IDEA

Innovations Deserving
Exploratory Analysis Programs

High-Speed Rail IDEA Program

Automatic Flagging System for Track Maintenance Workers

Final Report for High-Speed Rail IDEA Project 17

Prepared by:
James Genova
Raven Incorporated

December 2000

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD

This investigation was performed as part of the High-Speed Rail IDEA program supports innovative methods and technology in support of the Federal Railroad Administration's (FRA) next-generation high-speed rail technology development program.

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Automatic Flagging System for Track Maintenance Workers

IDEA Program Final Report
For the Period October 1998 Through December 2000
Contract Number HSR-17

Prepared for
The IDEA Program
Transportation Research Board
National Research Council

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Executive Summary

The safety of track maintenance workers is a vital concern, especially where high-speed trains are operating. These maintenance workers must often rely on a so-called flagman or watchman who is assigned the responsibility of watching for approaching trains, and alerting workers in time to clear all personnel and equipment from the right-of-way before the arrival of trains. This technique is labor intensive and not always effective. Occasionally, those assigned the job of spotting trains do not see them in time to provide adequate warnings. This can, and does, result in fatal accidents and untold near collisions.

As a result of this concern, there is a need to develop a low-cost, reliable, automatic system to provide effective warnings to track workers of approaching trains.

The concept on which this project is based is the detection of train-induced rail vibrations to activate a warning system for track maintenance workers. The effectiveness of this technology for train detection was demonstrated in a previous IDEA project (HSR-4). This follow-on project is to develop a warning system that combines the moving train sensor with a robotic signaling and train stop device. Initial application would be designed for rail transit applications such as on the Chicago Transit Authority (CTA). Currently, a "slow zone" is established at a track maintenance work site, and a "trip staff" that will automatically stop the train is installed on the tracks. When a train approaches the "slow zone" the flagman sounds a horn to alert the track workers that a train has entered the zone, and signals the train operator to halt with a flag or light. After receiving a track-clear signal from the foreman, the flagman removes the trip staff and signals the train to proceed.

This project was to investigate the feasibility of a robotic signaling device to replace the flagman. It would use rail vibration technology to detect the presence and speed of trains approaching track maintenance work zones. The robot would be designed to place and remove the trip staff, and would be under the control of the track maintenance foreman by means of a hand-held device with a radio frequency link to the robot. The primary objective was to determine whether rail vibration technology could be used to detect the presence and speed of trains approaching track maintenance work zones.

Project Progress

Prototype design drawings for all of the mechanical assemblies were completed. Initial measurements of the acoustic signatures in the rails of approaching trains were recorded and analyzed to determine whether approaching trains could be distinguished form background noise form other sources. The next steps were to be the fabrication and preliminary testing of a design prototype. The final stage was to consist of operational testing and evaluation of the prototype on the CTA, and an evaluation the potential of the concept for high-speed rail applications.

Analysis of the acoustic signature data generated by approaching trains revealed that it was difficult to distinguish between trains and background noise. Moreover, the signatures could likely not be detected far enough down the track to provide adequate warning to track maintenance crews, particularly in territory with high-speed train operations (See Appendix). Consequently, fabrication and testing of a prototype was not undertaken.

The Stage 1 report that follows documents the design of the prototype, and the Progress Report in the Appendix summarizes the results of the rail vibration analysis.

RVN/RED/TR-99/005

IDEA Program Stage 1 Report for the Period 11/98 through 2/99 Contract Number HSR-17

Prepared for the IDEA Program
Transportation Research Board
National Research Council

James J. Genova, Ph. D.
Raven, Incorporated

February 12, 1999

Automatic Flagging System

.AFS for the Chicago Transit Authority

Project Overview and Status

.CTA Slow Zone

.AFS Requirements and Design

FRA Regulations for Flagging

..FRA Regulation

.High Speed Rail

.Application of the AFS Technology

Discussion

1. Introduction

This report documents the status of the IDEA Project to develop automatic flagging and lookout concepts. At this time, stage 1 of the three stage program has been completed. The objectives of the project are to develop an automatic flagging system (AFS) for the Chicago Transit Authority (CTA) and to investigate potential applicability of the technologies to flagging and lookout tasks for Class I railroads and especially High Speed Rail (HSR). The project is supported by the Transportation Research Board and is being performed by Raven, Inc.

