106

U.S. Department
of Transportation

**Federal Railroad
Administration**

Interim Report: Screening Tests of Alternative Grade Crossing Detection Technologies

Office of Research and
Development
Washington, D.C. 20590

DOT/FRA/ORD-

May 1998
Final Report

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May 29, 1998
CON/ERW/98-037

Mr. Manuel Galdo, RDV-31
Contracting Officer's Technical Representative

Federal Railroad Administration
Office of Research & Development
400 Seventh Street, S.W., **Mail Stop 20**
Washington, DC 20590

Subj: **Summary Report--** Grade Crossing Prototype Presence Detection Devices

Refr: Contract DTFR53-93-C-00001, **Task Order No. 106**

Dear Mr. Galdo:

As the follow-on to the draft version mailed to you by Mr. Reiff on March 12th, forwarded is the "camera ready original" and two (2) copies of the subject report titled *Interim Report: Screening Tests of Alternative Grade Crossing Detection Technologies*. Mr. Reiff, TTCI's Project Manager for this task order, has informed me that this report is intended to meet the deliverable requirement of paragraph 5.2 -- Summary Reports, of the September 11, 1996 revision to the SOW.

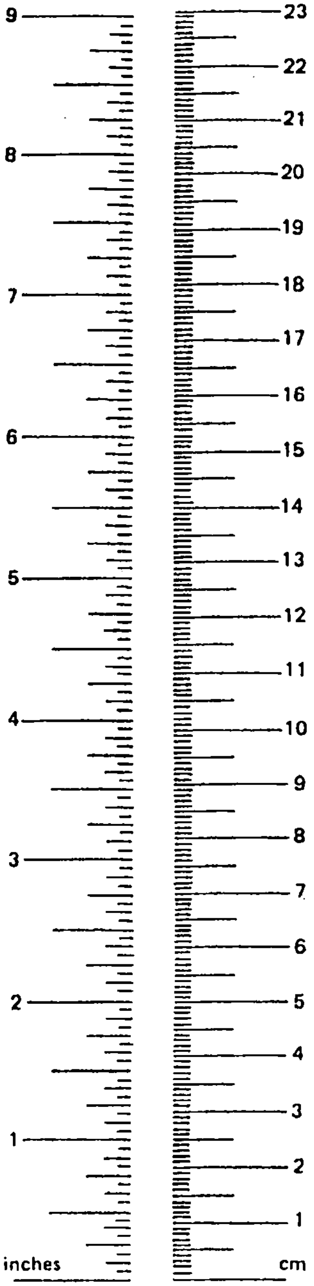
Sincerely,
TRANSPORTATION TECHNOLOGY CENTER, INC.
Edward R. Walsh

cc: G. Spons, RTC-01
R. Spratling, RAD-30
M. Fateh, RDV-31
K. Hawthorne
K. Laine
R. Reiff

METRIC CONVERSION FACTORS

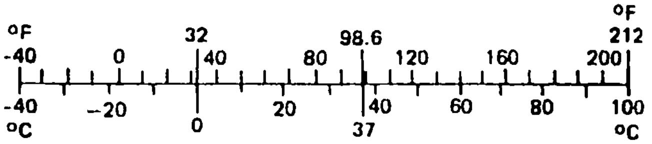
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
		MASS (weight)		
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
		VOLUME		
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0 76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
		AREA		
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32	Fahrenheit temperature	°F



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* 1 in. = 2.54 cm (exactly)

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16. Abstract

Eight grade crossing island detection technologies designed to eliminate problems associated with loss of shunt were evaluated by engineers at Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads, Pueblo, Colorado. Performance of these alternative technologies was compared to that of a standard track circuit and an independent sensor. Conventional track circuits can be susceptible to non conductive films on rails and wheels resulting in unreliable shunt and operation of crossing warning devices. Alternative technologies, which include enhanced track circuits and non-contact sensors, are designed to determine when a train occupies and departs the grade crossing island limits. Screening tests conducted at the Transportation Technology Center were designed to evaluate the effect of parameters such as train switching, speed, wheel load, induced electrical ground return current, and other items on the reliability of these alternative technologies. Three technologies were ultimately selected for field reliability testing.

17. Key Words

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EXECUTIVE SUMMARY

Improved reliability of grade crossing shunting will result in a more reliable operation of grade crossing warning devices. Existing grade crossing island circuits are utilized to determine when a passing train departs the immediate vicinity of a grade crossing and release the warning system within 2 seconds. These conventional track circuit based systems can be susceptible to films on the rail and wheels, which can result in premature release of warning devices before the train departs the crossing limits. Time delays or other filtering of train presence signals could result in unacceptable delay to the public after the train has passed. Results of recent screening tests of eight technologies indicated that two enhanced track circuit designs and at least one count in/count out technology exhibited performance of sufficient reliability to warrant installation at field sites for long-term monitoring and reliability testing.

The Association of American Railroads' Signal Technical Advisory Group (Signal TAG) reviewed technical proposals from 12 vendors offering alternative detection methods, and selected 8 for screening tests to be conducted at the Transportation Technology Center, Pueblo, Colorado. Technologies were selected based on technical merit and susceptibility to parameters affecting conventional track circuits, such as ability to circumvent films or other parameters inhibiting shunting.

The eight technologies selected included detection systems based on magnetic anomaly devices, radar, enhanced track circuits, and count in/count out detectors using both magnetic wheel counters and strain gaged rail. Each technology was evaluated after going through a number of screening tests to determine its reliability and susceptibility to outside influences. Typical train operations including high speed, switching, stop and change of direction, with a variety of wheel loads, were operated over a simulated grade crossing. Detection and release times for each alternative technology were compared with an independently measured occupancy time to determine system operation. Outside influences that might exist at a crossing site were also applied to determine what might influence and cause a system to misinterpret the entry or exit of a train. These incorrect interpretations were classified as a failure to release or failure to arm, and submitted to the Signal TAG for review.

Three systems were selected by Signal TAG as performing with sufficient reliability for installation at three field sites and observation for long-term reliability and accuracy. These field tests are ongoing as a continuation of this task order.

TABLE OF CONTENTS

1.0 INTRODUCTION

The evaluation of alternative technologies that accurately detect trains within the short 120-foot island length of a grade crossing was undertaken by the Association of American Railroads' Transportation Technology Center (now known as Transportation Technology Center, Inc., a subsidiary of the AAR). The exact time a car enters, occupies, and departs the island limits is important to allow prompt release of grade crossing warning systems to avoid unnecessary public delay at grade crossings.

Between 1994 and 1995, the Federal Railroad Administration, under Task Order 106, sponsored screening and field tests of alternative technologies in control circuits. Results indicated that field reliability of several potential technologies was not acceptable for extended use (FRA/ORD Limited Distribution Interim Report, 1993: "Influence of Contact Patch Resistance on Loss of Shunt," by Howard G. Moody, Richard P. Reiff and Scott E. Gage). However, with further development, many of these technologies showed promise. Therefore, vendors were given an opportunity to evaluate and assess failure modes, and upgrade and improve their respective technologies for a second series of screening and field evaluations, as recommended by AAR's Signal Technical Advisory Group (TAG). Other accepted new technologies could also be included in the second test series.

2.0 SELECTION PROCESS

Selection of technologies was conducted by AAR's Signal TAG. A performance specification was updated from the first test series and is included as Appendix A. The selection process including the following steps:

1. The performance specification was sent to all previous participants and vendor representatives expressing an interest in improved grade crossing technologies.
2. Vendors were requested to submit a technical proposal addressing issues stated in the specification.

3. The TAG membership reviewed each proposal for technical merit, selecting those which addressed performance specifications for further discussion.

4. Vendors were asked to make a detailed technical presentation and address specific questions.

5. The TAG then selected eight systems for TTCI screening tests.

6. Results of TTCI screening were reviewed and technologies showing successful performance were selected for subsequent field testing.

Ongoing and future activities include:

7. Selected technologies were installed at field locations to determine long-term reliability. These tests are currently in progress (test series II)

8. If both screening and field tests are successful, one or more alternative technologies will be recommended for eliminating loss of shunt occurrences at grade crossing sites.

Upon receipt of 12 technical proposals from vendors, the Signal TAG reviewed each for technical merit. This included the ability to interface with existing detection and island control operating systems. The intent was for the alternative technology to act as a "backup" to the existing island.

The Signal TAG selected the following eight technologies for TTCI screening tests:

1. Overlay circuit providing additional voltage to overcome high impedance of films.
2. Overlay circuit providing high voltage pulses.
3. Count in/count out technology using magnetic wheel detectors.
4. Count in/count out technology using a different type of magnetic wheel detector.
5. Count in/count our technology using strain gage rail for wheel counters.
6. Magnetic anomaly detectors buried in the ballast.
7. A second magnetic anomaly detector system with a different array of sensors.
8. Radar sensors.

Other technologies submitted but not selected by the Signal TAG included:

- Transponder based system
- Infra-red sensors combined with magnetic anomaly
- A proprietary system with operating technology not specified
- A system currently under development and not ready for evaluation

The technical content of these last four systems was deemed insufficient to consider inclusion for TTC screening tests. In one case, the system had failed under previous screening tests and insufficient product development had been shown by the vendor.

3.0 SCREENING TESTS AT TRANSPORTATION TECHNOLOGY CENTER

The eight vendors selected for evaluation were notified by the Signal TAG. A complete operating system was to be provided by the vendors selected to TTCI for installation by June of 1997. This was to be installed at the TTC simulated grade crossing site under the direction of the vendor. After installation, TTCI provided a number of train passes to check out the system and verify operation. Once completed, no additional adjustments were permitted. In addition to the eight "test" systems, the TTC's conventional grade crossing island circuit and an independent "in/out" detector system for determining train location and island occupancy status was installed. The layout of the test site once all systems were installed is shown in Figure 1.

The independent system utilized automatic location detectors (ALDs) to determine the physical location of the head and rear of each train, thus providing additional information as to entrance and departure times. The screening tests consisted of a number of test matrix run conditions (Section 3.1) using a variety of train consists (Section 3.2) to determine if any operating condition was not properly interpreted. These operating conditions included a variety of train speeds, directions and switching moves, all of which could be encountered in revenue service.

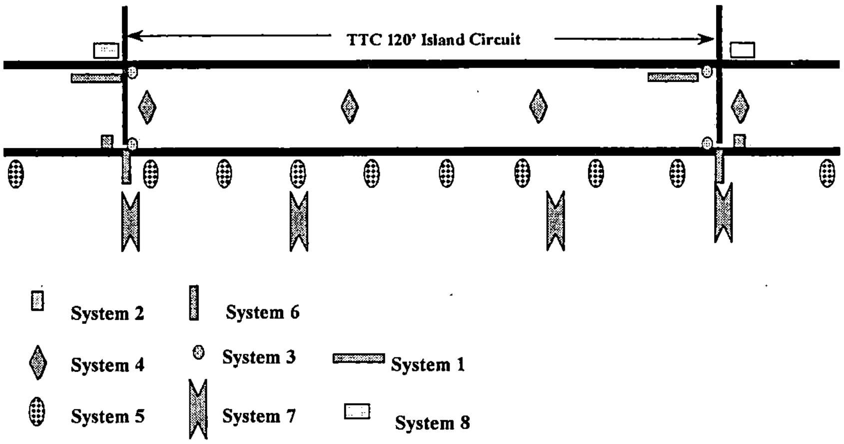

Figure 1. Test Site Layout

In addition to the standard train moves, some technologies could be susceptible to outside influences. This might include induced voltage in running rails, vehicles parked or moving near the track, flat train wheels, or other periodic conditions. The test plan and Signal TAG specified the test conditions for evaluating the new technologies. During the screening tests TTCI engineering staff observed conditions that should be investigated further and added some additional test parameters. Some of these parameters caused a few of the technologies to malfunction. These are summarized in the results section (Section 3.4).

3.1 RUN CONDITIONS

Table 1 is a matrix grouping of the objectives for each test series.

Table 1. Matrix Groupings

Matrix	Objective
1	Baseline runs, no braking, speeds from 2 mph to 70 mph
2	Optional repeat runs with island circuit enhancement on
3	Stopping, starting, backing and switching moves
4	Contaminated rail sequence for creating loss of shunt
5	AC traction locomotive runs
6	Induced ground return current into rails
7	Additional runs and conditions selected in the field based on results of other runs, availability of special equipment, track maintenance, etc.

Each test matrix included a series of passes to provide repeatability data. Multiple passes (up to 5) were made for each speed and condition. For most tests, the baseline (conventional) island system operated with no shunt assisting (enhancement) circuit on. The enhancement circuit was turned on only during selected matrixes. A complete breakdown of each test matrix is found in Appendix B.

3.2 TEST CONSISTS

The orientation of the test consist was such that the primary direction for forward moves was clockwise around the Railroad Test Track (RTT). This allowed train acceleration to be aided by the downgrade profile of the RTT north of the test site. The primary consist for the test was as follows. One locomotive and 26 cars were included in the primary consist.

1	GP 40-2 locomotive
5	Loaded 100-ton hopper cars
5	Loaded 5 unit 100-ton aluminum coal hoppers with solid drawbar
5	Empty 5 unit articulated spine car

5	Empty 100-ton hopper cars
1	Loaded 100-ton covered hopper
1	Loaded 100-ton tank car
1	Empty box car
2	Loaded 100-ton hopper cars - flat spots on wheels of axles 1 and 4
1	Empty 6-axle flatcar

3.3 INSTRUMENTATION AND DATA COLLECTION

Data was collected at a sample rate of 20 Hz and stored on a computer located in a wayside bungalow located next to the test zone. Table 2 shows channels used for data collection.

Table 2. Channels

Channel	Description
1	ALD sensor - east
2	ALD sensor - west
3	System 1
4	System 2
5	System 3
6	System 4
7	System 5
8	System 6
9	System 7
10	System 8
11	Conventional island circuit
12	Island circuit voltage
13	Motion sensor

Each system in test, except System 3, was given an approach warning signal from the motion sensor. This was a requirement from the Signal TAG to keep them from activating when no train was approaching.

ALDs were located track side at each end of the island limits. The ALD system was set up as the baseline system and provided exact timing for the train entering and exiting the island limits. This provided an independent island-occupancy system against which all other systems in test could be compared.

All systems in test plus the conventional island circuit were monitored using transistor/transistor logic (TTL). TTL is a simple "on/off" type of logic. The systems in test gave a 5-volt signal when no train was occupying the island and 0 volts when a train was occupying the island (or vice versa). Each vendor was responsible for providing the signal either directly or through a relay. All systems were keyed to the same time code and performance rated on the delta times between each system and the baseline (ALD).

