U.S. Department of Transportation
Federal Railroad Administration

Advanced Train Control System Evaluation

Office of Research and Development
Washington, DC 20590

George I. Kuehn

IIT Research Institute
10 W. 35th Street
Chicago, IL 60626

FRA/ORD-92/32

October 1992
Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

06 – Signals, Control and Communications

NOTICE

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FRA/ORD-92/32		

4. Title and Subtitle	Advanced Train Control System Evaluation
5. Report Date	October 1992
6. Performing Organization Code	
7. Author(s)	George I. Kuehn
8. Performing Organization Report No.	E06606
9. Performing Organization Name and Address	IIT Research Institute 10 W. 35th Street Chicago, IL 60616
10. Work Unit No. (TRAIS)	
11. Contract or Grant No.	DTFR53-89-C-00015
12. Sponsoring Agency Name and Address	Federal Railroad Administration Washington, D.C. 20590
13. Type of Report and Period Covered	Final Report 3/1/89 to 9/1/92
14. Sponsoring Agency Code	
15. Supplementary Notes	

16. Abstract

This study was an evaluation of whether an Advanced Train Control System (ATCS) helped, hindered or was neutral with respect to the train handling and operating rule observance of locomotive engineers.

Thirty engineers were randomly assigned to three groups representing the use of (1) an ATCS display, (2) an alternative display, and (3) conventional track warrants with a printed track profile. The performance of the subjects was then assessed as they operated the Federal Railroad Administration (FRA) Research and Locomotive Evaluator/Simulator (RALES) located at the IIT Research Institute (IITRI).

The traditional paper warrant and alternative display groups had speed violations while the ATCS display group had none. An apparently concomitant result was that the ATCS group produced a significant reduction in fuel consumption over the conventional paper warrant group. No ATCS group member technically violated a slow order while members of the other two groups displayed a total of 9 of these failures (4 in one group, 5 in the other). Two slow order violations would have been produced by the ATCS group, but these were prevented by the penalty brake application of the ATCS system. While the ATCS group did not produce significantly more in-train force errors (run outs) than the paper warrant group, they did post significantly more of these errors than the alternative display group. There were no significant differences between groups in number of failures to blow the horn at crossings. No subject in any group failed to respond to a stop signal.

17. Key Words	18. Distribution Statement
ATCS Display Alternative Display Study Subjects	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
U	U	36	

Form DOT F 1700.7 (8-72)

PREFACE

The work described in this report was conducted by IIT Research Institute (IITRI) under authorization of Federal Railroad Administration (FRA) Contract No. DTFR53-89-C-00015, Tasks 3 and 4. The period of performance was from March 1, 1989 to September 1, 1992. The work was directed at a study of the effects of the ATCS Specification 320 level 30 display on the train handling performance of locomotive engineers.

The original IITRI Project Manager for this work was Mr. John Granath. The work was concluded, subsequent to Mr. Granath's retirement, by Dr. George I. Kuehn. Mr. Garold R. Thomas was the FRA Contracting Officer's Technical Representative on this project. The assistance of all concerned throughout the course of the work is gratefully acknowledged.

Respectfully Submitted,

George I. Kuehn
Research Data Analyst
Transport Technology

Approved:

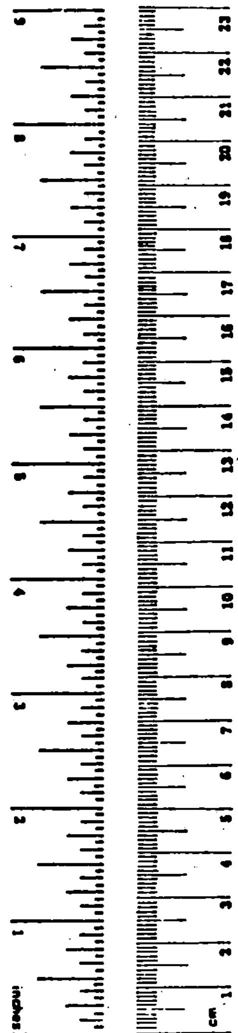
Charles E. Radgowski
Director
Transport Technology