In the first section the project overview is presented and then a detailed description of the AFS design and requirements. In the next section the FRA regulations and potential applicability of the technology to HSR are presented for discussion. Finally, comments from the TRB project oversight panel and plans for stage 2 are summarized.

Tasks

Stage 1 Design

1. AFS Design
2. Explore cost-effectiveness
3. Explore application of AFS to HSR

Stage 2 Prototype Evaluation

1. Fabricate and test prototype AFS
2. AFS field demonstration
3. Potential application to HSR

Stage 3 Final Product Evaluation

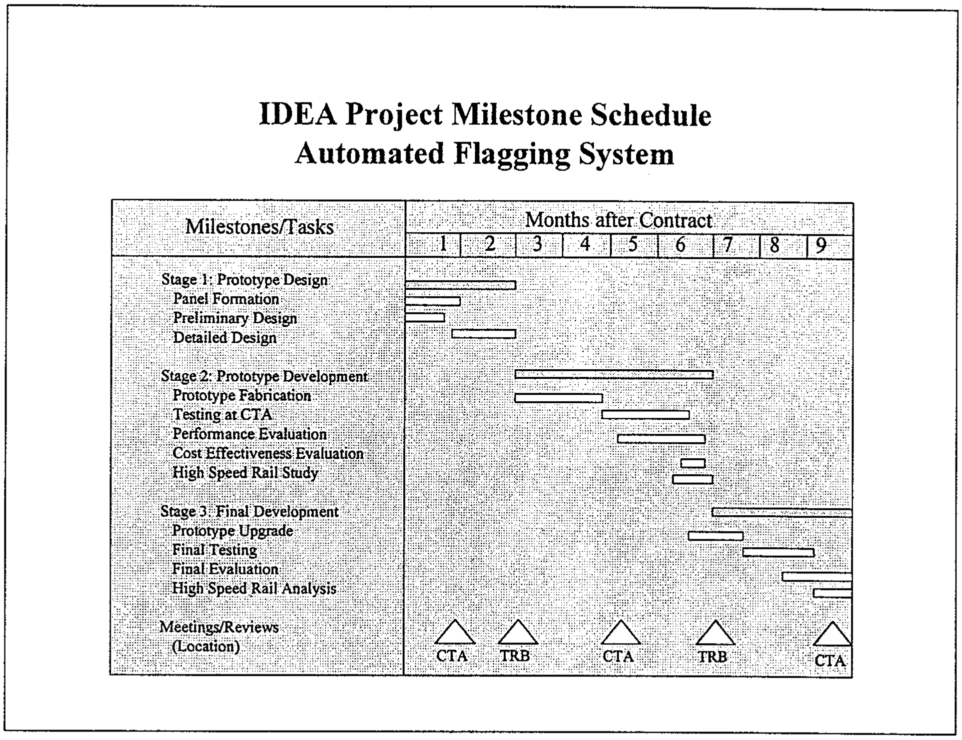
1. Test production prototype
2. Assess AFS cost-effectiveness
3. Review technology applications

2. Project Overview

The project is divided into three stages. During stage 1 the AFS design was completed. Pricing estimates and cost-effectiveness issues were investigated. In addition the impact of liability and insurance issues was addressed. Finally, a preliminary investigation was made of FRA regulations and HSR aspects of the technology development.

In stage 2 the AFS prototype will be fabricated. This will be accomplished during the first two months while the test plan is being developed. Field testing will be conducted for at least two months and a field demonstration will be held at the next panel meeting. Further investigation of HSR applications will be conducted.

In stage 3 the prototype will be upgraded to a production model and further testing conducted. Additional cost-effectiveness evaluations and HSR applicability issues will be studied.



The project began in November, 1998. The first stage has been successfully completed. The second stage is expected to begin soon. The prototype fabrication (planned for two months) may take longer than anticipated. Also, the field testing (planned for two months) will take at least two months. The test planning will be finalized during the fabrication stage. Preliminary algorithm testing is being planned for the beginning of stage 2 during fabrication.

The next panel meeting will be held during the field testing and be held in Chicago. The meeting will include a demonstration of the system. At this time it is expected that CTA testing will begin by May and that the next panel meeting will be held in June in Chicago.