The primary analysis will consist of island-occupancy time comparisons for each system. Delta times for all systems will be taken from the baseline island occupancy time. When the baseline time is not available for comparison, the delta times were taken from the conventional island circuit time.

3.4 RESULTS OF SCREENING TESTS

Table 3 summarizes testing results of the alternative systems. There was a possibility of interference between similar technologies (i.e., magnetic systems creating a field that might interfere with the other technology). To avoid interference some runs were repeated with various systems disabled.

Table 3. Results of All Alternative Systems Tested

Number of Failures for each run series. Run series listed below table.

	100	200	300	400	500	600	700	800	900
System 1	7	▨	▨				▨	5	
System 2						1**	▨		
System 3	▨	▨		▨			***		
System 4		▨		▨			▨	1	4
System 5	▨		▨	2*	▨		▨		2
System 6	▨		▨		▨		***		
System 7	▨	▨		▨			▨		
System 8	9	▨	▨	15	▨	4	▨		
Total runs	30	30	30	32	32	16	7	14	8

Shaded cells = Not active during series
*Failed when large truck parked next to track while train still in island
**Failed due to "latching" on approach indication
***Conditions for LOS may have been excessive

Run Series
100 - Baseline 1 - Systems 3, 5, 6 & 7 off
200 - Baseline 2 - Systems 3, 4, 7 & 8 off
300 - Baseline 3 - Systems 5, 6 off
400 - Switching 1 - Systems 3, 4 & 7 off
500 - Switching 2 - Systems 5 & 6 off
600 - High Rail/AC Traction Locomotives
700 - Loss of Shunt
800 - High Speed - 80 mph electric transit consist
900 - High current - 5 runs > 40 amps 2 rails/5 runs > 40 amps 1 rail
Each system on for 4 runs

System 1 - Count-in-count-out/magnetic wheel detectors (H)
System 2 - Count-in-count-out/magnetic wheel detectors (T)
System 3 - Overlay circuit (G)
System 4 - Magnetic anomaly (K)
System 5 - Magnetic anomaly (P)
System 6 - Overlay circuit (H)
System 7 - Radar (T)
System 8 - Count-in-count-out/strain gages (S)

Failure, as defined in the table, was noted any time the alternative system displayed a release time over 2 seconds longer than when the train actually departed the island limits. Appendix C 1 through 13 shows the individual data runs for each matrix

4.0 TASK FORCE REVIEW OF TTCI SCREENING TESTS

The following is a description of the systems and the Signal TAG comments on each:

System 1: This system uses magnetic wheel detectors and count-in-count-out logic. It experienced software problems, especially during high-speed runs. The vendor decided to stop testing and remove its system from consideration until a re-test could be performed (at the vendors expense).

System 2: This system uses magnetic wheel detectors with count-in-count-out software logic. Only one failure occurred when a technician in the signal bungalow inadvertently triggered the motion detector, thus arming the system. Once armed, the system detected a hi-rail truck, which is regarded as a failure. Vendor will be advised that it will be essential during revenue service testing to arm the system only when the approach circuits are activated to ensure track equipment does not activate crossing warning system when no train is present.

System 3: This is an overlay type circuit that is activated when the island is occupied and provides additional voltage, intended to overcome high impedance contamination at the wheel-rail interface. Some failures were noted, but only occurred when significant quantities of sand, oil, dirt and other contaminants were placed on the rail. Dropouts that occurred during these runs did not always match the time or duration of the conventional island circuit.

Note: The Signal TAG suggested that during some of the testing of buried magnetic sensors, a large current should be induced into the rails. This was to simulate field conditions where stray ground return currents can be found in rails. TTCI staff initially tried to induce an AC voltage; however, sufficient current could not be safely developed. A DC battery charger was used between the rails and ground to induce up to 43 amps with 12 volts, simulating a severe condition. This caused failure of both magnetic systems, prompting Signal TAG to reject such systems for field installation until further evaluations were conducted

System 4: This system uses magnetic anomaly detectors buried in the ballast along the center line of the track. They detect short-term disturbances in the earth's magnetic field caused by a large mass of ferrous metal such as freight cars and locomotives. This system experienced failures during an 80 mph passenger run and when a high current was induced into the rails.

System 5: This system uses magnetic anomaly detectors. For the purpose of this evaluation, the sensors were buried in the ballast at the end of the ties. System 5 experienced failures when high currents were induced into the rails while a train was occupying the island and when a large truck was parked close to the sensors while a train was occupying the island. Both of these cases changed the baseline magnetic state.

System 6: This is an overlay system that, once a conventional island circuit activates, induces high-voltage pulses into the rails intended to overcome high impedance rail and wheel films. No failures with this system were observed. There was a nearly constant two-second delay between baseline and System 6 train departure times. Signal TAG discussed that the extent of this delay may have contributed to the performance of the system.

System 7: This system uses two types of radar sensors. One is used to detect train movement (approaching and departing) and the other type detects trains and/or cars stopped within the island limits. Alignment of the radar units proved to be critical. The vendor was not able to get the rugged mounting system for its radar units on site in time for testing, so the units were mounted on temporary poles. A ½ degree error in alignment resulted in early/late dropout/release times. To compensate, the vendor insisted that the radar units be mounted 7 feet from the track center. This is unacceptable for most revenue service installations, where a minimum distance of 12 feet from the track center is normally required. The radar units had to be re-aligned during the course of testing due to wind shear and vibration from passing high-speed trains.

System 8: This system uses strain gages bonded to the rail for wheel detection , combined with count-in-count-out software logic. It experienced a number of failures throughout the test. A variable release time, up to 53 seconds depending on train speed, was observed. When a single car was stopped within the island limits, the system would release after 53 seconds if no movement was detected. These problems appeared to be related to a miscount of wheels in and out, resulting in hang ups or pre-mature island releases.

After reviewing the data and results, Signal TAG selected three technologies for further evaluation in extended field tests. These three systems were:

1. Overlay circuit providing high voltage assistance
2. Overlay circuit providing high voltage pulses
3. One of the count in/count out technologies

Note: Due to possible interference between the two overlay circuits, field testing would include installing both systems at all sites; however remote activation would be used to operate only one of the two systems at any given time. Thus each week alternative systems would be activated. Also, one additional count in/count-out magnetic wheel sensor technology was to be considered if vendor re-testing indicated system failures were eliminated. Re-testing was successfully completed at vendor cost.

5.0 REVENUE SERVICE TESTING

Current information is provided in this report on the technical selection of systems, TTCI screening tests, and test results up until the time of field installation. Another report will be issued upon completion of the field testing phase. Field tests are being conducted currently on the four systems at the following locations:

- Sterling, Nebraska - BNSF
- Columbus, Nebraska - UPRR
- Effingham, Illinois - ICRR

6.0 CONCLUSIONS

Signal TAG's review of the results indicated that the buried magnetic sensor systems failed due to changes in magnetic field from outside sources and/or induced voltages in the return rails. As the TTC site did not incorporate a complete road crossing, a concern was raised regarding field performance of magnetic and radar based systems, as some failures occurred when highway vehicles were parked near the track. As a result, further testing and development of such systems are encouraged.

The other systems that failed appeared to do so from software related issues. Additional development by vendors followed by screening tests would be required before being considered for field testing.

7.0 RECOMMENDATIONS

Three systems passed screening tests and were recommended for field testing. Field testing began in November 1997 (another system passed later and was added in January 1998 to the others being field tested). Several other technologies offered the ability to detect not only train presence within the crossing limits, but the presence of highway vehicles. Such a capability was deemed important in areas where high-speed trains are operating. The ability to warn a train operator of a road crossing that was not clear may be an important issue in the future. In order to properly simulate such conditions, it is recommended that the grade crossing test site at TTC be relocated to an actual road crossing to allow test and evaluation of systems capable of determining crossing status. Although this will increase the cost of screening tests (due to potential need for removing and replacing crossing surfaces), the condition will allow improved simulation of crossing conditions.

APPENDIX A

Request for Information

ASSOCIATION
OF AMERICAN
RAILROADS

January 6, 1997

The Association of American Railroads (AAR) is issuing a Request for Information (RFI), attached, to identify alternative reliable, cost effective systems for train presence detection. Selected systems identified through this process will be tested rigorously by the AAR to determine if any can meet railroad industry requirements for detecting train presence at grade crossings.

If you have a system that can meet the requirements described in this RFI, I encourage you to respond, either individually, or as a part of a larger consortium. As is described in the RFI, the potential market for improved train detection systems is substantial.

Those companies whose responses we consider promising will be asked to meet with the AAR Signal Research Task Force, which is overseeing this project. At this meeting, these companies will be asked to make presentations on their systems, and answer questions from the Task Force. Written questions may also be provided to you in advance of the meeting.

Complete information about responding to the RFI is included in that document. Responses are due by February 28, 1997. Any questions should be directed to Tom Guins at the AAR Research and Test Department [202 639-2258, fax 202 639-2285].

Yours truly,

John T. Sharkey/TSG

John T. Sharkey
Illinois Central Railroad
Chairman, Signal Research
Task Force

Attachment

cc: Signal Research Task Force

Research and Test Department
50 F Street, N.W., Washington, D.C. 20001 (202) 639-2240

Request For Information

Grade Crossing Train Presence Detection

Association of American Railroads

January 1997

1.0 PURPOSE

On behalf of the North American railroad industry, the Association of American Railroads (AAR) is issuing this Request for Information (RFI) to identify and evaluate safe, reliable, cost-effective alternatives for train presence detection at highway-railroad grade crossings. Potentially, a reliable, cost-effective detection system identified through this process could also be used in other applications, such as alternatives to conventional approach circuits forgrade crossings and track circuits for train control. The primary objective will be to evaluate prototypes of technologies that are compatible as a retrofit or enhancement for existing grade crossing detection installations. Consideration will be given, however, to complete, stand alone systems, on a case by case basis.

Reliable train presence detection systems are essential to activate and control warning systems at grade crossings to warn highway motorists and pedestrians of trains approaching and occupying the grade crossing. There are approximately 60,000 gradecrossings in the U.S. with active warning devices. Approximately 2,000 - 3,000 active crossing warning systems are newly installed or upgraded each year.

Shunting of track circuits has provided a means of detecting train presence since the basic DC track circuit was invented in 1872. It is still the principal means of train presence detection, and is used world-wide, with some variations to enhance performance. These variations include AC track circuits, and DC coded track circuits.

As other technologies, such as transponders, have become more reliable and less expensive, they are gaining increasing use internationally for detecting train presence in a variety of applications, including grade crossing warning systems. Such alternatives for detecting train presence may also be used to supplement track circuits to improve performance.

Refer to the Appendices for additional background information about crossing warning systems and train presence detection.

2.0 PERFORMANCE GOALS

AAR is seeking information on safe, reliable, cost-effective alternatives to detect trains within standard island limits (120 feet to 300 feet) at highway/rail grade crossings. The intent is to select the most promising systems for test and evaluation. However, AAR does not guarantee that any system will be selected for evaluation or testing.

Following is a description of the performance goals for these systems.

2.1 Functional Requirements

The train presence detection system shall be capable of detecting the presence of a train of any configuration in any situation, within the parameters of the operational environment, as described below. The system shall be capable of communicating the detected train presence to a grade crossing warning device. The preferred configuration will allow existing systems to interface with proposed technologies. Installation must permit new technologies to be placed within 2 feet of existing island limits. Further, the system shall be capable of determining when the train has left the specified area and communicating that information to the warning device.

2.2 Operational Environment

2.2.1 Detection Zone

Trains must be detected immediately upon entering island limits, and release immediately upon departing the island limits, regardless of train direction, or change in direction. The minimum length of the detection zone is 120 feet.

2.2.2 Track Structures

A wide variety of track is in service, which must be accommodated by the train presence detection system. Variations occur in types and quality of ballast, ties, rail, and associated hardware. Island limits may be at or near mechanical track joints, which utilize angle bars and bolts. The presence of gaps at rail ends must be considered. These properties may affect the electrical resistance (impedance) of particular track. Variations in rail profile also affect the wheel/rail contact patch.

Contiguous multiple crossings may be present in an area where simultaneous operation is required. Proposed systems must be able to operate within four hundred feet of another crossing, equipped with either similar technology or conventional track circuits.

Multiple, parallel tracks may also be present, at track centers of as little as 11 feet. In addition, turnouts, crossing frogs and other components may be placed within 5 feet outside of the island limits. If auxiliary approach circuits are needed for the alternative technology, these circuits must operate when nearby turnouts are set for either mainline or diverging directions.

Reference the American Railway Engineering Association's Manual for Railway Engineering for more detailed information on track structures. The Association of American Railroads Communications and Signal Division's Signal Manual provides additional details in Section 3.1.20 on related electrical issues.

2.2.3 Train Consist Characteristics and Speeds

Characteristics of trains or cars that need to be detected vary greatly. The trains range from long, slow bulk commodity trains to short high speed trains. Detection must accommodate freight trains operating as fast as 80 miles per hour and passenger trains operating as fast as 110 miles per hour. Detection and operation during slow train passage is also required. Slow speeds of less than 2 mph, along with stopping, starting, and change of direction must be accommodated. Additionally, the system must detect the presence of a single car standing or moving in the crossing. Train consists may accelerate or decelerate at rates up to 3.2 feet per second per second. Consists may enter the detection zone and leave the zone via the point of entry, or stop for any length of time up to 30 minutes, then proceed.

Trains may be as short as 40 foot single-unit switching locomotives or a cut of one or more cars. They may be as light as 5,000 pounds per wheel for empty aluminum coal cars or innovative intermodal equipment. (These assumptions do not consider trends towards future lighter axle loads or the presence of hi-rail and similar maintenance-of-way equipment.) Equipment that is intentionally insulated, such as certain work or hi-rail vehicles, will operate over the island, and in some cases be "set-off" and removed without making a compete pass through the island limits. These types of equipment will not provide an approach indication from conventional grade crossing systems.

Axles may be spaced as far apart as 70 feet. Some equipment may have split-axle designs, which may raise wheel-to-wheel shunting impedance substantially. However, in most cases, the wheel/axle/wheel DC resistance is a maximum of 50 micro-ohms. Any mix of equipment types may be found in any given train consist. Car shape and physical profile may very, with both fully loaded and empty flat and spine cars, high or low floor cars, and a variety of paint, materials and surface finish color on car side surfaces.

Variations in wheel profiles also occur, due to variations in both design and wear. Also, wheel flats may occur on random cars. Impact loads of 90,000 lbs from flat wheels will be encountered (this limit will vary with changes in AAR interchange standards), however occasional impacts exceeding 100,000 lbs can occur.

2.2.4 Highway Traffic Operational Requirements

While safety is the highest priority, delays to highway traffic due to activation of grade crossing warning devices must be minimized. In general, systems should not maintain activation of highway gate/signal operation more than two seconds after trains have cleared island limits.

