Commission Briefing Paper 4G-01

Evaluation of the Potential Impacts of ITS Deployment and Operational Strategies to Increase Effective System Capacity and Safety

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Introduction

This paper is part of a series of briefing papers to be prepared for the National Surface Transportation Policy and Revenue Study Commission authorized in Section 1909 of SAFETEA-LU. The papers are intended to synthesize the state-of-the-practice consensus on the issues that are relevant to the Commission's charge outlined in Section 1909, and will serve as background material in developing the analyses to be presented in the final report of the Commission.

This paper examines the impact that Intelligent Transportation Systems (ITS) technologies and operational strategies will have over the next 15-50 years. For definitional purposes, ITS is seen as the enabling technology that allows for various types of operational strategies to be deployed. Impacts are assessed in terms of the effects on travelers (the amount of congestion delay and crashes) and deployment costs to agencies. For existing strategies and those on the near-term horizon, the results of recent analyses have been used to quantify the impacts as much as possible. A discussion of advanced technologies and strategies – most of which have not been fully defined – is presented.

Background and Key Findings

- ITS and Operations strategies have been successfully deployed over the past two decades. The deployments have been concentrated in urban areas but rural areas are starting to receive attention. The deployment levels for a core set of urban ITS and operational strategies are relatively high, but additional benefits can be achieved by: (1) expanding coverage, (2) implementing more intensive activities (e.g., higher densities of equipment and control strategies) and more sophisticated technologies and methods (e.g., advanced traffic signal control), and (3) developing and deploying new technologies not currently deployed (e.g., advanced traveler information dissemination).
- Substantial reduction in congestion (26 percent delay reduction) and modest gains in safety can be achieved if ITS and operations are aggressively deployed between now and 2035. Additional safety gains can be achieved with advanced roadway and vehicle control systems, but were not assessed in this paper. (The Cooperative Intersection Crash Avoidance System is one example of technologies that are currently being researched that will have a positive effect on safety by 2035.) The approximate cost of this deployment – including both initial outlay and ongoing operation and maintenance – is about 11 percent of total current highway expenditures; if the cost of replacing and maintaining routine traffic signals is removed, the cost is about 5 percent of current expenditures.

- ITS and operations benefits are achieved without expanding the physical size of the highway system. Also, because many operations strategies deal with the delay caused by unexpected events like incidents and bad weather, the reliability, predictability and consistency of travel is improved. Studies have shown that providing reliable/consistent travel times is very important to travelers and businesses because it allows more efficient activity planning (e.g., ensuring on-time arrival at work, reducing inventory costs for "just-in-time" deliveries).

Commission Staff Comments

While this paper presents a sound evaluation for the potential impacts of deploying ITS and operational strategies, the staff wishes to include some of the challenges related to more widespread deployment as described in the following paragraphs in this section.

The culture of most of highway agencies charged with managing and operating the transportation system is based on a civil engineering, project-oriented, build and maintain mindset. Effective system management and operations requires a shift in culture to a system-oriented, performance-based, proactive, technology-oriented, customer-focused, 24-7 mindset. This shift - which is occurring slowly - is essential to achieve the kinds of gains identified in the paper.

There is a trend for increased implementation of proven and established technologies and strategies, but the generally conservative, risk-averse nature of public transportation agencies results in slower adoption of advanced technologies. As these advanced technologies become more proven through their use by leading edge, early-adopting agencies and the private sector, their acceptance and implementation increases.

The impacts and benefits of a number of the ITS technologies and operational strategies discussed in this paper are dependent upon the cooperation of multiple agencies and organizations. For example, the challenges associated with implementing traffic incident management, integrated corridor management and traveler information are generally not technical in nature but institutional. Multiple public sector agencies and private sector firms from various disciplines must act cooperatively in order to maximize the benefits of deploying ITS and operational strategies. This cooperation can also help in acquiring the resources needed to expand and enhance ITS and operations.

The Case for Operations and ITS Technologies

The strategies discussed and analyzed in this paper are important elements of a well-run transportation system. But they are much more important as one component of a comprehensive metropolitan transportation investment plan. The benefits of a well-operated system might generally be divided into productivity and accountability.