Stage 1 Status

1. AFS Requirements and Design
   -Draft

2. Insurance Issues
   -Being addressed

3. FRA Regulations
   -See below

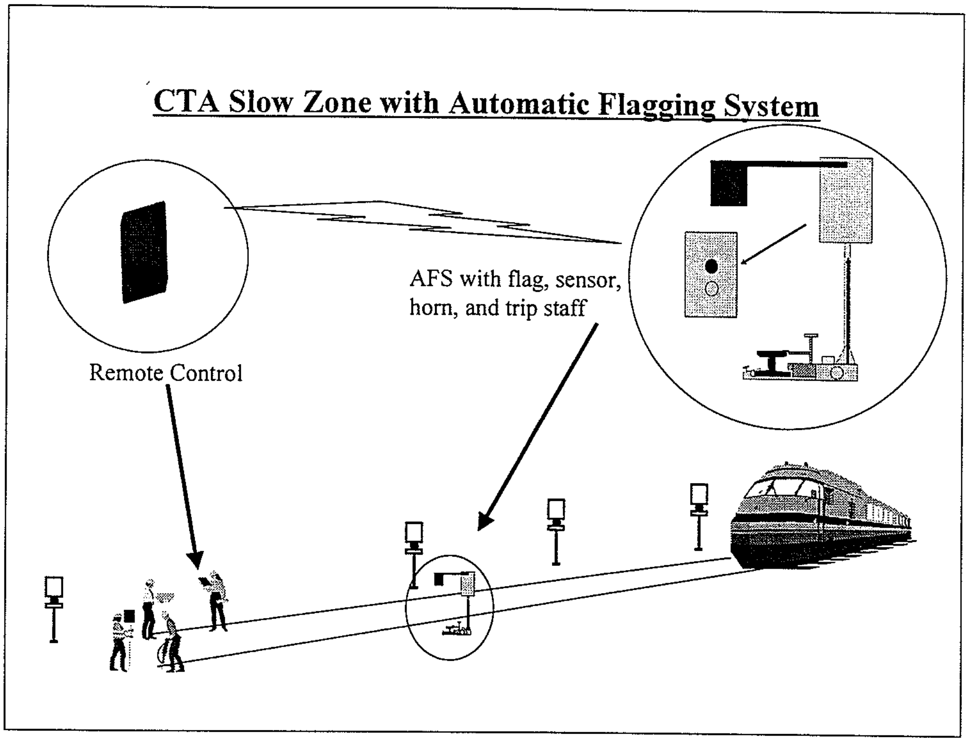
4. Cost-effectiveness
   -Preliminary estimates

The AFS requirements have been defined and the prototype design completed. Details follow below.

Several contacts have been made to the insurance companies to explore the issues relating to railroad protective liability insurance. The basic response is that "We will insure just about anything. But you may not be able to afford the premium." An insurance company representative in Chicago has agreed to advise the project personnel on this issue. Further contacts with the major underwriting companies are being sought.

FRA regulation issues will be discussed below.

The AFS is expected to result in improved safety and reliability for the CTA. The AFS will enable flagging for lone workers. The AFS (one side including HHU) for the CTA is expected to be priced such that it will pay for itself within 12 months.



3. AFS for the CTA

When the CTA work crew arrives at the site the flagman sets the signs and trip staff for a Slow Zone. A sign reminds the motorman of the work area. A sign at 600ft from the flagman notifies the motorman to proceed at 15mph and be prepared to stop. The flagman issues a blast from his horn to alert the crew of the approaching train. Positioned 200ft from the work area the flagman is moving a flag over the track, a sign indicates the zone speed of 6mph, and the trip staff is in place. The motorman stops 50ft before the flagman. If the train is approaching in a potentially unsafe manner, the flagman moves the flag vigorously and repeats short blasts on the horn. Upon receiving the clear signal from the foreman, he removes the trip staff, removes the flag, and signals the motorman to proceed. He then resets the trip staff.

The AFS (described below) is required to perform all of these same functions.