2.2.5 Environmental Conditions

The equipment detection system must operate in the range of conditions found throughout the North American continent. These include shock and vibration and extremes of weather (temperature, lightning, precipitation, ice formation, etc.). A wide range of environmental contaminants is also present at various roadbed locations, including spilled lading (e.g., coal dust, iron ore dust, taconite, chemicals, grain), leaves, sand, mud, diesel fuel, greases, iron oxides, and highway salt.

The Association of American Railroads Communications and Signal Division's Signal Manual provides additional details in Sections 3.1.20 and 11.5.1.

2.2.6 EMI Susceptibility

Installations may be subject to electromagnetic fields from radiated and conducted emissions. Guidelines for the limits on the electric field strengths encountered may be obtained from ATCS Specification 110, "Environmental Requirements," Revision 3.0, March 1993.

2.3 Interface with Grade Crossing Warning Devices

Not more than two seconds may elapse between the exit of the train/car and a signal sent to the warning device indicating no occupancy.

The ability to interface with existing grade crossing equipment is desirable. Since there are multiple types of existing grade crossing devices, and no standard electrical or logical interface, this ability is not a requirement for responding to this RFI. However if there are specific interface limitations, or the system will not interface with existing equipment, these limitations must be clearly stated. Alternative means of approach detection must be provided.

Current grade crossing warning systems are capable of operating using a backup low voltage power supply, since a backup power source of all systems is required by law. Proposed equipment must be able to self reset or otherwise recover and operate properly, without excessive downtime, from power supply failures or other interference.

2.4 Reliability

Reliability of the train presence detection system is critical to the reliable operation of the crossing warning system. The highest achievable reliability is desired.

Reliability will be monitored by determining occurrences of:

* failure to release after train departure
* failure to detect a train
* false or premature release while train is still within island
* late detection of train entering island limits
* intermittent release and re-detection (loss of shunt)
* variable release times

These errors will be compiled and expressed in terms of occurrences per 1000 trains. However, the duration of failures is also significant and must be considered, since longer-duration failures are usually more critical than shorter ones.

2.5 Maintainability

The system shall be capable of being promptly maintained by railroad signal forces. Tasks included are fault diagnosis, fault isolation, removing and replacing necessary components, and performance verification testing. Built-in diagnostics may be helpful in meeting this requirement.

2.6 Costs

As is generally the case, systems that have a lower life-cycle cost will be preferred, other factors being equal. This is particularly relevant because of a desire to implement the solution at a maximum number of crossings in a relatively short time period.

3.0 INFORMATION REQUIRED

Suppliers with systems that will meet the requirements summarized above are requested to respond to this RFI by providing the following information.

3.1 Proposed Solutions

3.1.1 Description of Proposed System

Provide a summary functional description of how the proposed presence detection system will operate. This description should be no more than one page of narrative plus any supporting illustrations, graphics, or photographs.

3.1.2 Current Status of Proposed Solution

3.1.2.1 Current Installations

Please state where your system(s) are installed (one or two examples only), and how long they have been in service (if applicable).

3.1.2.2 Operational Conditions

Please state what the volume of rail traffic is and what the operational conditions are at the site(s) described above (if applicable).

3.1.2.3 Current Performance

Describe the performance of the system(s) described above (if applicable). Include maintainability and reliability (mean time between failures (MTBF) and duration of losses of train presence detection) in your response.

3.1.2.4 Test Results

Include results of any testing that supports your statements describing your system's performance, or that would provide evidence of your system's ability to meet the performance goals discussed in Section 2.

3.1.3 Expected Performance

3.1.3.1 Reliability

Discuss the level of reliability that you project for your system, if different from the current performance indicated in 3.1.2.3, above. Quantify in terms of mean time between failures and duration of losses of train presence detection. Identify the differences between your proposed system and current operational systems that would contribute to the difference in MTBF, if applicable. Also address the tradeoff that is available between reliability and cost for your system.

3.1.3.2 Maintainability

Discuss the level of maintainability that you project for your system, if different from the current performance indicated in 3.1.2.3, above. What will be your system's maintenance requirements? (Specify frequency of repairs, mean time to repair, labor hours, skill level, built-in diagnostics, estimated annual cost per device.)

3.1.3.3 Interface

Describe how your system will interface with existing warning systems (physical/electrical/logical interface - if known). This includes interference with existing approach and island systems.

3.1.3.4 Assumptions

What conditions have you assumed that may affect the performance of your system (e.g. climate, train speeds, train frequency, maintenance)?

3.1.3.5 Susceptibility to Environmental Interference

What is the susceptibility of your system to environmental interference? Specific issues include electromagnetic energy generators, such as AC traction motors and electrical storms.

3.1.3.6 Other Advantages and Applications of Your System

Please address any other advantages or applications of your system For example, could your system be used to provide train presence detection for grade crossing approach circuits, or could it support constant warning time devices? (Constant warning time devices provide the same, fixed amount of warning time regardless of the speed of the train that is approaching the crossing.)

3.1.3.7 Stand Alone vs. Supplemental

The preferred format is for alternative technologies to supplement existing island systems to improve occupancy reliability. This will reduce costs by having the proposed technology utilize existing approach indications, thus acting as a "backup" to the primary island system. In the production application, existing crossing warning systems will remain activated if either the primary or backup island indicates occupancy, thus reducing false releases. On the other hand, any "hang-up" or delay in release of either system will result in the undesirable delay in release of warning devices.

If the proposed technology must be installed as a complete stand alone system with its own approach circuitry (due to the existing island approach not being compatible, and a separate approach signal required), then this must be stated. Task Force review of this technology will be conducted prior to being considered as an acceptable alternative under this program funding.

3.1.3.8 Susceptibility to Vandalism and Damage From Passing Trains

Indicate areas where hardware could be suspectable to vandalism and/or dragging equipment, and how the technology is designed to go "fail safe" should this occur. Also include how system can notify maintenance personnel where damage has occurred. This is to also include damage, blockage or other interference from snow, ice buildup, fog, rain, wind, blowing debris or other contaminants that are part of the field environment.

3.1.4 Schedule and Costs

Indicate when you will be able to provide one or more prototypes for screening and evaluation tests a the Transportation Technology Center (TTC). Provide estimated costs for your system in production quantities. This estimate should clearly state what components it does or does not include. If the prototype successfully completes screening tests at TTC, three prototypes will be required for a 6 to 9 month field evaluation. Availability of these three systems should also be stated, one of which may be the unit evaluated at TTC.

Assume electrical power is available. Specify your systems power requirements, both steady state and peak, and normal operating voltage.

3.2 Capabilities to Develop Solution

Summarize your previous work in this field, including a list of references or customers, and the nature of the system developed for each.

Describe your ability to design and manufacture comparable systems and provide systems integration, and to provide technical support for tests and evaluation.

4.0 SELECTION PROCESS

Responses will be evaluated by AAR based on its examination of the information provided.

AAR will compare the expected performance of each supplier's system with the requirements and performance goals that have been identified in this document.

AAR will evaluate the suppliers' ability to meet the requirements of this effort according to the following criteria:

- Projected reliability of the candidate system;
- Projected maintainability of the candidate system;
- Supplier's adherence to schedule;
- Supplier's provision, installation, and maintenance of equipment for testing;
- Supplier's provision of technical support for testing.

Systems that already have undergone beta testing or have been demonstrated in service will receive preference in the evaluation process relative to those that have not.

5.0 TEST PROTOCOL

The following is a brief summary of the test protocol that will be used to evaluate candidate systems to detect train presence.

5.1 Test Procedure

Suppliers of selected candidate train detection systems shall each furnish a detection system, including a complete technical description, for preliminary testing and screening at TTC. Suppliers would not need to furnish entire warning systems, but only the detection systems that would control the actual island limit warning devices. If the proposed technology cannot interface with standard, existing approach technologies, the supplier will also provide a means of detecting train presence in advance of the test zone in order to turn on the data collection equipment. The output of the detection systems would be recorded during this preliminary testing. At this stage, the detection systems will not be used to control actual warning devices.

The tests will be conducted using a variety of on-track equipment including a train consist composed of a range of freight cars from very light empty cars to very heavily loaded cars and both two- and four-axle cars, work equipment and high-rail vehicles. The train consist will pass the crossing island at speeds ranging from zero to 80 mile-per-hour. A variety of movements, designed to test the limits of the systems, will be used including stopping, backing, switching (including consist changes) and other movements that may be deemed useful for the evaluation of a specific technology.

The data collected will be used to estimate each system's capability to consistently and reliably detect the presence of each car and locomotive in a section of track, and for train movements such as those described above. Once the prototype is installed at TTC, a three stage test procedure will be conducted as follows:

1. A two week checkout and debugging period will be provided. During this period, a limited number of train passes will be provided to assist in the installation process.

2. A one week preliminary test will be conducted. During this period, no upgrades or changes will be permitted. After this test, results for each system will be reviewed with the supplier. Following the preliminary test, a period of approximately two weeks will be allowed for upgrades or changes. After that time, no further upgrades or changes (other than repair of damaged or failed components) will be permitted.

3. A final series of tests will be conducted to fully evaluate the capabilities of the candidate systems. Any equipment failures will be monitored and reported as such. It should be emphasized that no alteration or adjustments will be permitted during this final test series.

If results of this preliminary testing are promising, more extensive testing at three sites around the U.S. may subsequently be conducted. This second phase will encompass testing at sites with different climatic, train operations, train consist, and rail contamination characteristics. All sites have significant traffic volumes so that each detection system experiences a large number of event recordings.

5.2 Data Analysis

Current industry standard track circuit detection systems that are in good functioning order will be used as the baseline for this experiment. The data collected from each candidate train detection system will be compared to this baseline system. The analysis will compare the candidate systems to the baseline system in several categories including:

-- Island occupancy time, the total time the Island relay is activated,
-- Failure to detect (Activate the island relay) a train entering the island,
-- Failure to release after train leaves the island,
-- Premature release or release before the train exits the island,
-- False release (Loss of detection during island occupancy), and
-- Late detection of the train entering the island.

Further, a log will be maintained of all activities related to each system including system problems, human interventions required, maintenance activities, software changes, etc. This log will be used to evaluate the field readiness of each system.

Candidate systems are expected to be at least as reliable as the current industry standard track circuit detection systems. To pass the test at TTC and be considered for field site tests, a system must not fail to detect any train entering the island, must not fail to release after the train leaves the island, must not release while the train is in the island, must have island occupancytimes consistent with actual train occupancy times, must not require a manual system reset following an unexpected event (a high rail vehicle that leaves the tracks in the middle of the island, for example) and must function for the duration of the test. All failures will be reviewed by AAR.

6.0 ROLES AND RESPONSIBILITIES

This project is under the guidance of a joint government-industry task force comprised of representatives from the Federal Railroad Administration, the Federal Highway Administration, and the railroad industry. Task Force members are knowledgeable in such areas as railroad operations, communication and signal systems, train control systems, freight car and locomotive design, track system design and maintenance, and grade crossing safety.

6.1 AAR/Task Force Role

AAR, under the direction of the Task Force, will select systems for test, specify test requirements, arrange for test sites, provide test management,collect and analyze test data, and write the final report.

6.2 Supplier Responsibilities

Suppliers shall provide the information that is requested. Those suppliers whose systems are selected for evaluation and testing shall furnish, install, and maintaintest equipment. Access to field sites for maintenance, repair or adjustments by vendors will be accomplished only after confirmation with AAR personnel, and through coordination with the appropriate field representative. Additionally, they shall provide field engineering personnel during testingto ensure that systems have been installed correctly andare working properly. All supplier representatives will be appropriately dressed with required safety equipment and will be required to attend a safety class at TTC and for each railroad field test site at which their equipment is installed.

It is the intent of AAR to maintain the confidentiality of proprietary information. However, AAR cannot guarantee confidentiality. Therefore, suppliers that wish to protect any proprietary rights, including but not limited to patents, trade secrets and copyrights, are advised that they must take all steps necessary to do so.

7.0 SCHEDULE

- Responses are due by February 28, 1997
- Selection of prototypes for further consideration will be made by March 28, 1997

- TTC Tests will be completed in May-June 1997.
- Field test sites installation, for systems selected, will start August 1997

8.0 AAR CONTACT

Responses to this RFI and any questions about this project should be directed to:

Mr. Tom Guins
Research and Test Department
Association of American Railroads
50 F Street, NW
Washington, DC 20001

Phone 202-639-2259; Fax 202-639-2285

9.0 REFERENCES

1. Moody, H., R. Reiff, and S. Gage, "Interim Report: Influence of Contact Patch Resistance on Loss of Shunt," August 1993.
2. Methods of Improving DC Track Circuit Shunting Sensitivity Report D21.3001, GRS, September 1937.
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5. American Railway Engineering Association, Manual for Railway Engineering, 1994.
6. Association of American Railroads, Communications and Signal Division, Signal Manual, 1993.
7. Association of American Railroads, Advanced Train Control System Specification 110, "Environmental Requirements," Revision 3.0, March 1993.
8. Reiff, R., Garule, S. and Gage, S., “Final Report, Phase 2, FRA Task Order 106, Alternative Detection Systems”, May 1996.
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APPENDIX A

A.0 BACKGROUND

A.1 Grade Crossing Signal Operation

The basic operation of a conventional DC track circuit provides for train presence detection when a train occupies the circuit. The train "shunts" or shorts out the circuit through the vehicle wheels and axles, de-energizing a track relay, which activates the signal or other control device. These circuits are low voltage devices - generally in the 2 volt range. This is required because the resistance of an alternative current path, the tie/ballast structure, is low -- on the order of two ohms per thousand feet. Normally, the wheel/axle/wheel resistance path is very low - on the order of 20 micro-ohms, making it well suited to shunt the circuit.

The signal-controlling track relay is normally energized to provide an indication of an unoccupied track. This provides the "fail-safe" feature of track circuits. If, for some reason, the circuit is interrupted or the power source fails, the relay "drops out," which causes the signal light or warning device to go to its most restrictive mode. A typical track circuit relay picks up (energizes) at 100 milliamperes and drops out at 50 milliamperes. A minimum "shunt" resistance of 60 milliohms must be detected as specified by FRA regulation.

The same principle applies to the grade crossing island circuit, except these circuits can be audio-frequency "overlay" track circuits instead of DC track circuits. This allows the circuit to be used on top of DC track circuits. Higher frequency AC signals attenuate rapidly in rail, eliminating the requirement for insulated joints at the boundaries of the circuit. These circuits are about 110 to 120 feet long, and overlap the highway crossing. The function of the island circuit is to keep the warning device(s), i.e. gates and flashers, active until the last car of the train leaves the island circuit This allows for a very rapid deactivation.