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	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

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	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	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

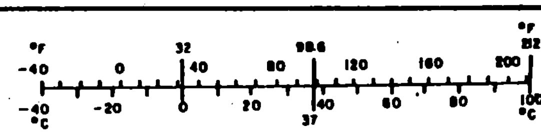


TABLE OF CONTENTS

ADVANCED TRAIN CONTROL SYSTEM EVALUATION

1. INTRODUCTION

This Task Order involved an initial evaluation of whether an Advanced Train Control System (ATCS) helped, hindered or was neutral with respect to train handling by locomotive engineers. Thirty certified locomotive engineer subjects were randomly assigned to groups which represented the use of three operational approaches. The three groups represented use of (1) an ATCS display, (2) an alternative display, and (3) conventional track warrants with printed track profile. The subjects' train handling performance was then assessed as they operated the Federal Railroad Administration (FRA) Research and Locomotive Evaluator/Simulator (RALES) located at the IIT Research Institute (IITRI).

1.1 THE STUDY

During the months of May, June and July of 1992, 30 certified train service locomotive engineers were individually oriented for a period of one hour to the objectives of the study and the operation of the RALES FRA Class 1 simulator at IITRI. Additionally, each group was introduced to the form of track information they would use during the experiment: the ATCS display; the alternative display; or, the conventional Track Warrants and Track Profile.

Following orientation, the subjects commenced to run the simulation over the experiment route. The territory used for the experiment was one which was unfamiliar to the subjects.

1.2 OVERVIEW OF RESULTS

The paper warrant and alternative display groups had speed violations while the ATCS display group had none. No ATCS group member technically violated a slow order while members of the other two groups displayed a total of 9 of these failures (4 in one group, 5 in the other). Two slow order violations would have been produced by the ATCS group, but these were prevented by the penalty brake application of the ATCS system. While the ATCS group did not produce significantly more in-train force errors (run-outs) than the paper warrant group, they did post significantly more of these errors than the alternative display group. There were no significant differences between groups in number of failures to blow the horn at crossings. No subject in any group failed to respond to a stop signal.

2. THE SUBJECTS

Thirty subjects were solicited on an individual basis from four railroads. There were two experience requirements. First, each subject was required to be currently holding valid certification as a train service locomotive engineer. Second, no individuals were accepted as subjects who had operating experience with the territory used for the route in the study (SOO Line route from Davis Junction to the Bensonville Yard).

Subjects were randomly assigned to the three groups used in the study. All subjects ran during the day or early evening hours (none later than 2200, none earlier than 0700) on the basis of availability during their individual work schedules. No subject appeared to the observer to be overly fatigued or otherwise unfit for duty at the time of the experiment.

3. THE PROCEDURE

3.1 ORIENTATION

Each subject spent approximately one hour in orientation, led by an experienced, certified supervisor of engineers. During this orientation, the specific signal aspects and operating rules (General Code) used in the study were covered. The subjects then operated the RALES simulator with the experiment train, but over different territory from that used in the study. The train consisted of 3 SD40 locomotives and 97 mixed goods cars for an average of 74.6 tons per operative brake.

The subjects were randomly placed in three groups. Group 1 consisted of 10 subjects who were provided with the ATCS Specification 320 level 30 display. The display was shown on a 14 inch VGA monitor located with its base 12 inches above the left side of a standard AAR 105 cab stand. The face of the monitor was inclined approximately 30 degrees to place it perpendicular to the engineer's line of sight.

The graphic display software itself was originally developed for the Canadian National Railroad and provided by the Advanced Train Control Systems program at Canadian National. The display software was processed by a standard IBM compatible personal computer. Adaptations were made by IITRI to allow communication between the RALES simulator and the personal computer.