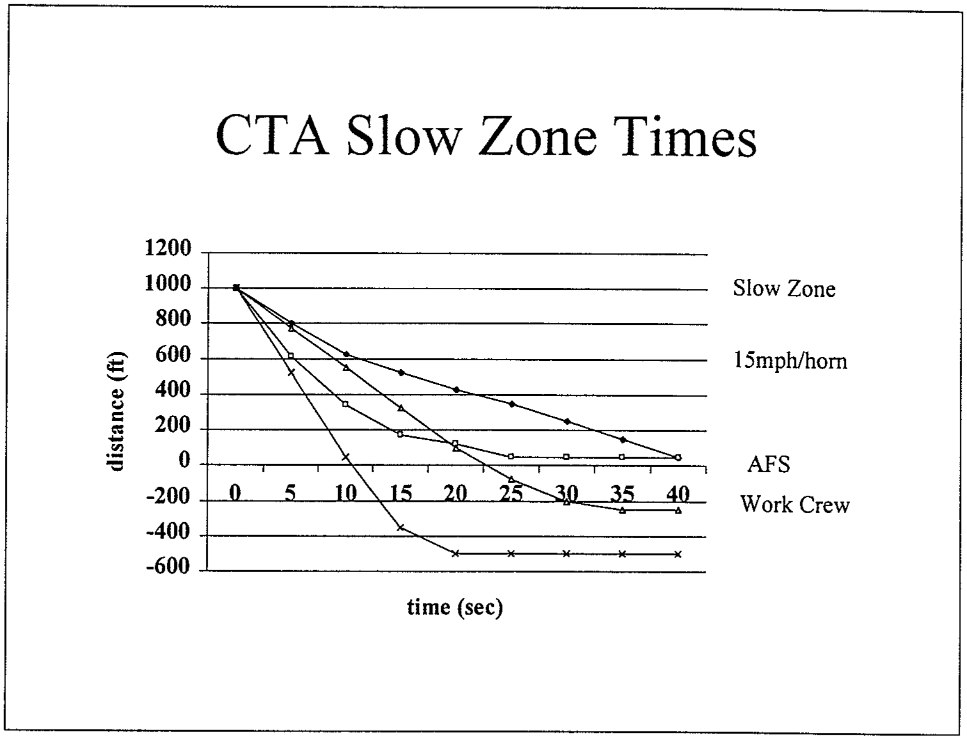
CTA Slow Zone Times

Position [ft]	I [30mph] [slowing]	II [60mph] [slowing]	III [30mph]	IV [60mph]
1000	39sec	25sec	23sec	11sec
600	27sec	20sec	14sec	7sec
0	0sec	0sec	0sec	0sec
-200	-23sec	-23sec	-7sec	-2sec

For later discussion purposes four scenarios are indicated in this chart and the following graph. All times and distances are referenced to the flagman. The work crew is approximately at position -200ft.

In the first two scenarios the train approaches at 30mph and 60mph, respectively. After the sign at 1000ft from the flagman, the train slows to 15mph by the 600ft sign in the first case and then slows to a stop before the flagman. In the second case the motorman continues to brake until just before the flagman. After receiving the signal to proceed, the train moves through at 6mph.

In the last two cases the train is assumed to continue at full speed (30mph and 60mph, respectively) until hitting the trip staff. In both cases the train goes past the work area. These examples are extremes for the sole purpose of indicating the limiting bounds on the AFS timing.



The graph illustrates the four scenarios discussed on the prior chart. The plot shows the position of the train relative to the flagman (AFS at 0ft) as a function of time referenced to 0 seconds (train at 1000ft from the flagman). Again, the work crew is on the tracks at -200ft relative to the flagman.

If the train enters at 30mph and brakes (diamonds), the flagman should blast the horn at least 30sec before the train stops. If the train enters at 60mph and brakes (squares), the flagman should blast the horn 18sec before the train stops. The motorman must brake continuously to stop the train.

If the train enters at 30mph and never brakes (triangles), the flagman should blast the horn at least 25sec before impact with the work area. If the train enters at 60mph and never brakes (crosses), the flagman should alert the workers at least 7 seconds before impact.

