congestion formation, usage patterns) will allow better identification of accident causes and measurement of the effectiveness of accident mitigation strategies, thus helping the Smart Highway agency select and implement the strategies that decrease accident rates and severities.

System planning can also benefit significantly from Smart Highway operations data. Information on how and where travel takes place allows the Smart Highway agency to more effectively understand its customers and, therefore, plan and prioritize the improvements needed to meet customer needs, attract new customers, and manage those customers who already use the facility. Combining information on customer usage patterns (where motorists get on and off, when they travel, how they respond to pricing and other control mechanisms) with detailed knowledge of the current facility geometry allows determination and prioritization of improvements that allow better flow and thus an increase in satisfied patrons.

To achieve the above benefits, operational data must be integrated with a variety of other data sources that should exist within a well run Smart Highway agency. For example, data sources such as the following should be available through the agency's asset management systems:

- roadway geometry
- construction details (e.g., pavement depth, pavement material, sub-grade material, and drainage features)
- signage

- safety treatments (e.g., guardrails, crash barriers, median treatments)
- lighting
- environmental treatments.

Because facility use and performance are so key to these analyses, the HNM and his/her staff must play a key role in facilitating the development of the software programs that make the analytical procedures described above possible.

Successful, cost-effective software development is a major part of converting a conventional highway agency into a Smart Highway agency. Successful software development is not a given. A number of long-term studies have looked at the success rate of major software development projects in both the public and private sectors. While results vary somewhat from study to study[5], the research is quite consistent in determining that a large percentage of major software development efforts end poorly. The seminal Standish Group report showed that a staggering 31 percent of projects were canceled before they could be completed. Over 52 percent of projects cost more than 189 percent of their original estimates. Only 16 percent of major software projects were completed on time and within budget. In larger companies, only 9 percent of major software projects were completed on time and under budget.

Even when projects are completed, many are no more than a mere shadow of their original specification requirements. Projects completed by the largest American companies had only approximately 42 percent of the originally proposed features and functions. Smaller companies did better than larger companies, deploying 78 percent of their software projects with 74 percent of their originally planned features and functions.

[5] A nice summary of several of the more prominent studies can be found at www.it-cortex.com/Stat_Failure_Rate.htm. This site summarizes among other reports, a KPMG Canada study from 1997, a study by Robbin-Giola, LLC in 2001, a 2001 study by the Conference Board of 117 firms that attempted major ERP implementations, and the Chaos Report written by the Standish Group in 1995. The Standish report is available on the web at http://spinroot.com/spin/Doc/course/Standish_Survey.htm

Many of the studies point out the reasons for these high failure rates. Common problems include the following:

- lack of an understanding by the software engineers of the business processes that the software is designed to facilitate
- lack of commitment of time and attention from the business side of the company to the software development team
- lack of continuity in the management of the software projects
- unrealistic expectations of the project
- incomplete or changing project specifications.

The HNM and his/her staff need to be the part of the Smart Highway organization that keeps these failure points from occurring.

The HNM is uniquely situated to, and must, understand both how the Smart Highway operates (the business side) and how the software systems work. The HNM can be supported by staff who specialize in these respective aspects of the business, but the HNM needs a solid grounding in both. To do this, the HNM must understand the basic capabilities of technology, as well as how software is written and the technology's current capabilities. The HNM also needs the vision to understand how data can be used to help the agency make better decisions. In addition, he or she must understand what relationships make sense (financially as well as mathematically) – and thus help the agency understand what data requests are worth meeting in order to provide the desired revenue enhancements and cost controls.

GETTING THERE FROM HERE

What does a roadway agency need to make this dream a reality? The answers to this question are discussed below, and summarized in Table 4.

Table 4: Needs For Converting A Roadway Agency To A Smart Highway Agency

Incentives and Direction
Provide Leadership Within the agency To the public which the agency serves To that public's decision makers
Control Systems for Managing Traffic
Monitoring Systems That Describe Current Facility Performance
Analytical Systems to Convert Data To Information
A Proactive, Business Culture

Incentives and Direction

First, the roadway agency will need political and/or financial incentives to optimize performance of the roadway. The current process of "build it and let it mostly operate itself" exists because the current public revenue/reward system for roadway agencies values funding the construction of new roads over funding the operation of existing roads. Therefore, more benefits are obtained by roadway agencies if they concentrate more energy on building roads than on optimizing the performance of roads they already operate.

Furthermore, common practice is that tolls are primarily used to repay existing construction bonds. They are not commonly used as a tool to optimize roadway use and performance, although several HOT lane tests are under way to determine how well these concepts work and how well the general public accepts these concepts .