Highway crossing warning systems also have an approach circuit. The long approach circuit, when shunted, activates the flashers and gates to provide suitable (a minimum of 20 seconds) warning of an approaching train in either direction. Once the train is in the island circuit, the island circuit controls the gates and flashers.

The performance of track circuits is dependent upon maintaining the circuit to prevent "wrong side" failures from occurring while also minimizing "right side" failures. A "wrong side" failure occurs when the track circuit is occupied but the control relay is energized, i.e., the warning system is not activated. This is opposed to a "right side" or fail-safe failure wherein the warning system is activated when no train is in the circuit. (See Appendix B for a discussion of fail-safe design concepts as applied to railroad signal systems.)

A.2 Loss of Shunt

Since track circuits operate at low voltages and currents, the effect of highly resistive thin films on wheels and the rail can affect their performance. As the film resistance increases, the likelihood of a loss of shunt increases. Thus, shunting sensitivity is dependent upon the ballast resistance, the rail and wheel surface condition (i.e., film resistance, wheel/axle/wheel resistance and contact pressure). Several European, North American and Japanese studies are referenced in the "Interim Report: Influence of Contact Patch Resistance on Loss of Shunt." These studies have identified the principal cause of the loss of shunt as films on the wheel and rail, which exhibit the characteristics of a semi-conductor.

These films are usually composed of various oxides of iron, either rust or magnetite (black iron oxide), sand, and small traces of other oxides and carbon. Other external materials such as leaves or lading are implicated in specific cases. Some laboratory tests have implicated films built up from brake shoe materials. At first, lubrication was thought to have contributed to the film make-up, but recent tests (see A.2.1) indicate that lubrication need not be present to have highly resistive films on the rail. However, there may be specific isolated cases where lubrication contributes to film resistance.

The wheel/axle/wheel resistance is negligible. Thus, within the limitations of the track circuit, the film resistance and how that resistance varies with contact pressure become the physical limiting factors for good shunting. This relationship has been known for years, and has resulted in not relying on track shunt for light axle load maintenance-of-way equipment.

The semi-conductor characteristics of these highly resistive films require the film to be "perforated" to allow appreciable current to flow.

An AAR Communications and Signal Division report of data taken from an Organization de Recherche d'Essais (ORE, now European Rail Research Institute) series of reports published in 1963 concluded:

1. The perforating voltage of the shunt path is the sum total of the perforating voltages occurring at each wheel/rail interface.

2. The perforating voltage of the wheel/rail interface depends inversely on the contact pressure.

3. The perforating voltage depends on the relative humidity of the air. In the ORE tests, the perforation voltage using a 50 hz sinusoidal current was cut in half in damp weather as opposed to dry weather.

4. When a wheel is moving, electrical contact between the rail and wheel is continually being created and destroyed.

The effect of humidity on the circuit performance may be countered by the overall circuit performance in wet versus dry conditions. As the ballast resistance goes up in dry conditions, the current in the track circuit goes up, potentially improving the shunting performance of the circuit. The effect of humidity may be an artifact of the circuit design, not any fundamental change in the perforating voltage requirements.

A.2.1 Findings to Date

A measurement program begun by the Association of American Railroads and the Federal Railroad Administration in 1992 and completed in December 1993 included a major data collection program with audio-frequency island circuits at several revenue service sites where loss of shunt was known to have occurred and at AAR's Transportation Test Center. Auxiliary sites were established at some of these revenue service sites. These auxiliary island circuits were set up adjacent to the island circuit at the grade crossing, with all the functionality of an island circuit except they did not control any gates or flashers. These auxiliary circuits were placed within 100 ft. of the functioning island circuit. The purpose was to enable train-by-train comparisons of the responses of the two adjacent circuits.

Each field site was equipped with a data collection system. The data system recorded the output or receiver voltage and the status of the "island drive relay." The island drive relay controls the active warning devices, i.e., the gates and flashers. Severe loss of shunt resulted in the activation or "pick up" of the island drive relay, resulting in a momentary deactivation of the warning system.

Please refer to the "Interim Report: Investigation of Contact Patch Resistance on Loss of Shunt" for a detailed evaluation of the data collection.

A.2.1.1 Results

Results of the field tests showed some shunt loss at each of the field sites. A few of these events caused the island drive relay to pick up, indicating a possible deactivation of the warning device. Of 42,048 trains measured over the sites, 127 or .30% had an occurrence of island drive relay pick up. The number of occurrences and their duration varied considerably from site to site, suggesting that site specific conditions exist, either physically or electrically. Because loss of shunt was known to have previously occurred at these sites, these data are not necessarily representative of all in-service sites.

An analysis of the longest duration event in each of the 127 occurrences of island drive relay pick up was conducted. Approximately 72% of all occurrences were less than one second in duration, with the maximum duration event of 17 seconds.

Since the total shunt resistance includes the resistance of the wheel/axle/wheel resistance, wheel/axle/wheel resistance data were taken on 140 wheel samples. The wheel/wheel resistance data indicated that the actual resistance is at most 20 micro-ohms, negligible for this analysis.

A.2.1.2 Wheel and Rail Resistive Films

Rail samples and film samples were removed from the field sites for film analysis. The result of laboratory measurements showed that:

1. There was a presence of a highly resistive film on the rail surface, but no film at the "normal" contact patch in the center of the rail.

2. Material in the resistive films was sand and iron oxides. Small traces of other oxides and carbon were detected. There was little variation in the material makeup from site to site. There was variation in the thickness and location of the films on the rail head.

These data suggest that the film on the rail head varies in extent and thickness across the rail head, and that wheels running off the normal contact patch may be more likely to cause loss of shunt. Also, the materials in the film are ordinary products: rust, magnetite (a normal byproduct of the contact between wheels and rails), and sand either from external sources or used to provide tractive effort. Sanders are required by Federal regulation on all locomotives.

A laboratory test was conducted to examine the relationship of axle load to film resistance. This test showed an inverse relationship between electrical resistance and load. This relationship could be expected as well in the field. The relationship appears to be log linear and monotonic.

APPENDIX B: EXPLANATION OF FAIL-SAFE DESIGN CONCEPTS

This appendix explains some of the major design concepts of safety circuits in "laymen's terms". The intent is to help those outside the signal industry understand the philosophy behind signal design.

FAILSAFE DESIGN, RELIABILITY, AND PROBABILITY

The theory behind failsafe design is to create systems and equipment in such a way that all possible failures will cause the system to be placed in its safest or most restrictive state. In the case of crossing warning systems, for example, if anything happens that would prevent the equipment from detecting an approaching train, the warning system should be activated to alert the public that the detection devices are not properly functioning. While it is recognized that in an imperfect world, nothing can be made totally failsafe, the concept of acceptance of any probability of a failure that could cause the warning devices to remain inactive (a "wrong side failure") and possibly allow the unsuspecting public to drive into the path of an approaching train has never been accepted. Every wrong side failure is investigated thoroughly. No matter how unlikely the probability of a second occurrence, if any design changes to the system or any component of the system can be made to prevent another occurrence, they will be. This policy has been in operation for over a century. Through it has evolved the remarkably safe equipment we use today.

Reliability of equipment is often mistaken for failsafe. If high quality devices with low probability of failure are used, it is assumed that the chance of a wrong side failure is very slim. It is accepted that reliability of equipment is important. A warning device that is often active even when there is no danger will, like the boy that cried "wolf" too many times, eventually be ignored. There is a constant battle to design a system that is as failsafe as possible without sacrificing reliability. Most of the sophisticated equipment in use today is constantly self-checking all of its components. If any single part is not functioning properly, the crossing will activate. In such a system, the reliability of proper operation is dependant on all of its parts.

In some systems, a "redundant" or backup warning device is designed to take over if the primary device fails any of its self-check tests. While this is done to increase the reliability of the crossing, it has nothing to do with its failsafe operation. The backup device will contain the same self-checking circuits as the primary device. If it also fails to work as intended, the warning system will be activated.

In spite of the use of high quality components, redundant equipment, extensive quality checks and periodic testing in the field, there are still many occurrences of crossing warning devices being falsely activated. The environment in which the equipment operates is very rugged. Lightning, water, vandals, and even vermin will sometimes cause problems. Most of all, though, there are thousands of crossings with warning systems. The more devices there are, of course, the greater the possibility that one or more of them will detect a problem and activate the warning system even though a train isn't approaching. Probably everyone has seen a crossing system operate when it shouldn't. However, very few have seen a crossing warning system not operate when it should. If only reliability and not fail-safety was a concern when the equipment was designed, probability would dictate that many of the false activations of warning devices that presently occur would be "wrong side" failures that would cause the equipment to not operate when it should. The resulting danger to the public would be intolerable.

As an example of non-failsafe signal design principles, assume that we need to provide a very simple crossing warning device. First, we take a section of track that is long enough to provide plenty of warning when the wheels of a train enter it and use insulated joints to electrically isolate it from the rest of the track (see Figure 1). Then, we take a battery and connect one terminal of it to one of the rails. Now, take a wire from the other rail and connect it to one side of the coil of a relay. Finally, we run a wire from the other side of the relay coil back to the other terminal of the battery. If an approaching train passes the insulated joints and runs onto our track circuit, its axles will short between the rails forming a path for the electricity to flow from one terminal of the battery to one rail, through the axles of the train to the other rail. It will then flow through the coil of the relay to the other terminal of the battery and energize the relay (see Figure 2). If the warning system is turned on by the contacts of the relay when it is energized, then the warning will occur whenever a train is coming near the crossing... Unless, of course, the battery goes dead, or one of the wires break, or a terminal or connection becomes loose or corrodes, or a rail breaks close to the crossing, or the relay coil burns out. If any of these things occur, then the warning will not be activated, and the flashing lights will remain dark as the train speeds across the highway.

Of course, we can do our best to "armor plate" the system to make it as reliable and safe as possible. We could use high quality and high capacity batteries with equally good battery chargers. We could use the best terminals and connections and cable and relays that money can buy. We could do all these things, but there would still be some risk.

Probability is accumulative. If the relay works properly 99.9999% of the time (fails after one-million operations), and there is equal reliability in the cable, battery and connections, the probability of the crossing failing is 0.0001% for the battery, plus 0.0001% for each of 6 connections, plus 0.0001% for each of three wires, plus 0.0001% for each rail. The total probability of a wrong side failure is 0.0012%, or about 1 failure every 83,000 operations. If we assume 10 trains a day, the probability is one failure every 8,300 days or every 23 years. This is an extremely reliable crossing. If we add the fact that due to the overlapping of many crossing approaches, timing circuits, cutout circuits to prevent the crossing warning system from continuing to operate as a train goes away from the crossing (tail-ring), as well as many other features that are needed at modern crossings, the 12 components of our simple warning circuit increases to dozens or even hundreds of separate components. This fact causes the probability of a wrong side failure to increase dramatically.

Obviously, merely using very reliable components will not make our crossing safe. To meet failsafe principles, a design change must be made. First, take the battery and connect one terminal to the end of one rail near the insulated joints, and connect the other terminal through a resistor to the other rail at the same end of the track section (see Figure 3). Now, go to the other end of the track section and connect a wire from one rail to one side of the relay coil. Finally, connect the other side of the relay coil to the other rail. Now, the current will flow from one terminal of the battery through the resistor to one rail. It then travels down the rail to the wire that is connected to the relay. It passes through the relay and back through the other rail and finally to the other terminal of the battery. The relay is now energized using the rails as if they are two wires. When a train comes into the track section, the wheels will short between the rails, as in Figure 3. (The resistor in the wire from the battery to the rail is to prevent the battery from being damaged when the rails are shorted by the train.) The energy to the relay will be cut off due to the short circuit caused by the train. If the contacts of the relay are wired opposite to the previous example then the crossing warning system will be activated when the relay is shorted out by the train.

This circuit is designed according to fail-safe principles. If the battery goes dead, if a rail breaks, if any connections are loose or a wire is broken or cut, the relay will be turned off thereby activating the crossing warning devices. Now, the reliability of the components become an issue of reduced false activation of the warning system rather than probability that no warning will occur when it is needed.

While the above example of the "closed-loop" principle used in design of signal systems is very simplified, it shows the basic concept that is used in even the most complex, high-tech devices. All modern railroad warning systems are based on activation by absence of an expected electric voltage or signal. This way, if anything fails to perform correctly, the warning system will activate.

When electronic circuits are used that contain transistors and integrated circuits, the failsafe concept becomes a little more difficult. A transistor is basically like a relay. A small voltage applied to its base will cause it to conduct like a switch. The problem is, the failure mode of a transistor is not as predictable as a relay. The relay contacts will almost always close if it fails, especially if it is designed according to proper Association of American Railroads recommended practices. A transistor, however, can fail in either a conducting or non-conducting mode. Most signal equipment checks the transistors by constantly turning them on and off. If the output of the equipment stays constantly on or constantly off due to a failed transistor or any other component, then the crossing warning system is activated. Here, again, the absence of an expected signal is used to turn on the warning system.

Microprocessors, too, are checked in a similar manner. Whether two processors are constantly checking each other, or some external circuit is used to check the processor, absence of an expected pulse at the proper output at the proper time will cause the warning to be activated.

Once it is understood, the failsafe design concept is really not very difficult. Its foundation lies in doing everything possible to make sure that if any part of a circuit fails, it will activate the warning system rather than allow the possibility of no warning being given. Because railroad signal design follows failsafe design concepts, the occurrence of a wrong side failure is extremely rare even though millions of crossing operations occur every day.

APPENDIX B

Test Plan for TTC Tests

TEST PLAN – RUNS FOR TTC TESTS

DATA COLLECTION:

Data will be collected utilizing digital media onto a computer located in the wayside bungalow. The digital data collection will consist of desk top computer with data collected at a 20 sample a load. The following data and channels will be utilized:

System 1 - Ground Based Data Collection Station: (independent train occupancy detector.
Channel - Data description

1. Time code baseline
2. Condition of Baseline Island-Relay (conventional system)
3. Condition of Test System 1
4. Condition of Test System 2
5. Condition of Test System 3
6. Condition of Test System 4
7. Condition of Test System 5
8. Condition of Test System 6
9. Island drive relay voltage - from Baseline system
10. ALD sensor - north end {10&11 used as an independent train
11. ALD sensor - south end entrance/exit indicator}

Note that channels 10 and 11 will be equipped so that they can also be triggered manually. This will permit noting events during special moves, such as switching and backup that may require a car be left on the island that is not equipped with an auxiliary ALD sensor.

The ALD sensors will be located track side, each set a different height above top of rail. The lower system will be located at the south end, the higher system will be located at the north end. These will be set so that a target located on the locomotive will activate only the higher system, while the lower target will activate the south system. This complies with test train makeup set for locomotive(s) leading a clockwise direction test consist.