<u>Productivity – The Engine Room of the 21st Century Transportation System</u>

Roads and public transportation systems will be expanded as metro regions and rural areas address population growth. Travel capacity continued to increase in the last 15 years although prevailing wisdom would have the public believe the era of "more" is over. New roads in suburbs served the rapidly growing population there, while new and widened freeways, toll roads, priced lanes, and major streets combined with public transportation system expansion to serve larger populations in urban and suburban areas. Certainly road expansions are not at the same rate as during the Interstate Era, but capacity increases are effective methods of improving mobility and safety. Operational improvements are the method of deriving maximum benefit out of the capacity that is created and provide the greatest efficiency for taxpayers, as well as travelers and shippers.

Operating strategies might be well-known technological developments such as freeway entrance ramp meters, incident management programs, traffic signal coordination, and roadside traveler information signs. Just as important however, are the programs and policies that govern the operation of the technology.

- Aggressive incident management programs that use private sector tow trucks with incentives for rapid clearance of stalled vehicles and crashes are an important advance on the usual motorist assistance programs.
- Traffic signal coordination programs that simultaneously monitor the number of bus patrons, on-time scheduling, other passenger vehicle delay and system level traffic and weather conditions can improve the efficiency of transportation service, while at the same time encouraging increased public transportation ridership.
- Access management programs that consolidate driveways and reduce the number of left-turn locations improve the operation of major arterials and reduce collisions.
- In addition to the operations strategies covered in this paper, ITS technologies enable congestion pricing and electronic tolling strategies to be implemented. Further, when used in combination, advanced operations strategies (such as sophisticated traveler information delivery) can work together with pricing and tolling to provide congestion relief.

All of these strategies increase the vehicle and person movement by addressing so-called "capacity-stealing" events – individual actions, technology breakdowns or a combination – that increases congestion and decreases safety.

<u>Accountability – Making the Case for Transportation</u>

One benefit of operating programs and ITS technologies that has been less appreciated is the role in "selling transportation" programs and benefits. The effect of operating strategies is becoming well understood by the public due to a number of factors:

- Traffic signals that turn green as a group of cars approach - the result of signal coordination and traffic monitoring systems
- Crashes that are cleared quickly and safely – the effect of incident management programs
- Travel time information for drivers and public transportation riders – provided by monitoring and messaging systems
- Work zone traffic controls – using prior planning, contracting procedures and partnering between system owners and construction/maintenance contractors that speed construction and accommodate travelers and freight shippers with minimal amounts of extra delay.

The challenge for agencies is to maintain consistency in performing operations. Most of these components are easy to understand to identify so the public believes that they know when systems are working well and when they are not. In some cases, however, the effects are counter-intuitive or not as obvious. Think about metering a freeway ramp on a high-speed freeway; it is difficult to communicate the problems with the downstream bottleneck that is not constricting flow due to the demand regulation provided by the meters. And it is much easier to gain public acceptance for increased transportation spending when the public understands that the current funds are well spent and the benefits are proportional to the costs.

Benefits of ITS and Operations

Regular day-to-day congestion and the unexpected events that increase congestion are both addressed by operational strategies. But the most significant congestion aspect addressed by ITS and operational improvements is the reliability concern. Information and technology both play a role in the improvement strategies, but a key element lies in the fact that the reliability improvements are relatively easy to accomplish. They typically enjoy wide support; the capital, operating and maintenance budgets are less costly than many capital programs; and implementation times are relatively quick. Benefits of ITS and operations may be expressed in terms of:

- The economic impact of the implementation activity facilitates increased employment, income and contribution to the national economy.
- Savings from increased economic efficiencies as a result of improving mobility (reducing the cost of travel). These savings come from lower production costs for businesses resulting from lower delivery costs of both inputs and finished goods.
- The economic impact of the increase in economic efficiencies resulting from these lower costs mean businesses can offer more competitive prices, which translate into a larger market share. That, in turn, generates more demand for products, more production, increased employment, income to employees, and profits to the business.
- Time savings to individuals as a function of reduced commute times and an increase in travel speeds.
- Fuel savings to individuals as a result of more efficient fuel burn from lower congestion levels.
- Reduced personal, medical, and societal costs due to fewer and less severe highway crashes.

For this paper, timesavings and safety costs are addressed quantitatively.