The level 30 ATCS display (Appendix A) provides a representation of the train on a track profile which scrolls from right to left in step with the forward motion of the train. The train is also depicted as a horizontal bar which rises and falls against a marked scale which indicates train speed. Track speed limits are shown in text form as well as in the form of a red, horizontal track authority bar plotted on the same speed display upon which the train appears. As the train increases in speed, it rises to meet (or exceed) the track authority speed bar. The end of authority to move is displayed by a 90 degree downward turn of the authority bar to the baseline. Slow orders are represented as inverted barrier blocks which descend from the authority/speed bar to reduce the "headroom" which indicates maximum speed. Work blocks under the authority of a track foreman are represented as inverted barrier blocks which descend from the authority/speed bar and touch the baseline. In the current study, a radio request to the foreman was necessary for the work block barrier to be raised (normally to a speed less than that displayed by the authority/speed bar). In addition, a white box appears in advance of the train bar. The white box predicts the future speed of the train at the track profile position of the box given current control settings and the effects of grade. Most importantly, *predicted* train speeds (white box, discussed above) which violated authority, work block or speed limits by 4 mph resulted in an automatic penalty brake application which required a full stop to reset.

The Group 2 subjects (alternative display, Appendix B) were introduced to the specifics of that display. The display shown these subjects was used as a contrast to the ATCS display. Specifically, the alternative display provided no advance knowledge of speed limits and no predictor relating to the future speed of the train. Additionally, the alternative display did not provide track warrant, work block information, or penalty brake application for violations of limits. The alternative display was provided as a means to determine if any study effects came as the result of a display in any form as compared to the specific information and control provided by the ATCS display.

The display provided as the alternative was one of numerous types actually used for engineman feedback in routine operation of the simulator. IITRI had originally defined this display as the "all in one" display because of the broad, telemetric information it provides. The display shows current speed, current track speed limit (which changes without warning), current position of the train on a scrolling track profile display, current grade inclination, coupler slack, in-train forces, traction motor load meter reading and braking systems status. Additionally, the alternative display showed acceleration/deceleration rate, the location of crossings, signals, bridges and other track location features. For purposes of the study, the alternative display was presented on the same monitor used for the ATCS display.

Group 2 subjects were also provided with conventional written track warrants and a track profile (Appendix C).

Group 3 subjects were provided only with the conventional written Track Warrants and the track profile.

All groups ran the same exercise as represented by the conventional written Track Warrants and over terrain as represented in the paper track profile. In each case, care was taken to be certain that each subject understood the applicable rules, signal aspects and track warrant format.

Each subject signed a consent form (Appendix D). The subjects were provided compensation of $250. The compensation was deemed appropriate for a half day period of service for a locomotive engineer acting as an independent contractor. No subject expenses were compensated.

3.2 THE SUBJECT'S TASK

Subjects were instructed to cover the planned 63 mile route as quickly as possible, following all movement authorities, slow orders, track speed limits and operating rules. The subjects were also instructed to manage in-train forces and observe safety rules just as they would in normal operation.

The RALES simulator cab is equipped with a radio and the subjects were directed to request authorities from track foremen and the dispatcher just as they would in the real world. The supervisor of locomotive engineers who had managed the orientation also played the rule of dispatcher and track foremen from the remote simulator operator's console.

During the experimental runs, an alerter and an end of train device were in operation.

4. DATA COLLECTION PROCEDURES

The RALES simulator allows the continuous collection of virtually every aspect of a chosen train's status as frequently as .5 second intervals. A data collection interval of 3 seconds was chosen. Previous experience has indicated this interval to be sufficient to capture all of an operator's control actions as well as accurately register both steady state and dynamic forces in the train.

The RALES system allows the evaluation of data in terms of flags which are set to capture instances where observed values exceed preset limits. Flagged errors were collected for each subject's run. The following performance data were flagged:

<u>Speed Limit Violations:</u> Specific speed limits were set for various locations on each run and were flagged when exceeded. Additionally, the time duration for each event of speed violation was recorded. Since the ATCS display clearly shows speed and speed limits, this flag tests the effect of the display on this aspect of safe operation.

The standard of a speed limit violation for purposes of the study was an excess of 4 mph or more over track limits. The ATCS display also reflected this standard.