Any move through the island will then be monitored by north ALD indicating island entry, and south ALD indicating island exit. Should additional time of island occupancy be required, temporary ALDs of the proper height can be installed on other equipment. The test control log shall have these noted to assist in data analysis. For clarity, the same channel numbers will be used on reports or data reduction monitoring real time operation. These will be channels 2-11.

RUN LOG:

In addition to the digital record log, a test controller log of all moves, keyed to the same time code baseline will be maintained. This log will contain entries indicating direction, speed, switch moves, consist and variations in consist, climate and weather conditions, changes made to rail, braking, and other variables for each test run.

ANALYSIS:

The primary analysis will consist of island relay drop time comparisons for each system. This will be computed from the primary digital data collection system by subtracting relay lift time code from the relay drop time code. The ALD system will be used as the primary "in/out" time base, comparing that to the test systems.

A report will include this data in a summary table(s) for various conditions, along with notes describing and problems in installation, operation or if any conflicting or false relay operations were noted, and equipment component failures.

TEST TRAIN:

Makeup of the test train will be such that the primary direction will be clockwise around the RTT. This will allow acceleration and high speeds to be aided by the downgrade profile that exists north of the test site. Actual equipment may vary day to day, depending on site availability. A typical consist will include:

2 - locomotives
3 - empty aluminum high side gondola cars
1 - empty single platform, 2 - axle car
1 - 5 pack spine car - empty
2 - loaded cars containing flat wheels (if needed for a specific test system)
3 - loaded hoppers or tank cars
1 - high clearance tank car

PROPOSED TEST MATRIX:

Notes:
CW - clockwise direction, north to south over test zone
CCW - counter clockwise, south to north over test zone
Dry - dry rail, as is, no contaminants
Contaminated - use of locomotive sand or other materials on top of rail
Braking - no brakes unless "braking" note included

MATRIX LISTING:

Each test matrix includes a series of passes to provide repeatability data. Generally these involve multiple (up to 5) passes at a given speed and condition. For most tests, the baseline (conventional) island system will be operated "as is", that is, with no shut assisting circuit. For selected matrixes, the shunt assistor, which is one of the proposed solutions being evaluated, will be switched on.

The TTC test layout will only be able to determine effectiveness of the shunt assistor if loss of shunt is first seen with the base system. For test planning purposes, it will be assumed that if loss of shunt is observed on the base system during execution of any given matrix, that matrix will be repeated as soon as feasible with the shunt assistor engaged. This will allow as close to back to back comparison as possible. Field data will be utilized as a "first cut" at determining if additional runs will be needed with the shunt assistor circuit "on".

The following is a summary of matrix groupings, describing briefly the objective of each series. The following pages outline in detail each run number and operating sequence:

Matrix	Objective
1	No braking, baseline data, speeds of 2 mph to 70 mph
2	Optional repeat runs, using island circuit enhancement
3	Stopping, starting, backup and switching moves
4	Contaminated rail sequences
5	AC traction locomotive runs
6	Induced ground return current into rails
7	Others, TBD based on results, availability of special equipment, track maintenance, etc.

MATRIX 1 Baseline test runs No braking

Baseline island as is, no auxiliary circuit

Run Number	Direction	Speed	Notes
101	cw	2	
102	ccw	2	backing up consist
103	cw	2	
104	ccw	2	backing up consist
105	cw	2	
106	ccw	5	backing up consist
107	cw	5	
108	ccw	5	backing up consist
109	cw	5	
110	ccw	5	backing up consist
111	cw	10	
112	ccw	10	backing up consist
113	cw	10	
114	ccw	10	backing up consist
115	cw	10	
116	ccw	30	backup
117	cw	30	
118	ccw	30	backup
119	cw	30	
120	ccw	30	backup
121	cw	50	Keep running around loop (if logistics allow, otherwise, backup at permissable speed and run forward at test speed)
122	cw	50	
123	cw	50	
124	cw	50	
125	cw	50	
126	cw	70	
127	cw	70	
128	cw	70	
129	cw	70	
130	cw	70	

MATRIX 2 Baseline tests using enhanced circuit:

Note: Repeat baseline test speed blocks with appropriate speed and braking conditions (ie: 5 passes at any given speed) utilizing baseline circuit and enhancement circuit "on", ONLY IF, analysis of island relay condition or island drive relay voltage history indicates potential loss of shunt conditions.

Exact run speeds, conditions to be determined from observing field strip chart data.

Any run with a "200" series will indicate baseline system with shunt enhancing circuit engaged, on clean rail.

MATRIX 3 Stopping, Switching Moves

Note: This matrix will utilize a sequence of leaving lone cars within the island, switching and coasting single, light cars through the island, reverse moves within the island , etc. The intent is to determine light car sensitivity of track circuit based equipment, as well as exercise logic software of "count in/out" and magnetic systems.

Run Number	Direction	Move Sequence
300	cw	Slow run, stop with spine car over island for 10 minutes, then continue in same direction
301	ccw	Repeat above
302	cw	Repeat above
303	ccw	Repeat above
304	cw	Slow run, stop with flat wheel cars within island for 10 minutes, then reverse out of island limits
305	ccw	Repeat above
306	cw	Repeat above
307	ccw	Repeat above
308	cw	Slow run, then stop consist with one wheel of short flat car directly over entering wheel sensor. Stop for 10 minutes, then continue run
309	ccw	Repeat above
310	cw	Repeat above
311	ccw	Repeat above
312	cw	Slow run, then stop consist with one wheel of short flat car directly over entering wheel sensor, Stop for 10 minutes, then reverse out of island area
313	cw	Repeat above
314	cw	Repeat above
315	cw	Repeat above
316	cw	Slow run into island with 3 empty aluminum cars, stop with cars in island. Uncouple last car, depart island. Leave lone, car standing in island for 10 minutes, back onto car, couple and depart in original direction.
317	ccw	Repeat above
318	cw	Repeat above
319	ccw	Repeat above

MATRIX 3 Continued:

Run Number	Direction	Notes
320	cw	Run consist of locos and one hopper through island, setting up for "kicking" moves below
321	ccw	Kick empty, single aluminum car through island, allowing to coast through. After car has departed island, follow with locomotive to capture and repeat runs
322	ccw	Repeat above
323	ccw	Repeat above
324	ccw	Repeat, but recouple to consist
325	cw	Run slow with at least 6 cars into island, stop. Wait 5 minutes, reverse for 2 car lengths, stop 3 minutes. Reverse again running train completely out of island going in original direction.
326	ccw	Repeat above
327	cw	Repeat above
328	ccw	Repeat above
329 - on	Suggestions from Grade crossing safety committee members.	

Notes: Other switching moves may be conducted based on equipment configuration calculable. Some runs may need to be repeated if physical location of various sensors requires multiple stops.

MATRIX 4 Contaminated Rail

Results from testing of contaminants and brake shoes on the AAR brake shoe dynamometer indicated mixes of: brake shoe application rates, oil & grease, sand, wind blown organic ground leaves, and water might lead to loss of shunt.

Objective will be to contaminate top of rail to bring the base system into a loss of shunt failure mode.

Any run with a "400" series number will indicate that the system being evaluated is being operated with intentionally contaminated rail. Notes will indicate if baseline system enhancement is on or off.

MATRIX 5 AC Traction Locomotive Interference

Run Number	Direction	Notes
		Remove TTC locomotives, replace with one AC traction locomotive borrowed from ongoing TTC tests. Add sufficient loaded HAL cars and/or add trailing locomotives in dynamic braking to ensure a full load resistance/full tractive effort is required to start consist. This sequence requires cooperation of another, on-site customer, thus scheduling sequence may require operating during a different time period.
500	cw	Start near island, with locomotive outside of island limit. Ensure locomotive is at near maximum power when traveling over island.
501	ccw	Repeat backing up at slow speed
502	cw	Repeat forward run
503	ccw	Repeat backing up run

AC locomotives in dynamic braking

Run Number	Direction	Notes
504	cw	Use DC locomotives to pull AC locomotive set to full dynamic braking. Objective is to travel length of island under AC locomotive dynamic braking. Repeat passes in both directions. Consist would be only as follows: 2-3 TTC locomotives under power 1 AC locomotive in DB
505	ccw	Repeat above
506	cw	Repeat above
507	ccw	Repeat above

MATRIX 6 - TBD

Evaluation of induced ground return voltage. Details are being worked out for power supply, its as of 5/28/97.

MATRIX 7 - OTHER EQUIPMENT

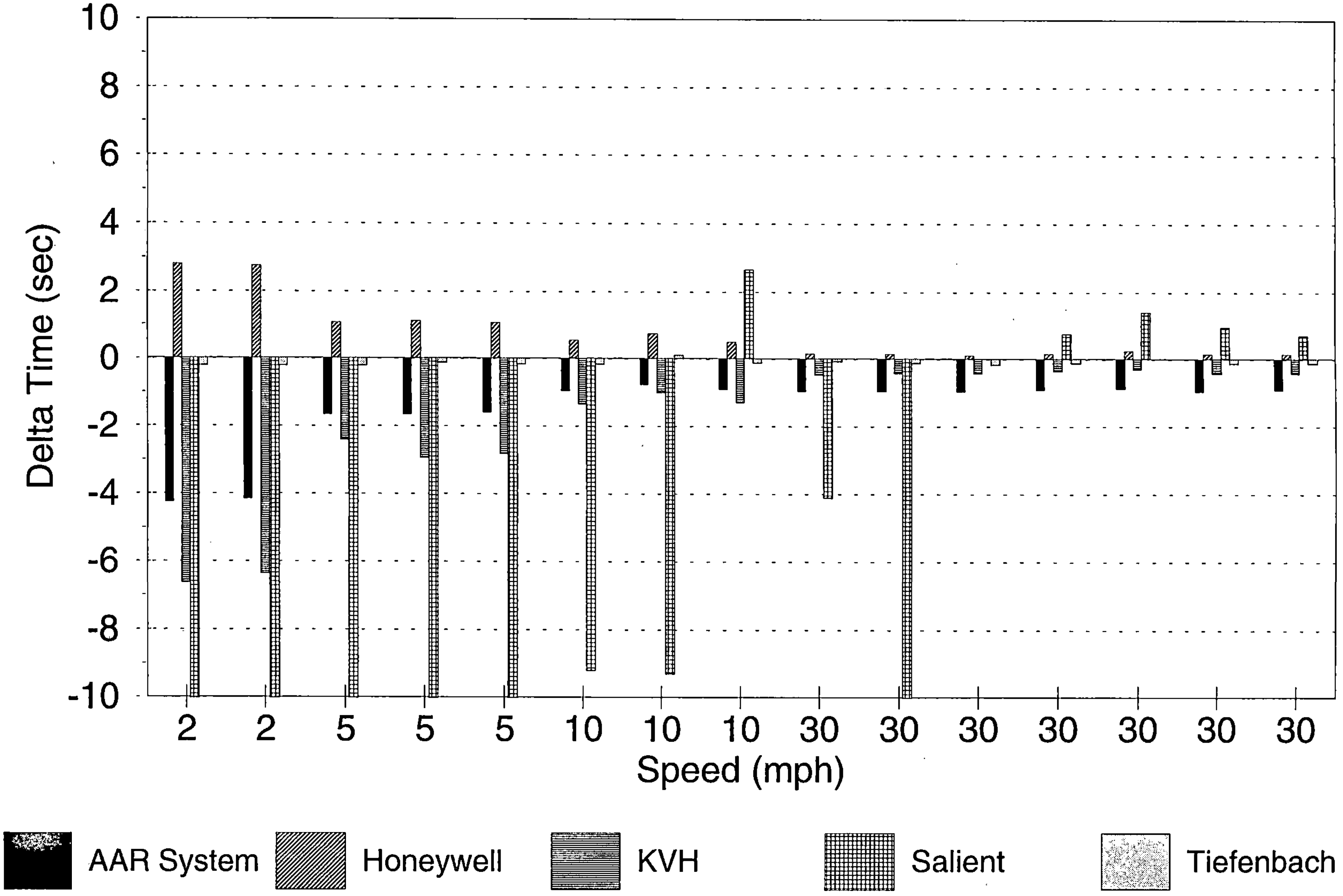
Use of insulated work equipment, inspection cars, etc. will be evaluated over the island limits.