AFS Requirements

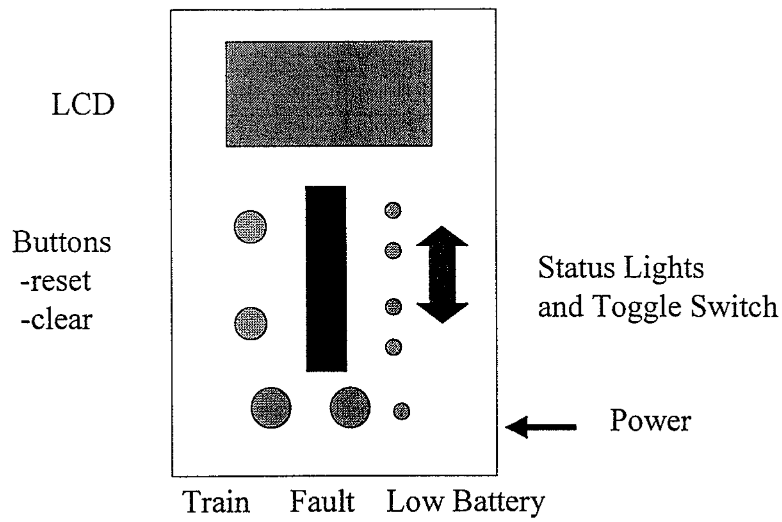
- Size, horn, flag, lights, trip staff, HHU, BIT
- Train Sensing [Detect and Classify]
  - >1000ft = 90%
  - 600ft-1000ft = 99.9%
  - FAR = <1 per 100hrs [5min/train]

The AFS Requirements Document has been generated. It details a functional description of the AFS and details the particular specifications and requirements. The document (still being developed) has been reviewed by the CTA and by the prototype design team.

The objective of AFS is to duplicate the duties, actions, sensing, and signaling of a CTA rail system flagman. The standard duties include operation of lights, flag, horn, and trip staff in response to sensing the status of a train in the area and in response to commands from the work crew foreman. The purpose of the AFS is to provide traffic control for improved safety of the work crew.

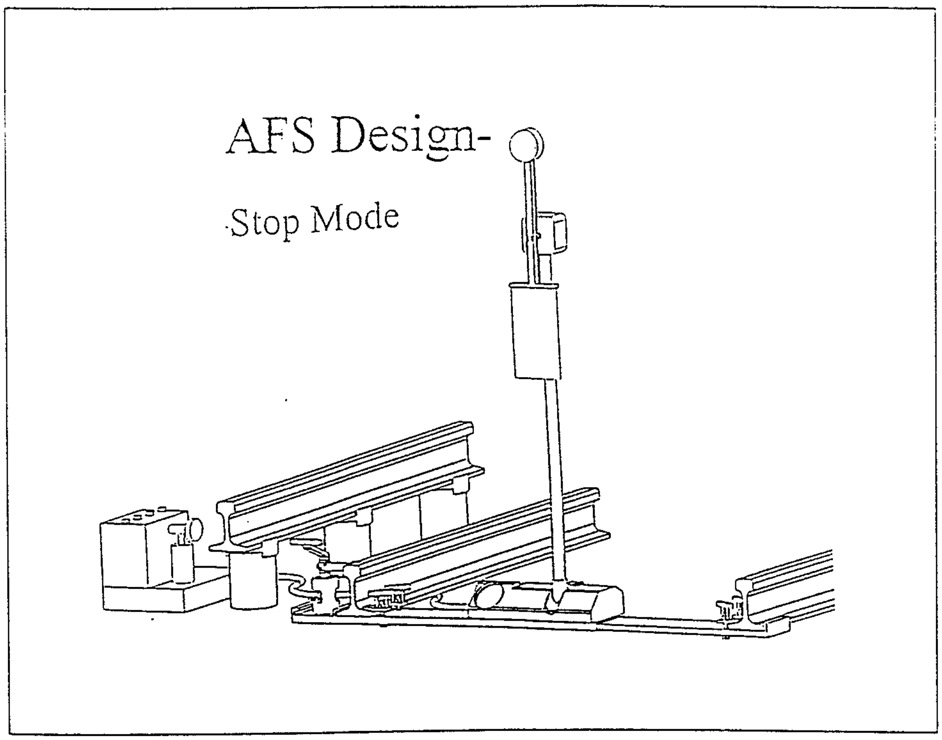
A single AFS includes the Automatic Flagging Mechanical Unit (AFMU) and a Hand Held Unit (HHU). The sensor processor will detect and classify trains 90% of the time in excess of 1000ft and with certainty before 600ft. The false alarm rate will be less than 1 per 100 hours of operation.