Types of Operations Strategies and How They Work

A variety of existing and near-term operational strategies have been deployed around the Nation or these strategies are in the development phase. These are listed below along with the impact relationships used in the analysis presented in the next section[1]:

- Ramp Metering. These are essentially traffic signals at freeway entrance ramps that limit the number of vehicles that enter over a period of time. By controlling the number of vehicles that merge, freeway flow can be maintained at high throughput levels and safety can be enhanced. Once flow breaks down, throughput drops and delay increases exponentially with

[1] Unless otherwise indicated, the impact relationships are the ones used by FHWA's Highway Economic Requirements System (HERS) model. These have been compiled from a variety of sources including the ITS Benefits Data Base (http://www.itsbenefits.its.dot.gov/) and the ITS Deployment Analysis System (http://idas.camsys.com/)

each additional vehicle that is added. Vehicles on the entrance ramps experience additional delay but the delay savings on the freeway is greater. *Impacts:* Delay reduction[2] and a 3% decrease in crashes.

- Dynamic Message Signs (DMS). DMSs are used to convey to travelers any disruptions in traffic flow they will experience as they proceed down a highway. Information on traffic flow (volumes and speeds) gathered by roadway sensors as well as information on incidents and work zones allows operators to determine traffic conditions. Recently, DMSs have been used to convey expected travel times from the sign to major destinations (e.g., "10-12 minutes to downtown"). *Impacts:* Delay reduction of 1/2 percent.
- Traveler Information. Traveler information systems convey the same basic data on travel conditions as do DMSs, but deliver it via a variety of devices and media such as 511, pagers, the internet, highway advisory radio, and other personal devices. *Impacts:* Delay reduction of 5 percent.
- Variable Speed Limits (VSL). By slowing all vehicles uniformly as congestion builds on a freeway, optimum flow can be maintained. The intent is to avoid the rapid stop-and-go of vehicles which causes "shock waves" to appear in the traffic stream. *Impacts:* Delay reduction of 5 percent.
- Incident Management. Rapid removal of incidents – events that periodically block traffic flow (e.g., crashes, vehicle breakdowns, debris) – has proven to be a highly effective way of reducing delay and restoring throughput to high levels. Incident management uses technologies to quickly detect incidents (cameras), dispatch responders (computer-aided dispatch systems and service patrol vehicles), and clear incident scenes (coordinated response among agencies). *Impacts:* Incident duration reduced by 32 percent (normal operations) and 41 percent (aggressive operations). Incident duration is translated into delay savings.
- Road Weather Management. Weather affects driver behavior, vehicle performance, pavement friction, and roadway infrastructure. Strategies to address weather-related traffic problems include advanced sensing and predicting of roadway conditions, pre-treating roads with anti-icing materials, and pre-positioning trucks for de-icing, sanding, or plowing. *Impacts:* Three percent reduction is annual delay in states normally experiencing snow and ice conditions.[3]
- Advanced Traffic Signal Control. Poorly timed traffic signals are a major source of frustration and delay for travelers. By using advanced control strategies that continuously adapt signal timing to prevailing conditions, wasted time is avoided and throughput is maximized. *Impacts:* Delay reduction of 10-20 percent.
- Emergency Vehicle Preemption. Emergency response vehicles lose much time as they travel through traffic signals. By changing the signal to "green" as they approach, they gain back the time they otherwise would have to use by carefully proceeding through "red" phases. *Impacts:* No quantified impacts on congestion or safety.
- Integrated Corridor Management (ICM). ICM expands many of the above strategies into a coordinated strategy that manages traffic flow across several facilities and modes in a travel corridor (usually a linear part of the network comprised of several parallel highways). The intent is to use traffic control and traveler information strategies to utilize fully all the

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[2] Delay with ramp meters = ((1-0.13) * *OriginalDelay*) + 0.16 hours per 1,000 vehicle-miles traveled.
[3] This relationship was assumed specifically for this work; no reference is available.

available capacity in the corridor, especially when some of that capacity is lost due to traffic-influencing events (e.g., incidents). *Impacts:* Delay reduction of 10 percent.[4]

- Work Zone Management. Work zones are a major source of frustration, delay, and unsafe conditions for travelers. Work zone management strategies seek to reduce the duration of work zones, improving guidance and flow through them (especially in peak hours), and making them known to travelers. *Impacts:* Not assessed in the analysis.
- Special Event Management. Special events such as concerts, festivals, and sporting events produce surges in traffic that frequently overwhelm the highway system. Adapting traffic control and providing traveler information, alternative travel modes and detours can lessen the impact of this high demand. *Impacts:* Not assessed in the analysis.