APPENDIX C

Data Plots

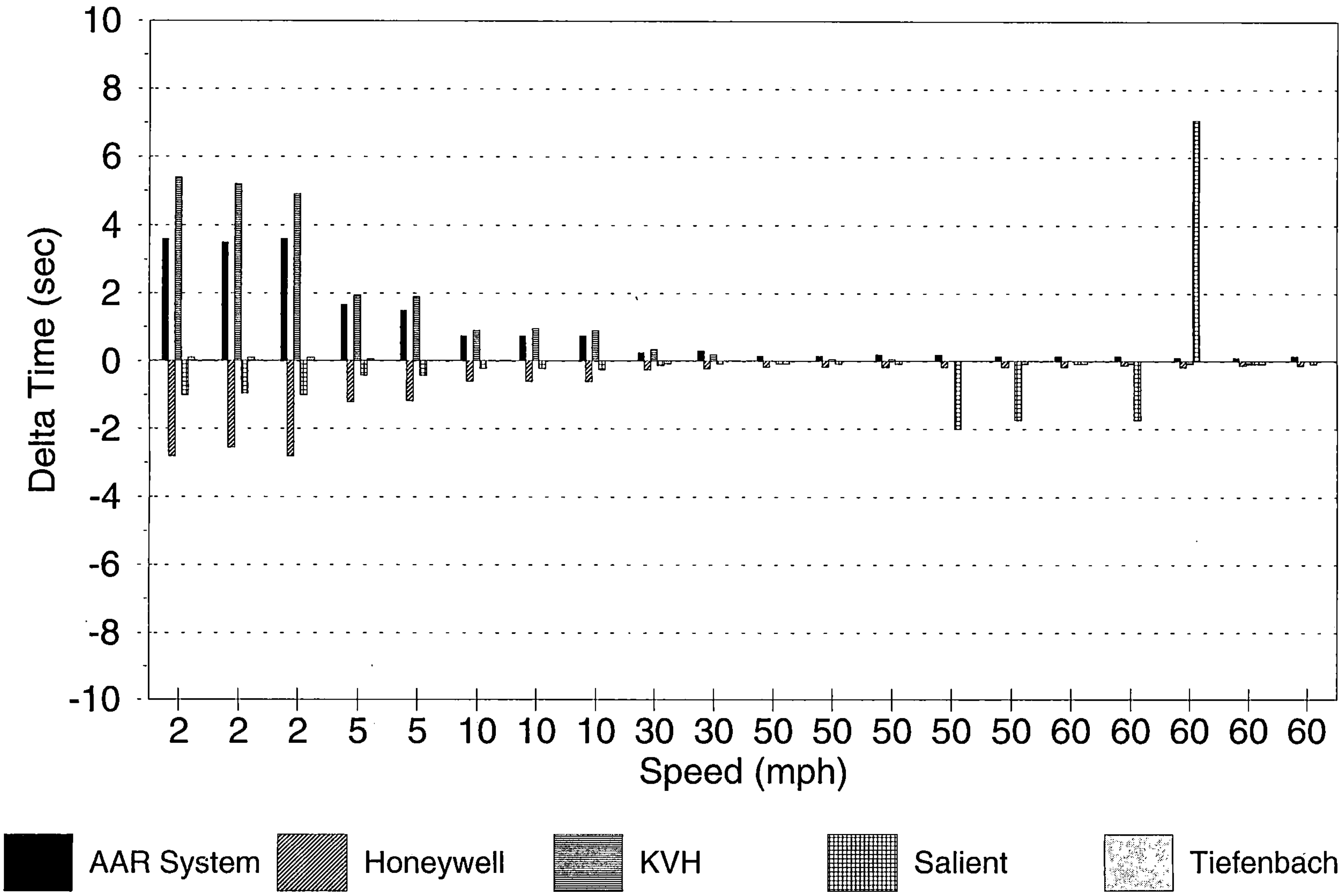
Exit Deltas VS. Baseline

100 Series CCW



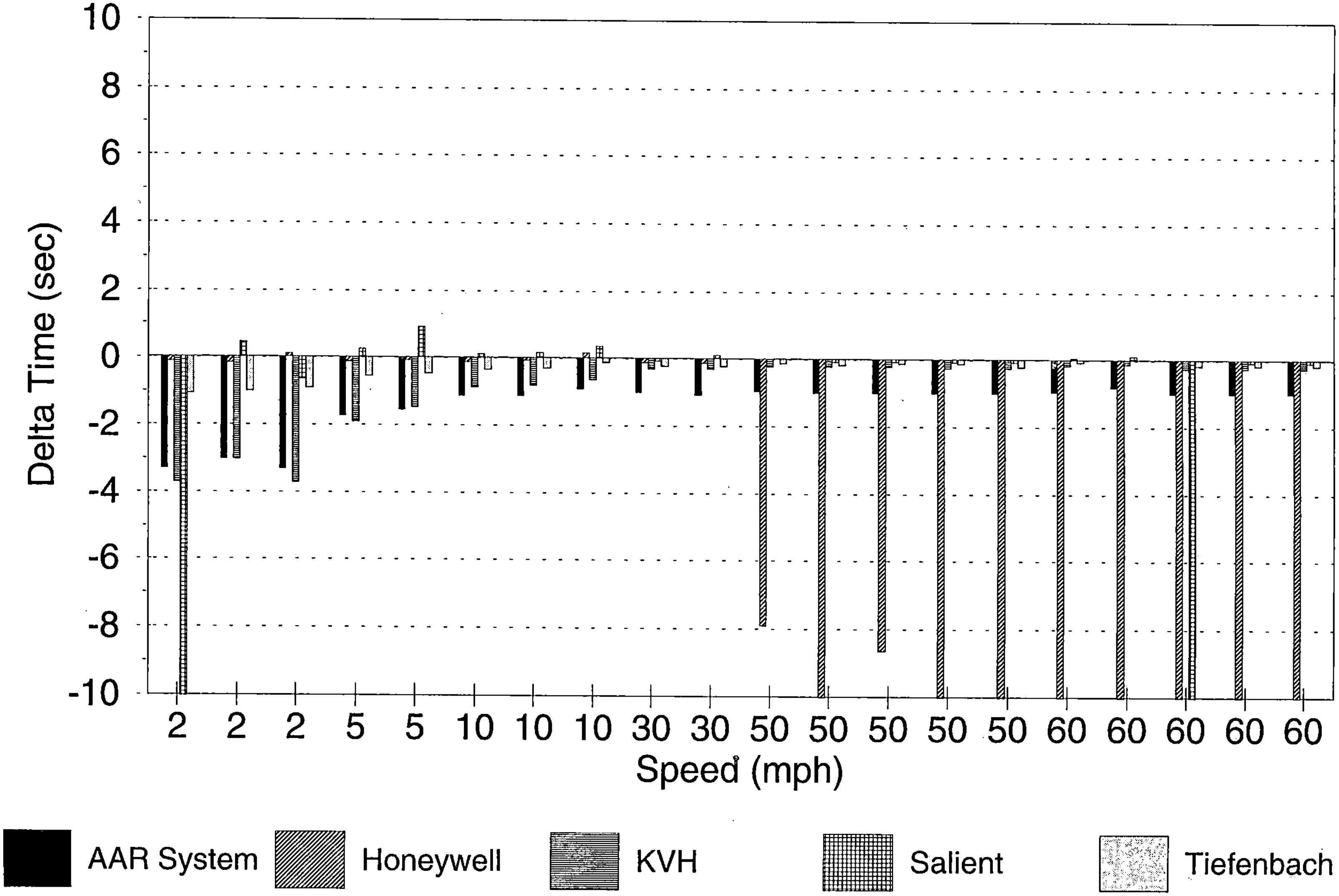
100 Series CW

Delta Entering vs. Baseline

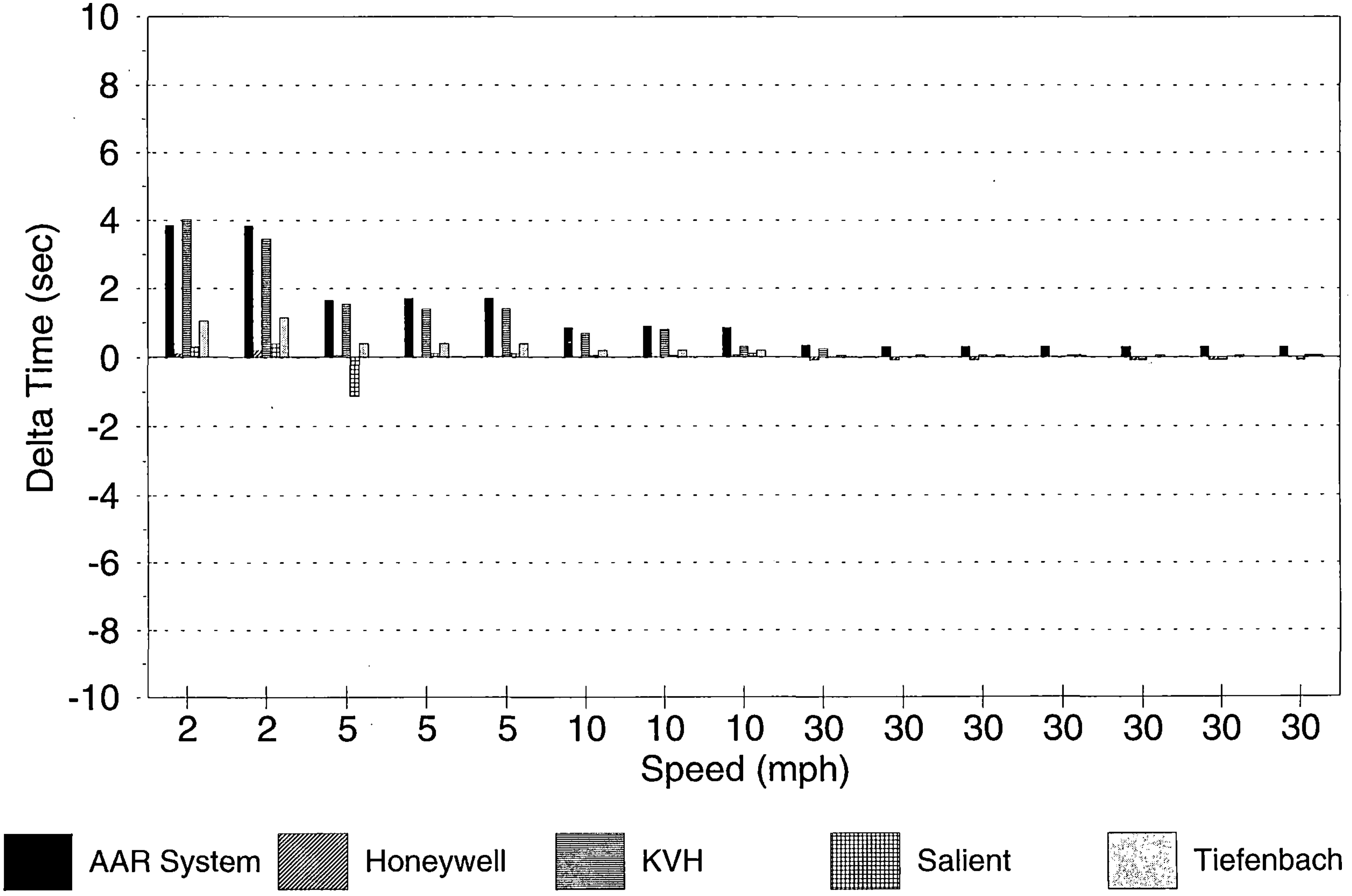


100 Series CW

Delta Exiting vs. Baseline

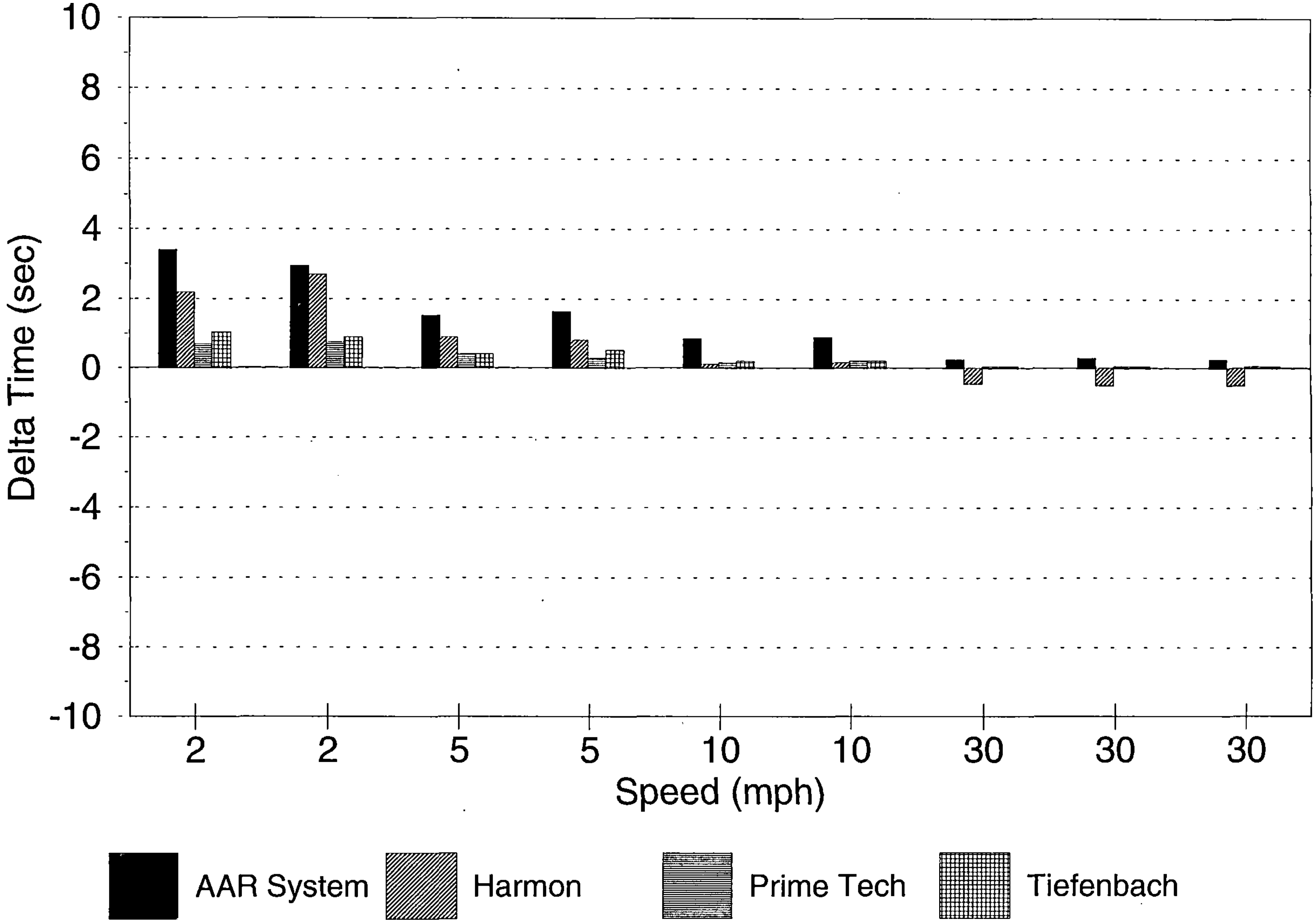


Entrance Deltas vs. Baseline
100 Series CCW



200 Series CCW

Delta Entering vs. Baseline



200 Series CCW

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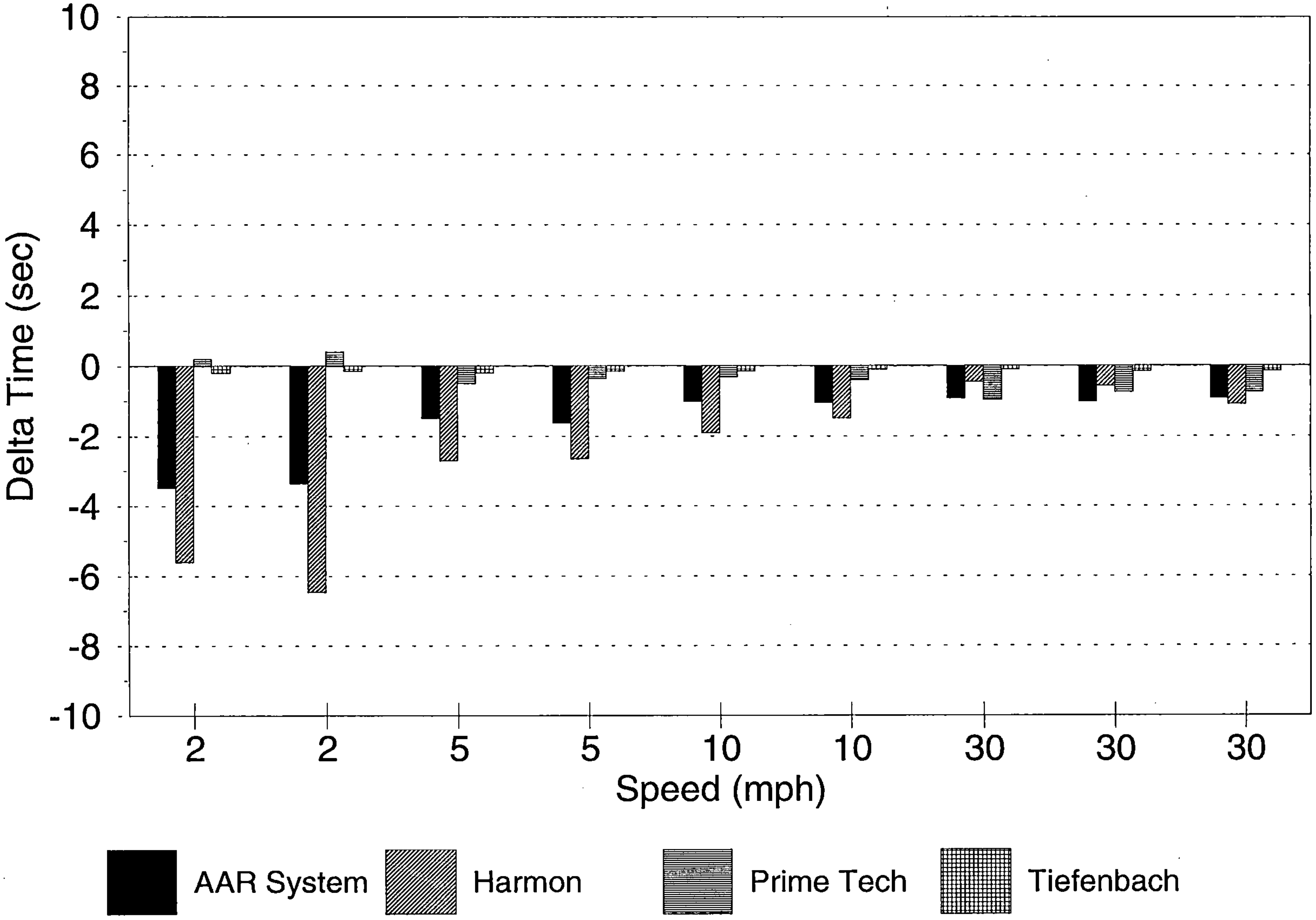
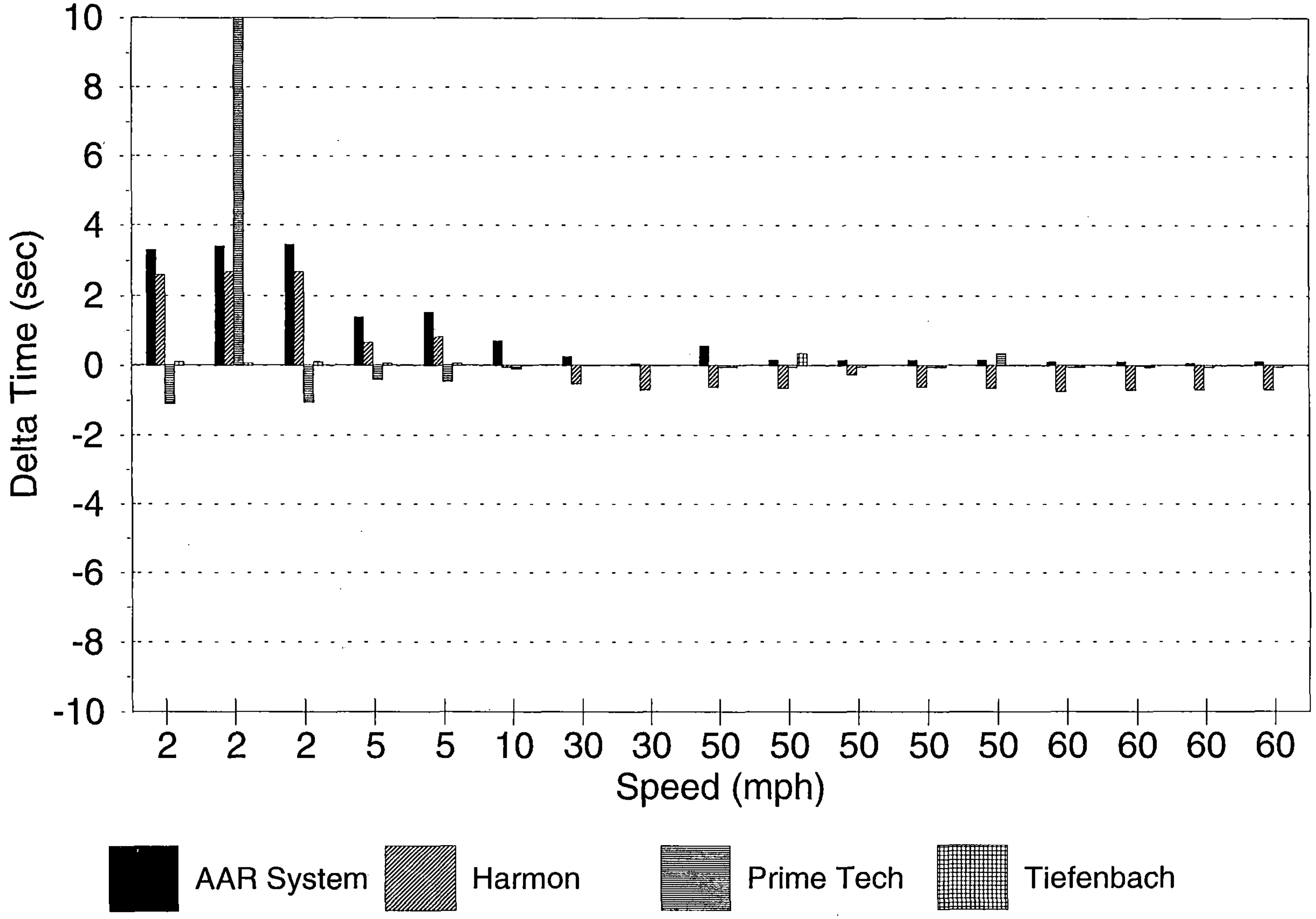