Hand Held Unit



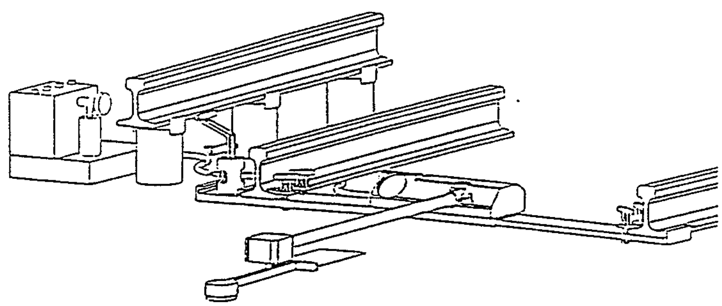
The HHU is designed to allow remote operation and communications while wearing gloves. A recessed power switch activates the unit. A low battery indicator and a fault light (together with the display panel) provide system status information.

The red lights will flash indicating AFMU is in Stop Mode. When a train is detected, the visual and audible signals notify the foreman. In an emergency the red light glows steady. When the track is clear the foreman must hold the toggle switch and depress the button to place a single AFMU in Slow Mode. If the foreman does not reset the AFMU within a sufficient interval the unit will signal automatic reset to occur.



The Stop Mode is the default configuration of the AFMU. In the Stop Mode the trip staff is in position to automatically brake a train, if necessary. Also, the red light and flag are over the center of the track and oscillating. When a train is detected a long blast of the horn is emitted. In an emergency the oscillation is more rapid and continual short blasts of the horn are emitted. At the command of the foreman the AFMU sets to the Slow Mode.

AFS Design-Slow Mode



Upon the command from the foreman the AFMU sets to the Slow Mode. The pole with the red light and flag folds towards the train, and only the clear light is visible. At the same time the trip staff rotates away from the rail to not switch on the train brakes. If the mode has not been not reset once the train has passed and sufficient time has elapsed, then the AFMU will signal the foreman that it is about to automatically reset to the Stop Mode.

FRA Watchmen/Lookouts Regulation

Statement of Regulation-49 CFR 214.329

Train approach warning must be given in sufficient time to enable each roadway worker to move to and occupy a previously arranged place of safety not less than 15 seconds before a train moving at maximum speed authorized on that track can pass the location of the roadway worker.

Waiver Discussion Notes (include BMWE)

4.0 FRA Regulations and HSR

It is believed that the most pertinent portion of the FRA safety regulations is the section quoted above. (The issues for lone workers will be further discussed during stage two.) In addition to the establishment of procedures and training, the regulation defines the requirement for detecting a train and successfully signaling the work crew.

In the prior discussion examples of timings for the CTA Slow Zone were illustrated. Also, the CTA work areas have the benefit of a trip staff to provide a fail safe resource.

The regulation addresses watchmen/lookouts and not flagmen. Most often the watchman is assigned the duty of alerting the workers of the approach of a train and not traffic control. The train proceeds at its designated speed and workers must move safely off of the tracks.

In the statement of the regulation handed out at the panel meeting it was indicated that the FRA stated a willingness to be informed of technologies to automate this function. However, the technology must be shown to be reliable and effective.

HSR Flagging

Speed of Train [mph]	Distance traveled in 15 seconds [ft]
30	660
60	1320
90	1980
120	2640

The above table serves to illustrate the detection and classification distances required to provide the 15 seconds once at the safety location. Additional warning time (distance) must be provided to allow the crew to remove equipment and themselves from the track. It can be seen that distances are in excess of 1/2 mile for trains at 120mph.

AFS and HSR

1. Applicability of AFS for non-transit systems?
2. Applicability of AFS for HSR?
3. Issues:
   - Automation of mechanical functions
   - Automation of signaling functions
   - Automation of sensing functions
     - -train induced rail vibration sensor
     - -other technologies
   - Attentiveness/reliability
4. Applicability of Automatic Flagging Aid
   - Advantages
   - Disadvantages

The flagging function includes the mechanical and signaling functions as well as the train sensing (detection and classification) function. In previous presentations to the TRB the use of train induced vibrations was discussed. Broad band energy (including transients) provides detection information as well as a combined range/speed parameter. It was also shown that narrow band information provides an additional speed measure. Potential concerns related to rail features (e.g. insulated rail joints and switches) were discussed. It was stated that more research into the potential of vibrations for flagman or watchman sensing was needed.

Other technologies may be available to assist in the train sensing function. A recommendation was made by a CSX watchman to provide the sensing function via point sensors ahead of the watchman and communicating the information to the watchman. The possibility of a real or robotic flagman with remote sensors will be explored more fully in stage two.