The U.S. public has traditionally chosen to accept congested roads rather than adopt pricing and control strategies (e.g., heavy ramp metering) that would keep freeways flowing. Historically, the public has preferred that everyone be treated the same (everyone sits in congestion), rather than changing the "rules" we have become accustomed to so that some may benefit over others. (In the case of congestion pricing, "willingness to pay" determines who uses uncongested roads and who experiences more delay. In the case of ramp metering, the specific metering strategy determines where delays take place in order to maintain flow for those already on the facility.) If Smart Highways are operated as purely private businesses, congestion pricing becomes an obvious mechanism for both increasing revenue and maximizing use of the facility during peak periods (because maximizing use is good for business). In such a case, there is considerable incentive within the agency to implement and use Smart Highway technologies. If the roadway agency does not have the ability to operate as a purely private business, it will need to change the traditional political and public expectation of how the roadway will be operated. Although there are considerable benefits to the public of Smart Highway operations (reduced travel time, increased reliability, creation of new revenue sources dedicated to the facilities being used), the public (and elected decision makers) will likely need to be convinced that this concept is in the travelers' and region's interest. The agency will also have to demonstrate that the benefits "sold" to the public are actually being delivered. Only with public buy-in will it be possible to obtain decision maker direction/permission to deploy and use the control systems needed to optimize roadway performance.

When financial and political rewards are obtained by optimizing flow, then the funding necessary to implement and operate Smart Highway technologies will become available. Smart Highway technologies are the only way to obtain these benefits. And if the agency is rewarded by providing operational improvements, then it will put in place and use those systems it needs to be rewarded.

Provide Leadership

Adopting the Smart Highway focus on facility performance will require a major change in organizational thinking, priorities, and actions. Achieving that change will require leadership. Leadership is needed to change the priorities of the roadway agency. Leadership is necessary to gain cooperation with jurisdictions and agencies affected by the operating policies of the Smart Highway. Leadership is necessary to educate the public about the benefits of such a change in traditional priorities and policies.

The potential benefits of the Smart Highway are large in terms of providing reliable travel options to the public. It has the potential to redirect funding to those activities which most directly meet the true priorities of the public. However, the operating policies of the Smart Highway are different from those that the public (and traditional highway agencies) have come to expect.

Change requires leadership. And therefore, changing the expectations of the public and of the agency's employees requires strong leadership.

Political leadership is also required because the Smart Highway may require changes to current legal statutes to operate effectively. For example, in some states, state laws may need to be altered to allow automated enforcement of toll collection. Similarly, strong public leadership may be necessary to gain the cooperation of the agencies that operate parallel and connecting facilities, allowing for more effective, region wide traveler information and traffic control system planning and operation.

Control Systems

Once the agency has the direction (permission) and funding to implement Smart Highway technologies and operational concepts, it will be necessary to select and implement the control systems that will provide the physical mechanisms to optimize facility performance.

Selection of these control systems must include an understanding of how effective they will be in maintaining optimal flow conditions, the cost of their implementation, the political acceptability of their operation, and the consequences of their use on neighboring facilities and jurisdictions.

Monitoring Systems That Describe Current Facility Performance

To operate those control systems, it will be necessary to have the monitoring systems that provide the knowledge of current facility conditions. This will likely mean an expansion of current facility monitoring systems, with initial emphasis on making sure the data needed to operate the control systems are collected in a reliable and cost-effective manner.

Over time, as funding becomes available, monitoring systems should be expanded to provide more comprehensive data on facility operations and the performance of neighboring transportation facilities that feed, drain, or otherwise interact with the Smart Highway. While considerable benefit can be gained simply by understanding the Smart Highway's performance, more optimal regional (and politically acceptable) control decisions can be made with more universal transportation system performance monitoring.

Analytical Systems to Convert Data to Information

When the facility performance monitoring systems are developed, it is key that their data be stored for later use, not just used for immediate control system applications. Resources need to be allocated to software systems that store, analyze, and use these data for the wide range of business decisions that can and should take advantage of these data.

Resources also need to be allocated to the implementation and active use of analytical procedures that routinely review and report on the performance of the control systems. The deployment of these management systems, fed by the data collected to operate the control systems, is key to effective, proactive management of the Smart Highway, and thus attainment of the operational benefits the Smart Highway promises.

A New Proactive, Business Culture

Last, the Smart Highway agency will need to adopt a corporate culture in which the agency prioritizes very good operational performance. Such a culture uses objectively collected and analyzed data to determine whether agency policies are being achieved, and whether staff are performing their jobs effectively. The culture needs to reward successful innovation that improves the agency's attainment of goals. It also needs to be willing to change policies when the data show that the policies are not achieving the desired outcomes.

The HNM will be a very visible part of that new culture. The HNM is visible precisely because his or her actions will have a direct effect on both the travel decisions and travel experiences of a large number of roadway users. If the Smart Highway builds the data and decision making systems needed to support the HNM, he or she will be successful, and as a consequence, the Smart Highway will be successful.