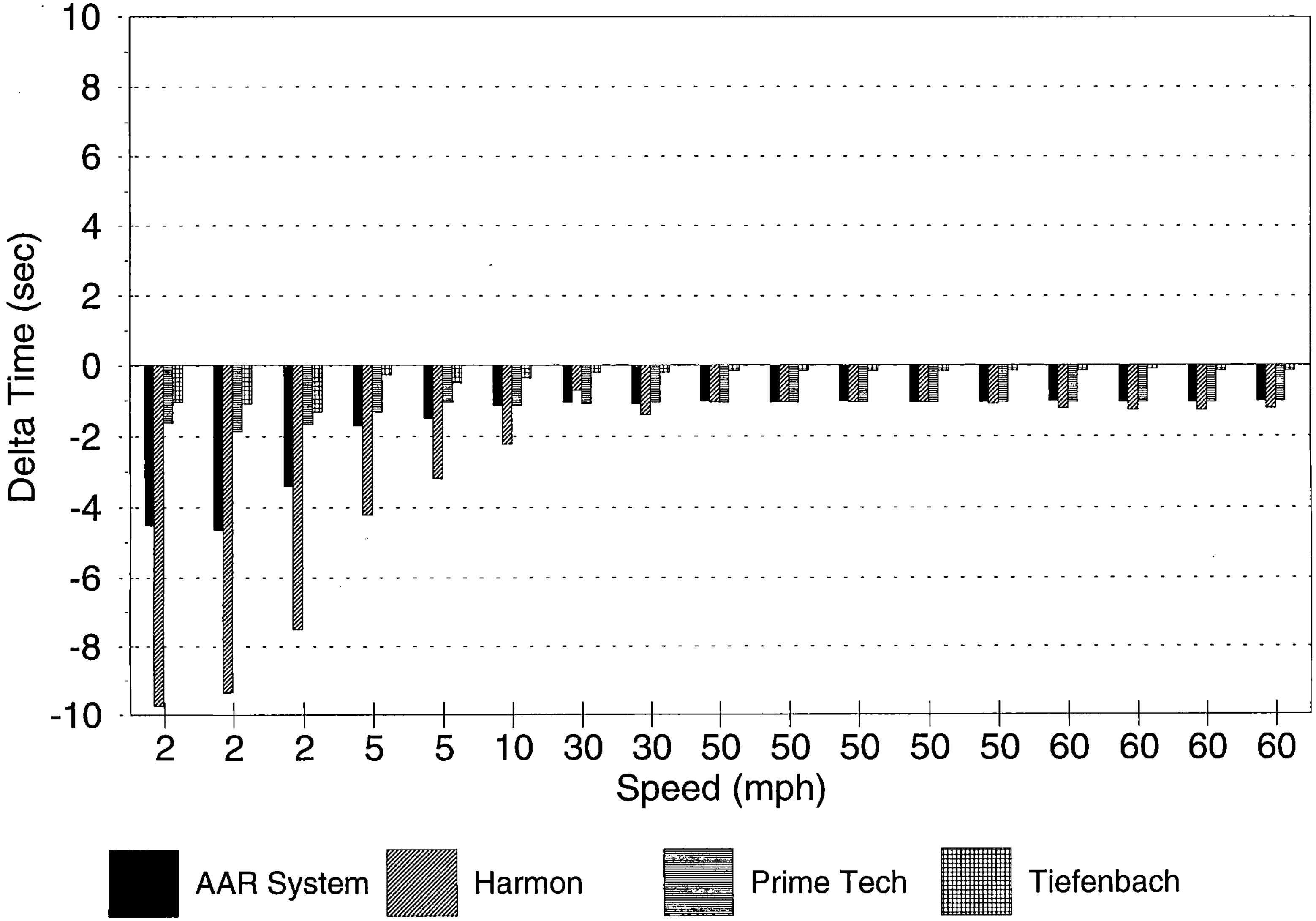
200 Series CW

Delta Entering vs. Baseline



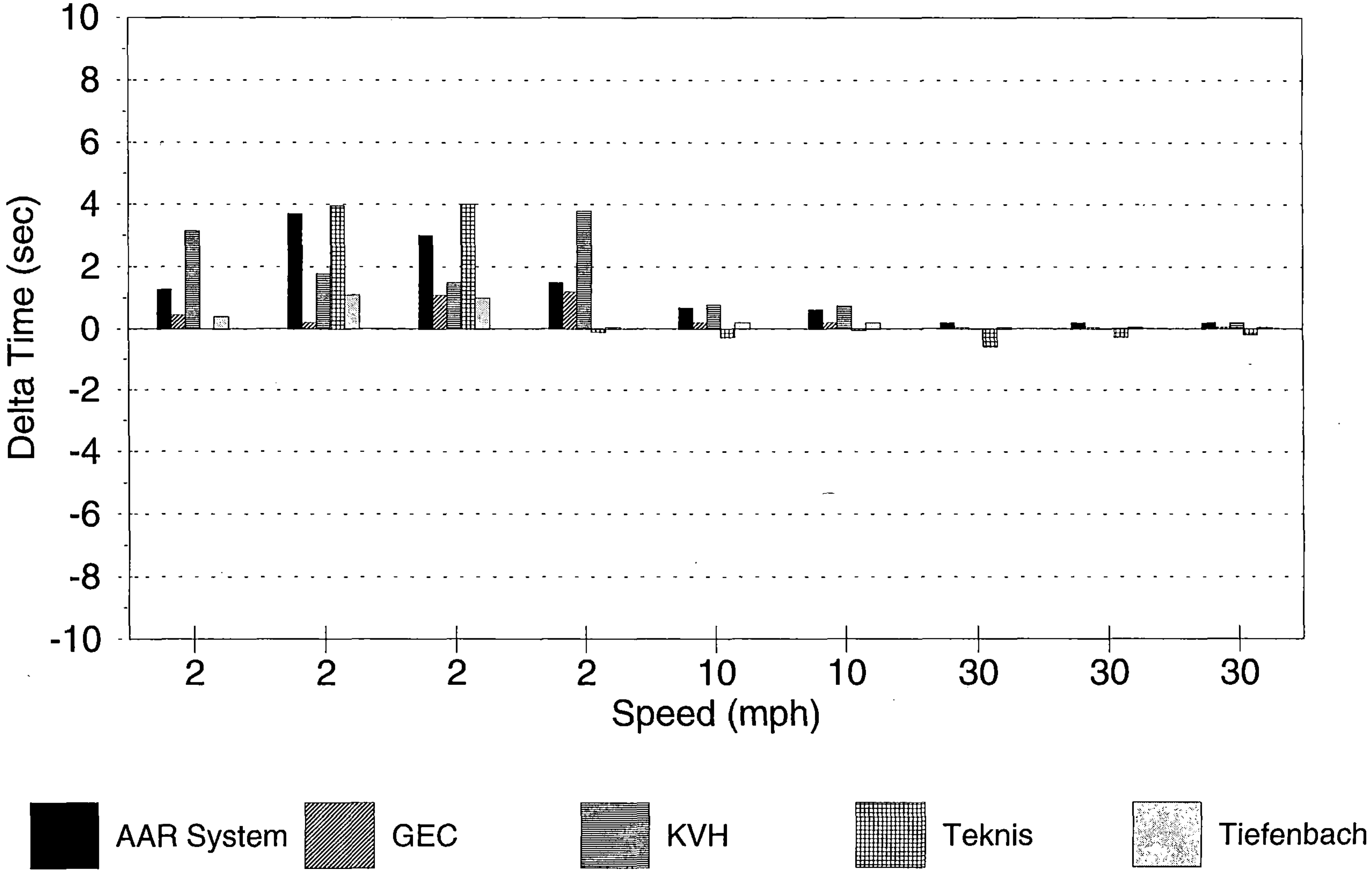
200 Series CW

Delta Exiting vs. Baseline



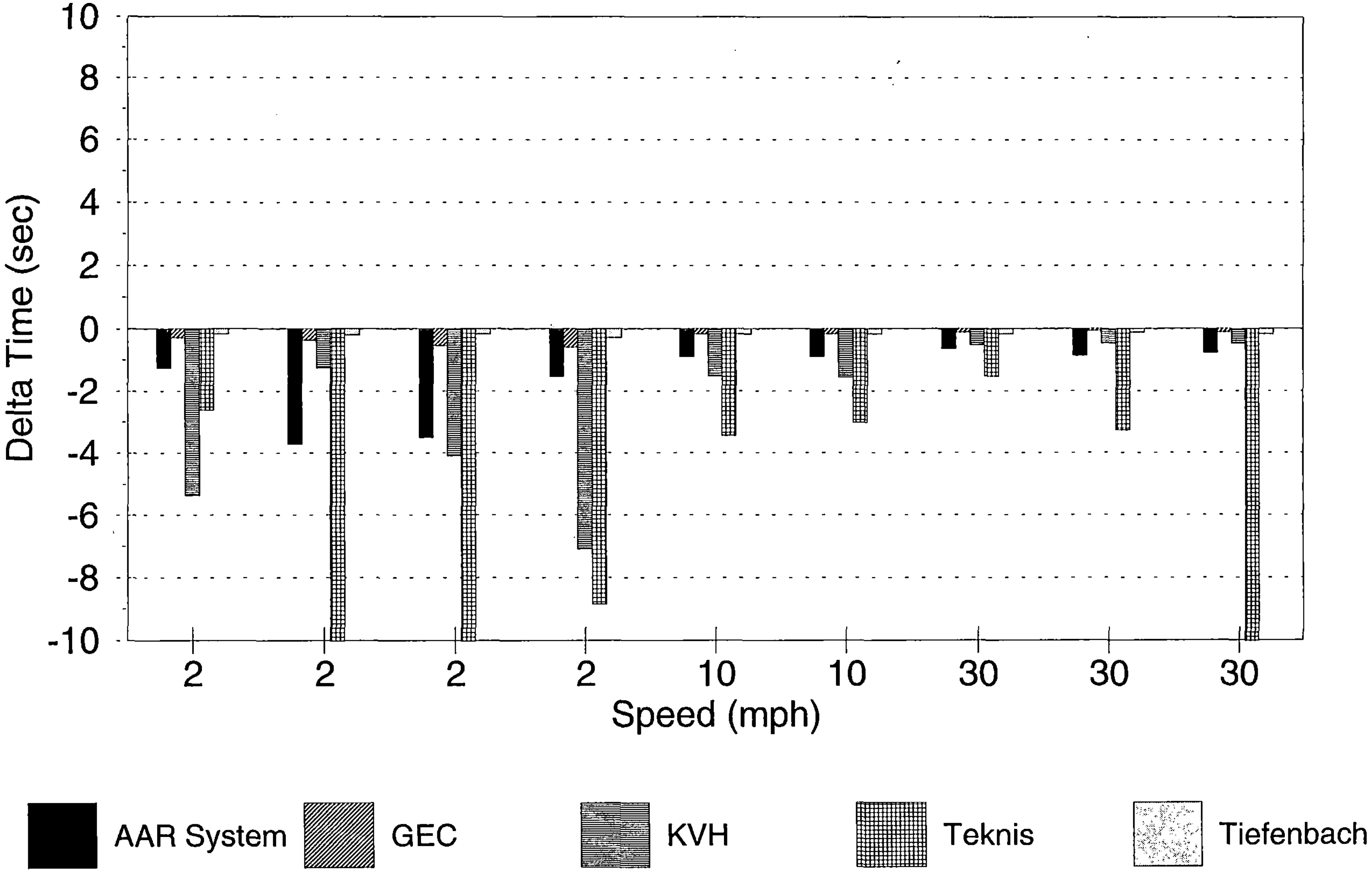
300 Series CCW

Delta Entering vs. Baseline



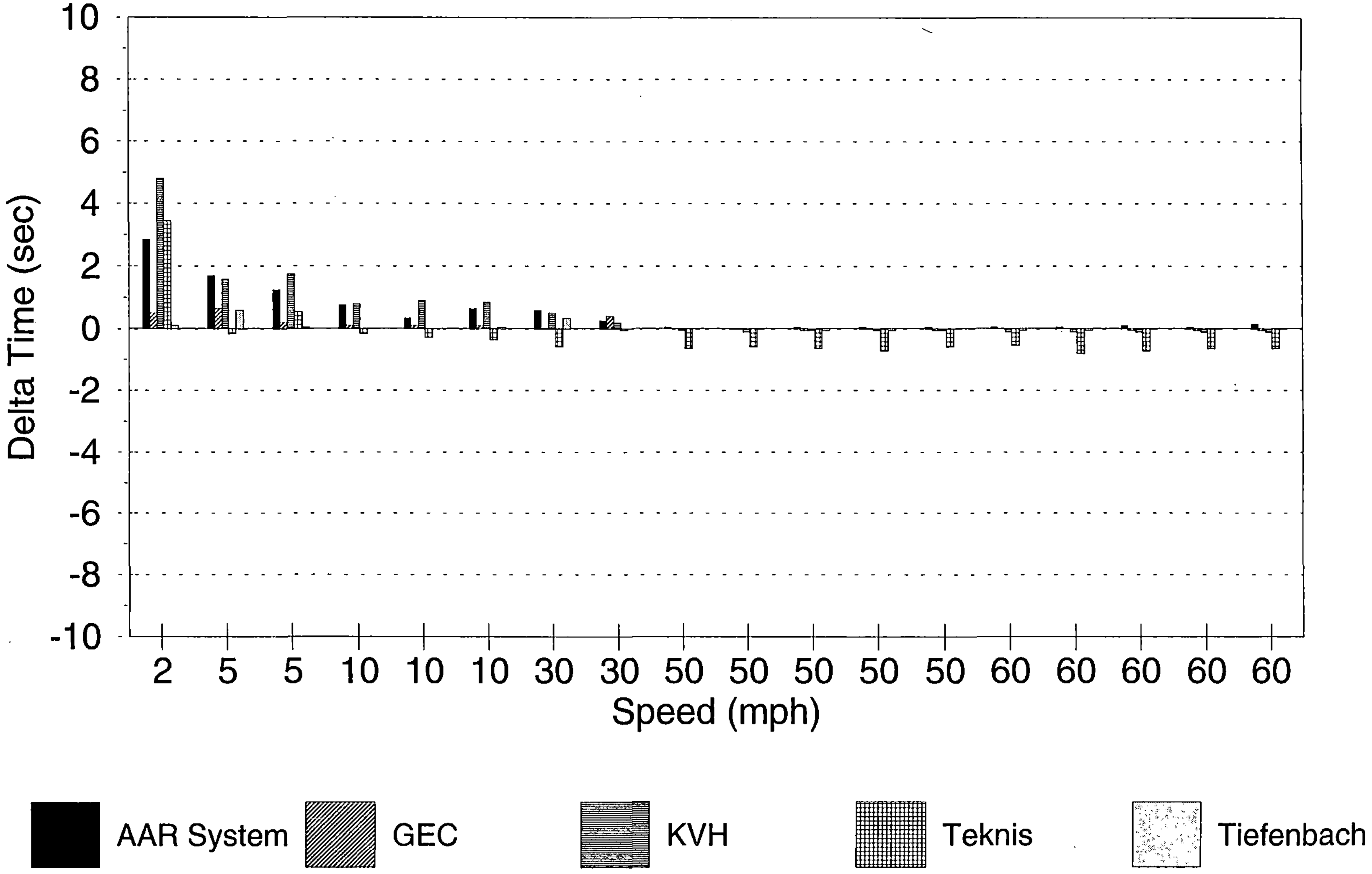
300 Series CCW