<u>Horn Violations:</u> When an engineer failed to blow the horn for a crossing, the event was flagged. The Specification 320 display used in the study did not show crossing locations but each crossing was visible in the scenario. This flag was used as a variable which had the potential to measure possible operator distraction caused by watching the display rather than the forward view. The IITRI "77 display" does show crossings and consequently gave a potential cross-check for observations concerning this variable.

The simulation scenario used for the current study had over 100 crossings, many of them of the rural type. These crossings are often difficult to discern because of limited sight lines and require a high degree of vigilance to anticipate.

Excessive Run-Out Force: There are 6 inches of slack in each standard coupler junction in a train. A freight train of 100 cars has a total of nearly 50 feet of slack. Sudden changes in the forward motion of the train can cause this slack to be suddenly taken up with a force sufficient to cause anything from damage to the lading to train separation and derailment. A limit of 100 thousand pounds was selected as a flag value on the basis of prior experience indicating possible damage to lading from instantaneous forces exceeding this level.

Excessive Run-In Force: Run-in forces are similar to run-out forces and can cause anything from damaged lading to derailment. The limit for run-in was flagged at -100 thousand pounds.

Violation of Slow Orders: The experimental run had six slow order areas (See Appendix C). Three of the slow orders were a function of work done by "maintenance of way" groups under the direction of a track foreman. When contacted by radio, the track foreman (played by the observer from the remote control console) granted authority to proceed at a specified reduced speed.

Violation of Track Authorities: Operation by an engineer of a train over a given route requires authorization by written orders or from a dispatcher to cover successive segments of track. In the experimental run, there were four such authorities which could be gained by contacting the dispatcher on the cab radio (dispatcher played by the observer). In the case of one authorization, the "dispatcher" purposefully did not respond in a timely way. This caused the engineer to stop at the end of the then current authorization. Compliance with the mandatory stop was recorded. It was considered a failure if the stop was not made, or was made past the authority end.

Failure to Stop Before a Red Signal: Track signal systems are the major defense against rail vehicle collisions. Locomotive engineers are expected to stop their trains in a location before, rather than after, the signal position. It was considered a failure in the current study if a subject were to stop the train with any part of the train past the signal position.

5. RESULTS

As indicated earlier, the study measured the following variables:

1. Track speed limit violations
2. Duration of track speed violations
3. Run-in forces
4. Run-out forces
5. Violation of slow orders
6. Violation of track authorities (warrants)
7. Failure to blow the horn at crossings.
8. Failure to stop before red signal.

The results are shown in tabular form below:

RESULTS: MEANS AND STANDARD DEVIATIONS

	Group 1 (ATCS)		Group 2 (Alternate)		Group 3 (Paper)	
Variable	Mean	S.D.	Mean	S.D.	Mean	S.D.
1. Speed	0.0*	0.0	6.5*	3.67	5.7*	5.65
2. Duration	0.0*	0.0	49.9*	46.40	52.1*	45.95
3. Run-In	4.2	3.16	4.4	1.20	3.8	3.06
4. Run-Out	3.0*	2.60	1.6*	1.56	2.8	1.25
5. Slow Order	0.0*	0.0	.5*	.50	.4*	.49
6. Track A.	0.0*	0.0	.2*	.40	.1	.30
7. Horn	6.8	7.15	10.8	12.30	6.4	7.28
8. Signal	0.0	0.0	0.0	0.0	0.0	0.0

(*Indicates significant difference; see discussion of results)

The units of measurement in the table above are MPH for speed and seconds for duration. All other variables are reported as number of occurrences over the 63 mile run.

6. DISCUSSION OF RESULTS

The level 30 ATCS display used in the study appeared to have a strong influence over the control of train speed and a corollary benefit in reduced fuel consumption. The alternative display, added as a comparison, did not show similar advantages. It is reasonable to conclude, therefore, that the differences noted were not due to the simple effect of having a display present. The alternative display did show deceleration/acceleration rates (in miles per hour per minute) and actual track speed limits whenever new speed zones were entered. It did not, however, include a speed predictor similar to that used in the ATCS display. The speed predictor would appear, therefore, to be a prime agent in the superior management of speed of the ATCS group over both the alternative display and the paper warrant groups.