Panel Membership

• Chuck Taylor	TRB	202-334-2065
• Christopher Schulte	FRA	202-493-6251
• Bea Hicks	WMATA	202-962-1106
• Alan Lindsey	BNSF	817-352-1133
• Howard Moody	AAR	202-639-2202
• Mark Dundovich	Consultant	847-803-2616

<u>5.0 TRB Oversight Panel</u>

The attached list are the members of an oversight panel. The panel will meet periodically to provide review and guidance to the development.

At the first meeting Mark Dundovich and Alan Lindsey were not present. Michael Cardinale (VP of Engineering, Raven) and Keith Gates (TRB) were present.

For future convenience:

James J. Genova	libbajim@gte.net
Michael Cardinale	cardinalem@raveninc.com
Bea Hicks	bhicks@wmata.com
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Summary of Panel Comments

.Automatic Flagging System

- .Project Overview and Status
- .Chicago Transit Authority Slow Zone
- .AFS Requirements and Design
- .Project Plans

.FRA Regulations for Flagging

- .FRA Regulation Statement and Review Discussion
- .High Speed Rail
- .Application of the AFS Technology

Discussion

A brief summary of the open discussion and action items follows.

Mr. Moody pointed out that the all metal AFS would electrically shunt the rails and the speed signals to the train. This would be interpreted in the cab as a stop command. [Dr. Genova confirmed this with John Blum of the CTA. Corrective action has been taken.]

It was stated that a safety analysis should be performed to address the belief that AFS will be as safe or safer than the flagman and present procedures.

It was requested that a fault tree be developed for the AFS to identify potential failure modes.

It was stated that if more data is required to explore applicability to other rail systems (e.g. HSR) that the need should be quantified and identified to TRB and AAR. The TCRP may be interested in the project.

The test plan should be forwarded to the panel as soon as it is available.

The session resulted in a very useful and informative exchange.

AFS Project Plans

1. Prototype fabrication
2. Test planning
3. Field testing
4. Insurance issues-continue
5. FRA regulations-continue
6. HSR applications-continue

6. Stage 2 Plans

During the next several months the prototype will be fabricated and bench tested. At the same time the test plan will be written. Also, simulations will be used to develop and test the sensing algorithm and system performance.

At least two months of field testing are planned during stage two. Testing will include performance, reliability, safety, and human factors issues. After the testing, the system will be upgraded, and a second unit fabricated for full (two direction) AFS testing. A demonstration is planned in Chicago during the second panel meeting. It is expected that this will occur during June, 1999.

During stage two, the insurance, FRA, and HSR issues will be further investigated.

APPENDIX

Automatic Flagging System

Progress:

Data collection
Data were collected at the Chicago Transit Authority (CTA) using a digital recording system and acoustic sensors. The main purpose of the test was to determine the transmission of train generated sound through the tracks, track joints, and track bed. The intent was to spend one day to collect raw data to provide a basis for noise background in the track and the train noise (signal) for the improvement of algorithms. Two channels were used, however, only one functioned properly.

Data were collected for the following track configurations:

1. Jointed Rail
2. Insulated Joints
3. Welded Rail

Data were collected using regularly scheduled CTA trains, which included "Express" (through trains), and " Local" (Trains stopping). Ten data sets were collected:

1. Jointed Rail Local
2. Jointed Rail Local
3. Jointed Rail Local
4. Jointed Rail Express (discarded)
5. Jointed Rail Express
6. Jointed Rail Express
7. Insulated Joint Express
8. Insulated Joint Express
9. Insulated Joint (discarded)
10. Welded Rail Local

All of the data from this test have been reduced, and data for runs 5 and 6 have been analyzed.

The analysis for the CTA shows that the ambient noise energy density in the track is about 10 to 20 pJ Hz^{-1} with several high energy noise spikes. (The causes of the spikes are currently unknown.)

Data Analysis
For the CTA four car train unit traveling at 35 mph, the signal becomes clearly visible above the noise energy when the train is 650 to 1000 feet from the sensor. At this speed, the detection time is about 13 to 20 seconds before the train arrives. The detection is with an non-optimized sensor and unaided by any algorithm, which is expected to increase the detection time by about 50%.

Technical Status
Two improvement will be implemented. The sensor noise floor can be increased to reduce the probability of false alarm in the receiver operating characteristic. An adaptive filter can be applied to the received signal to improve the signal to noise ratio (SNR).

We also believe that high speed rail will generate greater noise signals because of the increased speed and weight of the trains.