Delta Exiting vs. Baseline



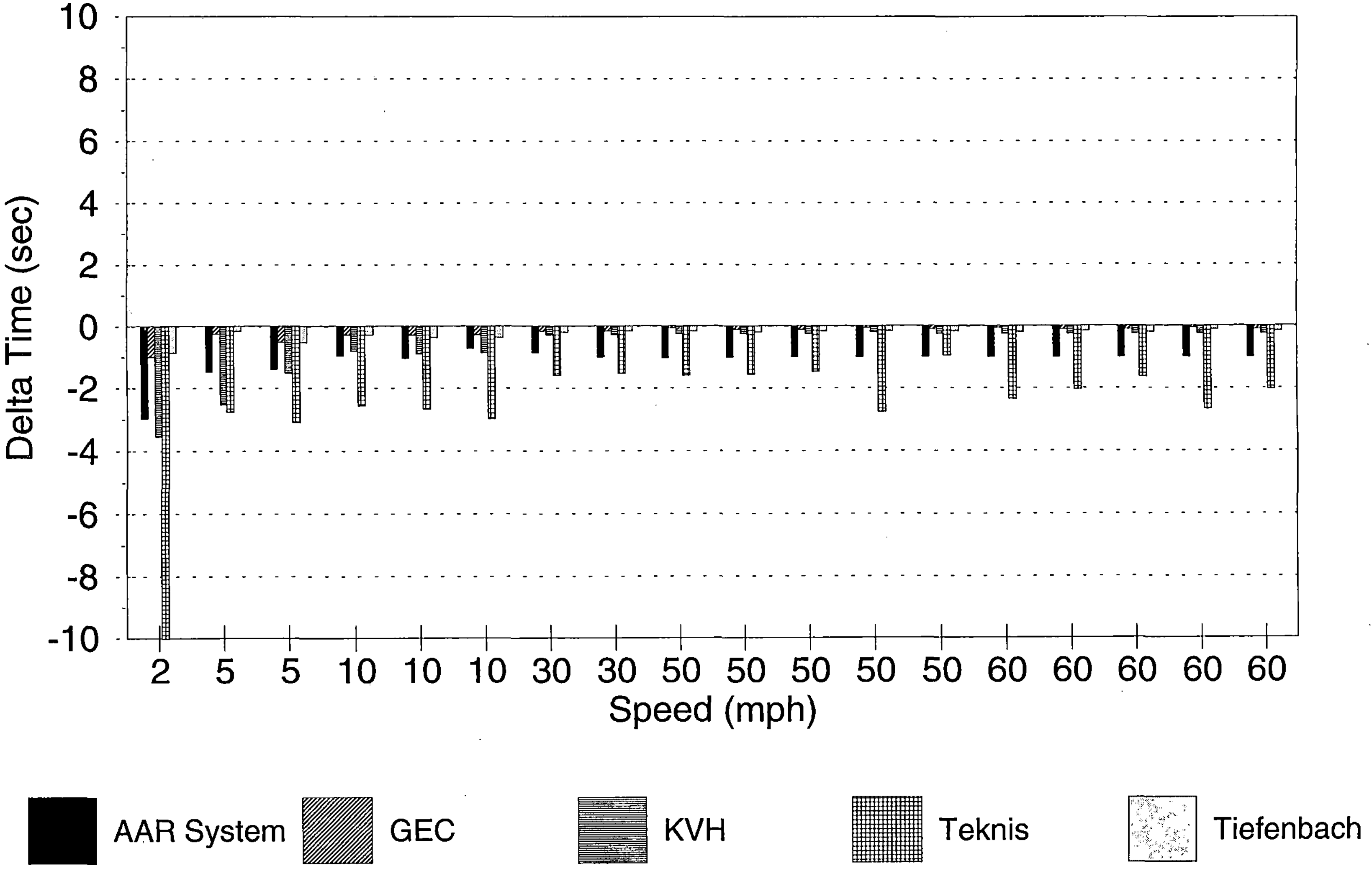
300 Series CW

Delta Entering vs. Baseline

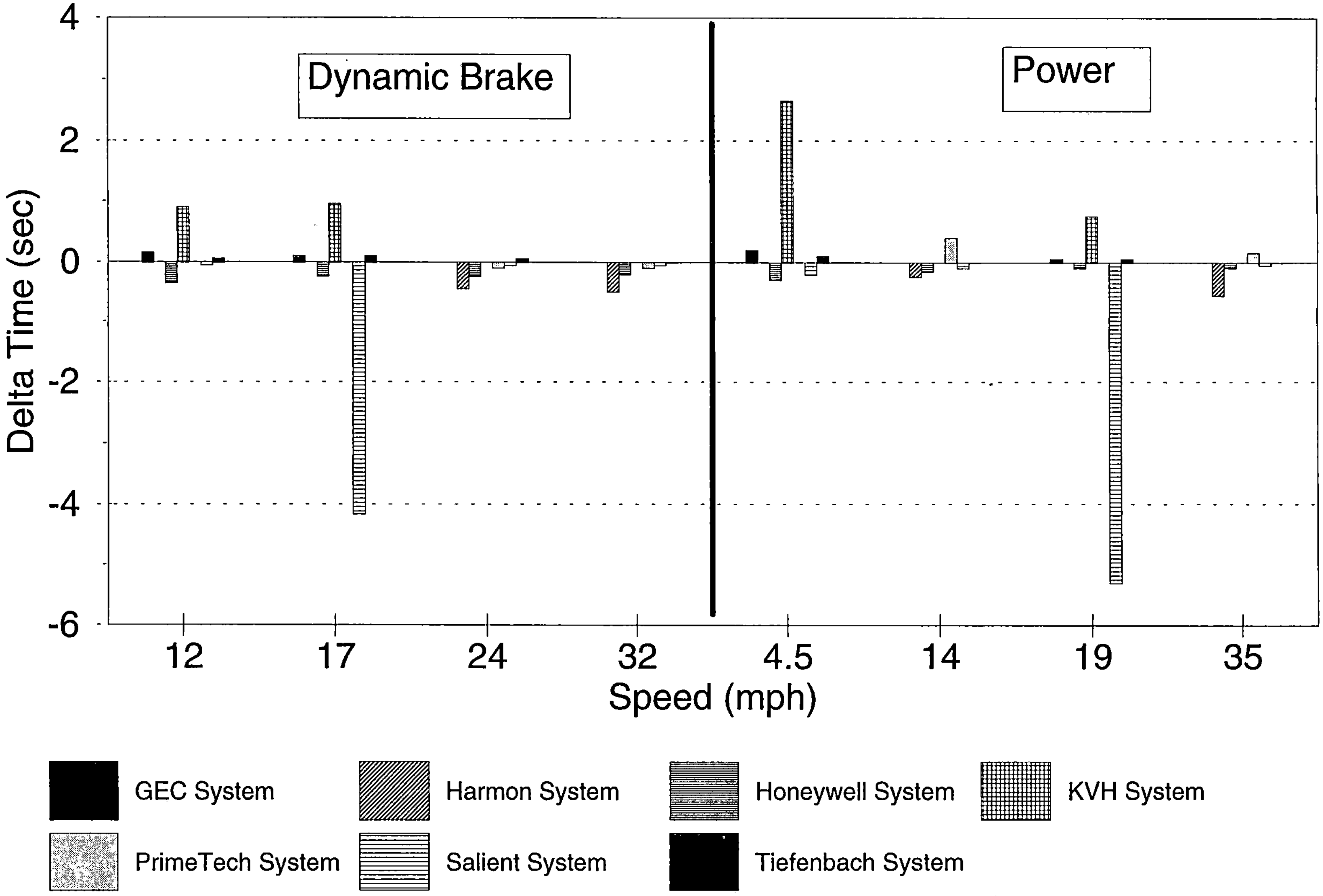


300 Series CW

Delta Exiting vs. Baseline



Entrance Delta vs. Baseline
AC Loco Series - AC in D.B. & Power



System Exit Delta vs. Baseline
AC Loco Series - CW