What We Have Currently Deployed

Table 1 provides a snapshot of the types of technologies currently deployed in the U.S. Market penetration is reasonably high for many technologies and strategies. However, the data do not reveal the degree of intensiveness or sophistication of some of the strategies, just whether or not an agency has deployed something. For example, an increased number of service patrol vehicles per mile of highway can enhance incident management. Also, signal control systems operate with varying degrees of sophistication in their algorithms and timing plans. Clearly, there is room for expansion in how operation strategies are implemented.

Table 1. Status of Current ITS & Operations Deployments, Top 78 Urban Areas, 2005

Area/Technology	Reported	Total	Percent
Freeway Management			
Miles under electronic surveillance	6,503	17,090	38%
Ramps controlled by ramp meter	5,284	25,198	21%
Miles under lane control	1,478	17,090	9%
Number of Dynamic Message Signs (DMS)	3,177	N/A	N/A
Miles covered by Highway Advisory Radio (HAR)	3,722	17,090	22%
Incident Management			
Freeway miles under incident detection algorithms	2,732	17,090	16%
Freeway miles under free cell phone call to a dedicated number	4,703	17,090	28%
Freeway miles covered by surveillance cameras (CCTV)	5,984	17,090	35%
Freeway miles covered by service patrols	8,241	17,090	48%
Arterial miles under incident detection algorithms	1,481	97,687	2%
Arterial miles under free cell phone call to a dedicated number	4,148	97,687	4%
Arterial miles covered by surveillance cameras (CCTV)	4,980	97,687	5%
Arterial miles covered by service patrols	10,468	97,687	11%

[4] www.itsbenefits.its.dot.gov/its/benecost.nsf/0/82BF86CB215F33EB85256C3000686484?OpenDocument&Query=Home

Area/Technology	Reported	Total	Percent
Arterial Management			
Signalized intersections covered by electronic surveillance	49,754	138,261	36%
Signalized intersections under centralized or closed loop control	73,295	138,261	53%
Number of Dynamic Message Signs (DMS)	1,157	N/A	N/A
Arterial miles covered by Highway Advisory Radio (HAR)	2,037	97,687	2%
Emergency Management			
Vehicles under Computer Aided Dispatch (CAD)	90,836	112,841	80%
Vehicles equipped with on-board navigation capabilities	20,065	1128,41	18%
Traveler Information			
States with websites for Traveler Information (2004)	42	50	84%
States with 511 Traveler Information Systems (2004)	17 (2004) 28 (2006)	50 50	34% 56%

Source: ITS Deployment Tracking Data, http://www.itsdeployment.its.dot.gov/

Future Operations and ITS Investment Needs

Building on previous analytical work for AASHTO,[5] an analysis was conducted to estimate the effects of aggressively deploying ITS and operations strategies between 2004 and 2035. (The AASHTO study had a time horizon of 2024.) Strategies are deployed incrementally over the 31-year period in five-year increments to replicate how deployments are actually made. Currently existing equipment and strategies are taken into account to avoid duplication. Impacts on congestion and safety are accumulated over the entire period as strategies are deployed, in accordance with the relationships used in the AASHTO study. The congestion level is the determining factor as to whether strategies need to be deployed in any five-year period.

Table 2 lists amount of deployment in place by 2035 along with the associated costs. It is extremely important to note that costs include not only the original outlay for equipment but the continuing costs of maintaining and operating the equipment AND the cost of replacing ITS equipment over the 31 year time period. Over an extended period, operations and maintenance costs can be much greater than the original capital outlay for ITS and operations strategies. Replacement costs do **not** include those for traffic signals – it is estimated that the cost of replacing and maintaining existing signals over the next 20 years alone will be in the range of $118 million. The cost of replacing and maintaining the ITS equipment that has already been deployed is another $22 million, bringing the total cost of maintaining what we already have (including traffic signals) to $140 million over 20 years. Extrapolating this to 2035 produces a total amount of $210 million.