Where differences existed between the ATCS display group and the "paper warrants" group (group #3), a statistical test called the "t test" was used to determine the extent to which differences could have happened by chance alone. A significant t test does not explain the cause of differences but does give a probability frame of reference to the degree of differences noted.

Speed violations and duration of violations were 0 for the ATCS subjects while the other groups posted 5 to 7 mph average excesses held approximately 45 seconds on average. The differences between the ATCS group and other groups were, understandably, significant in a statistical sense. The t test showed that the differences between Group I and the other two groups could have only happened by chance fewer than once in 5000 times.

The ATCS system used in the study calculated a predicted speed for the train based on its current state of operation and the grade changes on the track ahead. This projection was displayed as a small white box which lead the location of the train on the display. When the predicted rate of speed was 4 mph or more higher than allowed for the projected track location, a penalty brake application was invoked.

There was no significant difference between the ATCS group and the paper warrant group in management of in-train forces (run-in and run-out). The ATCS group did, however, produce significantly more run outs than the alternative display group. A difference of this order could have happened by chance fewer than 1 in 10 times. This finding would appear to support the validity of the alternative display as a contrast, since that display does show coupler clearances and in-train forces on a real time basis. These data also invite a conclusion that engineer train handling performance in general can be improved through graphic displays of telemetric data.

The level 30 ATCS display appeared to be better than an alternative display or normal "paper" operation in preventing violations of slow orders or track authorities (warrants). No ATCS subject violated slow orders or track authorities. It should be remembered that the ATCS system assessed penalty brake applications if the speed predictor indicated that the operator would not be able to slow the train to a limited speed (or zero speed for an authority) given current control settings. While these differences were significant, they were not large. A close inspection of the run summaries of all subjects show a universal tendency to slow for slow orders and track authorities. But the ATCS group did so with complete compliance. It seems reasonable to conclude that the speed prediction based penalty brake feature of the ATCS display used in the study has the power to force a high level of compliance. Two of the ATCS display subjects would have violated slow orders associated with work blocks which appeared on the displays had it not been for penalty brake application produced by the ATCS system. In the current study, the penalty application was sufficiently in advance to bring the speed of the train within the limit when the beginning of the speed restriction was reached. In both instances, the observer noted that the subjects were slowing appropriately, but narrowly misjudged the deceleration rate necessary to meet the slow order limits. The display itself may have contributed to these errors, as the speed prediction "box" frequently jumped erratically up and down while the train was being decelerated.

The level 30 ATCS display did not appear to cause distractions in train handling in comparison to an alternative display or normal (traditional warrants and profiles) operation. The ATCS display did not have any indication of the location of crossings while the alternative display did have identifying markers. Neither display appeared to have an effect on signaling for crossings, as no substantial difference appeared between the three groups in this respect. Had either of the two displays caused distractions, they would have shown differences in comparison to the non-display group. This was not the case. The experimental run had many small, rural "farmer's crossings" located in areas with curves and moderate vegetation. In addition, many of these small crossings were unmarked and none of this type had highway vehicles or farm equipment present. Since a number of subjects in each group missed no crossings whatsoever, it may be that missing crossings was a function of engineer experience with conditions similar to those in the experimental run rather than lack of vigilance.

No subject in any of the three groups failed to stop for the red signal presented in the simulation. "Getting past" a red signal is grounds for major disciplinary action on U.S. railroads; consequently, locomotive engineers tend to respond to these signals with a high level of compliance. The complete compliance with red signals by the subjects in the study suggests that they undertook the simulation exercise with a level of seriousness similar to that which they apply to train handling in the real world.

Because of the apparent advantage the ATCS display had for control of speed, the data were inspected for elapsed time and fuel consumption. The findings are shown below:

AVERAGE ELAPSED TIME AND AVERAGE FUEL CONSUMPTION (IN GALLONS)

Group	Elapsed Time	S.D.	Fuel Used	S.D.
ATCS Display	2:12:57*	0:11:37	475.4*	30.05
Alternate Display	2:01:33*	0:07:30	482.7	38.93
Paper Only	2:07:34	0:04:38	504.9*	51.96

(*Indicates significant difference; see text)

The group using the ATCS display took, on average, just under 11 minutes 30 seconds longer (approximately 9.5%) to cover the 63 mile route than the fastest group. As was noted earlier, the ATCS group had no speed violations while the other groups produced a significant number of violations. The ATCS group used less fuel on average than any group and significantly less than the paper warrant group (t of -1.46 implies the differences could have happened by chance less frequently than one time in ten). While the difference noted works out to a savings of only 4.2% based on averages, total group consumption is more telling. The ATCS display group used a total of 4,754 gallons, while the paper warrant group used 5,049 gallons, a savings of 295 gallons. The ATCS group savings was 73 gallons over the alternative display group, a difference which was not statistically significant. The conclusion seems warranted that improved feedback to the engineer of train conditions seems to decrease fuel consumption and that this benefit comes from improved management of speed.

7. IMPLICATIONS FOR FURTHER RESEARCH

One of the tendencies noted in the current study, when the data were reviewed on a line by line (trip log) basis, was that of "running at the limit." All subjects showed a tendency under these conditions of occasionally going over the nominal limit, as a consequence of grade effects. Since the ATCS subjects were less likely to exceed speed limits by the 4 mph level used in the study, it appears that performance was the result of either or both of the two distinctive features of the display: (1) an impending penalty brake application; and/or (2) the leading speed prediction marker. Since these features of the ATCS display worked so well, and did so without apparently causing decreased vigilance, it seems reasonable and productive to study the independent and interactive effects of penalty brake and leading speed prediction.

In recent years, simulation and instrumentation studies have established an improved knowledge base in regard to the effect of various train handling practices upon in-train forces. Since many train handling problems arise from untimely attempts to alter the speed of the train, it stands to reason that an ATCS instrumentation which leads to better speed management may well decrease train accidents and incidents which are caused by improper train handling. Research aimed at displays intended to optimize speed and in-train forces seems justified by the potential benefit.

In a recent pilot study of stress and fatigue in locomotive engineers (FRA-ORD/92/17), a tendency was noted for vigilance to be apparently lowered in situations requiring reduced operator control actions. It may be that the refined control of speed available to the engineer and/or the impending penalty brake application of the level 30 ATCS display used in the current study may provide an influence which increases vigilance during periods of reduced control demand. It may be productive, therefore, to see if the presence of the level 30 ATCS display causes an increase in control actions and in measures of vigilance over territory segments characterized as "low control demand."