[5] Cambridge Systematics, Inc., *System Operations Investment Needs Measurement and Analysis*, NCHRP Project 20-24(54)C, September 2006. A modeling framework was developed and used to forecast deployment needs to 2020. For this paper, the same model was used to forecast deployment needs to 2035.

Under the "Aggressive Deployment" scenario, in which nearly all freeways and a high amount of signalized arterials receive multiple forms of operational treatment, $152 billion in new investments must be made. When the cost of maintaining existing infrastructure is added in, the total price tag is $362 billion. At the current pace of highway spending ($104 billion per year), this amounts to 11 percent of total expenditures.

The costs of the ICM and Travel Information strategies are likely to be higher than shown due to limited experience in deployment. The costs shown are basically the additional cost of deploying advanced software to control flow and disseminate information. Additional equipment (along with increased personnel requirements) will have to be deployed, depending on what form these strategies take in the future. Further, emerging forms of operational strategies – either in the conceptual stage now (e.g., Vehicle-Infrastructure Integration) or not yet even envisioned – will impose additional costs.

The effect of deploying ITS and operations at different levels is provided in Table 3. Overall, by aggressively deploying ITS and operations, total delay is reduced by 26 percent. Note also that incident-related delay is nearly halved. The safety improvement is modest, but largely because underlying relationships have not been developed and other forms of advanced ITS and operations that will have a significant impact on safety – such as vehicle-infrastructure integration and intersection collision avoidance – are not considered here. (Other papers in this series cover these topics.)

The large reduction in incident delay is significant because it is largely unexpected delay – delay that cannot be planned for or predicted. This points out a key aspect of ITS and operations: the idea that they can improve the *reliability* of travel. From an economic perspective, reliability is highly important because travelers must either build in extra time to their trips to avoid arriving late or suffer the consequences of being late. This extra time has value beyond the average travel time used in traditional economic analyses – studies have suggested that this "extra" or "unplanned" or "unpredicted" travel time is valued by travelers at anywhere from 1-6 times the value of expected or typical travel times.[6] Commuters and freight shippers are both concerned with travel time reliability. Variations in travel time can be more frustrating and are valued highly by both groups. And the increase in just-in-time (JIT) manufacturing processes has made a reliable travel time almost more important than an uncongested trip. Significant variations in travel time will decrease the benefits that come from lower inventory space and the use of efficient transportation networks as the new warehouse.

Table 2. Amount of Deployment and Associated Costs, 2004 – 2035

	Miles of Deployment, 2035		**Cost of Deployment ($M)**	
Operations Component	**Continue Existing Deployment Rate**	**Aggressive Deployment**	**Continue Existing Deployment Rate**	**Aggressive Deployment**
Freeways				
Ramp Meters	5,404	37,757	$1,347	$11,473
Electronic Monitoring	3,201	37,810	$1,261	$12,859

[6] **Cohen, Harry, and Southworth, Frank,** ***On the Measurement and Valuation of Travel Time Variability Due to Incidents on Freeways*****,** Journal of Transportation Statistics**, Volume 2, Number 2, December 1999,** **http://www.bts.gov/jts/V2N2/vol2_n2_toc.html**

	Miles of Deployment, 2035		Cost of Deployment ($M)	
Operations Component	**Continue Existing Deployment Rate**	**Aggressive Deployment**	**Continue Existing Deployment Rate**	**Aggressive Deployment**
Dynamic Message Signs	4,084	33,784	$445	$3,526
New Traffic Management Centers	12	304	$459	$7,631
Traveler Information	N/A	N/A	$2,000	$10,000
Integrated Corridor Management	0	38,766	$0	$10,413
Incident Management	3,805	44,203	$2,770	$49,535
Signalized Highways				
Signal Control Upgrades	12,257	37,222	$6,306	$14,377
Electronic Monitoring	2,381	37,222	$3,096	$13,542
Signal Preemption	2,381	37,222	$43.85	$784.38
Dynamic Message Signs	0	9,673	$0	$1,433

Table 3. Impacts of Deploying ITS and Operations, 2004 – 2035

	Delay (millions of hrs)				Safety (Freeway Only)	
Scenario	**Recurring**	**Incident**	**Total**	**Savings**	**Fatalities**	**Savings**
No New Operations; Existing Operations only	1,270,163	229,749	1,499,912		196,400	
Continue Existing Deployment Trends	1,226,585	203,411	1,429,996	-4.7%	195,100	-0.7%
Aggressive Deployment	991,410	116,647	1,108,057	-26.1%	179,000	-8.9%

Note: "Recurring delay" is that delay caused by too many vehicles trying to use a highway with a fixed physical capacity. It is sometimes called "bottleneck" or "capacity-related" delay.

Also, because of the extra time required in planning trips – and the uncertainty about what travel times will actually be for a trip – reliability influences decisions about where, when, and how travel is made. Research has shown that as the base congestion level ("recurring congestion") increases, unreliable travel also increases[7]. That is, as traveler's typical travel times increase, they must also plan on even higher amounts of unexpected delay.

[7] Cambridge Systematics, Inc. and Texas Transportation Institute, *Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation*, prepared for FHWA Office of Operations, September 1, 2005, http://www.ops.fhwa.dot.gov/congestion_report/index.htm

Advanced Strategies and Technologies Not Currently Envisioned

Beyond the technologies, policies and programs that are on the ground, in the development process, or in future plans are other improvements that cannot be viewed in the crystal ball. One framework for thinking about these is to adopt the current taxonomy of vehicle, road or roadside and global technologies; and policies or operating strategies.

Technology enhancement trends appear to be toward communication improvements between technologies and between technologies and travelers or shippers. Certainly there will be much more information about travel conditions and the destination or travel plans of people and freight. Vehicle-Infrastructure Integration systems, discussed in other papers, will provide more ability to fine-tune the reactions to transportation problems, whether these are based on route-changing to avoid congestion or path changing to avoid an on-coming vehicle. Substantial delay reductions are expected because of the information available to travelers.

Technologies that are built into the roads, bridges and operations equipment are beginning to show they are capable of real-time enhancements of services to users. But the more advanced side of these might be the role of self-healing, self-diagnostic and automated control of roads, rails, bridges and other infrastructure elements. The effect of these advanced materials will be fewer out-of-service days or lanes for construction or maintenance activity, less travel delays and more reliable information about travel conditions.

The bureaucratic, near-term problem-solving nature of many agencies and equipment providers, however, might get in the way of future visions of the wealth of opportunities. Today's grade and high school students are more comfortable with rapid information flows; as they move into the workforce they should be more open to daily decisions about commute mode, departure time and route based on work load, weather, traffic, family plans or other conditions. Freight manifests have destination and delivery times and dates; using and integrating that information with transportation network information can improve services in both real-time and on subsequent trips.

Improved access to and use of information will reduce the number of peak period trips per million jobs. Pre-trip and in-route information will be more available to travelers, who may have greater access to telecommuting options that would allow a trip to be avoided, and a much wider variety of travel options that mean departure time can be changed, facilities that provide high speed, reliable trips for a price, and public transportation and carpool travel can be more viable. The effect of this will be a reduction in delay of approximately equal to the 511 and private ISP traveler information services.

The role of agencies and operators in the advanced strategy discussion should not be overlooked. While private vendors and suppliers are the groups that typically develop technologies, operators have a significant role in deployment and operation. As they gain experience now, for example, agencies are less content to simply watch cameras or monitors and post messages about the amount of extra time to allow for a trip. They are, instead, more aggressive about operational changes or adjustments to the institutional arrangements that might improve the mobility and predictability for travelers and shippers. These dynamic changes would improve the incident duration reduction to 45% (10 percentage points above the aggressive level).

CONSOLIDATED COMMENTS FROM MEMBERS OF THE BLUE RIBBON PANEL OF TRANSPORTATION EXPERTS - PAPER 4G-01

One reviewer commented as follows:

This paper discussed the benefits that Intelligent Transportation Systems (ITS) technologies and operational strategies will have over the next 15-20 years on highway travel. This reviewer suggests it would be appropriate to also note that freight railroads are pursuing a somewhat parallel system of technologies and operational strategies – *i.e.*, an integrated system will provide a more comprehensive picture for railroads and their customers as to where freight is and how it is moving across a network with respect to a transportation plan. The integrated system will track trains, monitor field conditions, compute authority limits, transmit movement authority and speed restrictions, and stop the train if unsafe operating conditions exist. Line capacity and fuel efficiency should be improved, and reliability and safety will be enhanced.