APPENDIX A

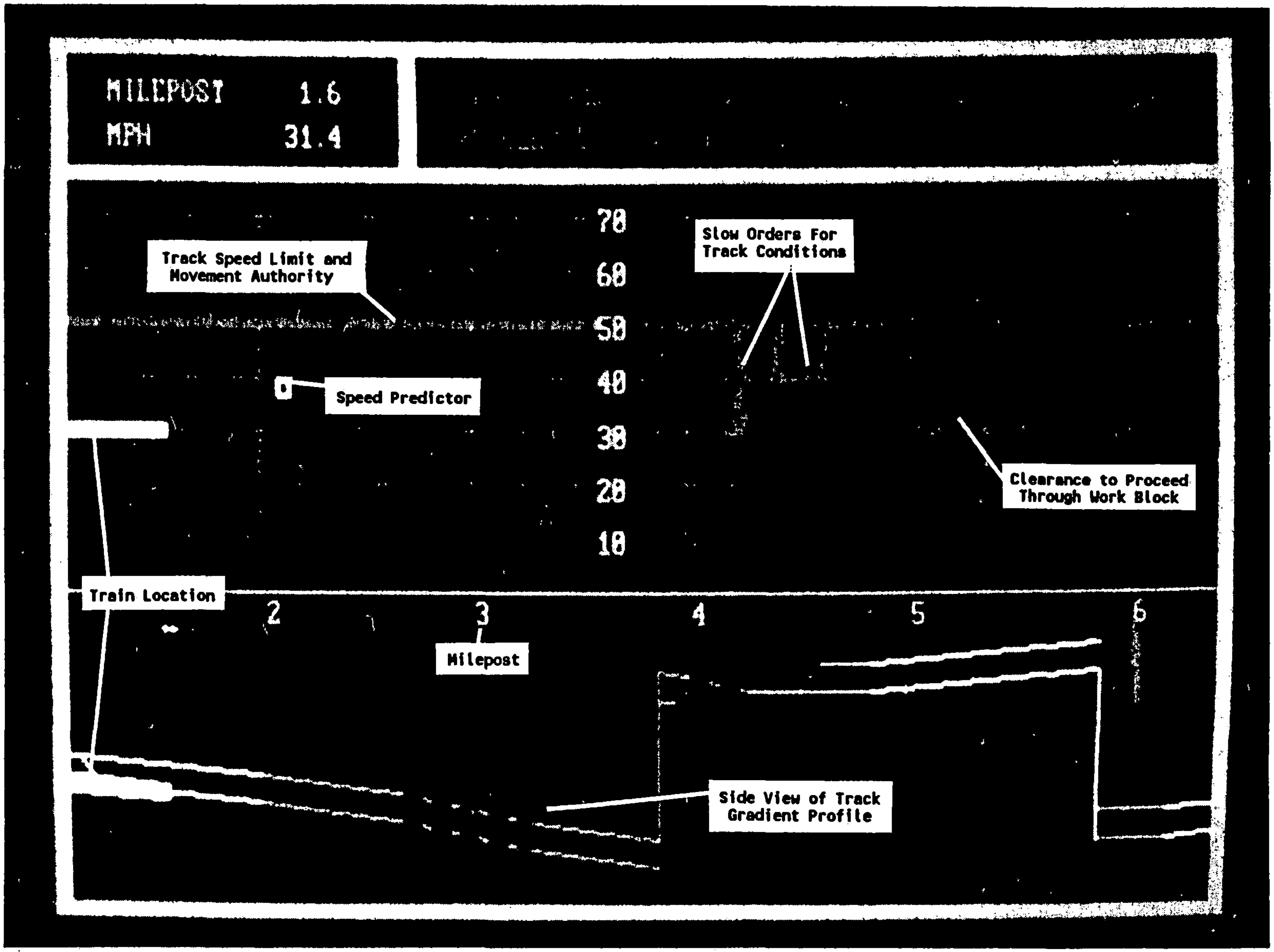
This appendix contains a representation of the ATCS Specification 320 display used in the study. Specification 320 permits variation in display formats. Extrapolation of results in the current study to other Specification 320 display formats should be undertaken with caution.

The simulation head end locomotive was run "short hood" forward. The display was shown on a 14 inch VGA monitor located with its base 12 inches above the left side of a standard AAR 105 cab stand. The display face was tilted approximately 30 degrees to place it perpendicular to the engineer's line of sight.

The graphic display software itself was originally developed for the Canadian National Railroad and provided by the Advanced Train Control Systems program at Canadian National. The display software was processed by a standard IBM compatible personal computer. Adaptations were made by IITRI to allow communication between the RALES simulator and the personal computer.

The level 30 ATCS display (page A-3) provides a representation of the train on a track profile which scrolls from right to left in step with the forward motion of the train. The train is also depicted as a horizontal bar which rises and falls against a marked scale which indicates train speed. Track speed limits are shown in text form as well as in the form of a red, horizontal track authority bar plotted on the same speed display upon which the train appears. As the train increases in speed, it rises to meet (or exceed) the track authority speed bar. The end of authority to move is displayed by a 90 degree downward turn of the authority bar to the baseline. Slow orders are represented as inverted barrier blocks which descend from the authority/speed bar to reduce the "headroom" which indicates maximum speed.

Work blocks under the authority of a track foreman are represented as inverted barrier blocks which descend from the authority/speed bar and touch the baseline. A request to the foreman is necessary for the work block barrier to be raised (normally to a speed less than that displayed by the authority/speed bar). In addition, a white box appears in advance of the train bar. The white box predicts the future speed of the train at the track profile position of the box, given current control settings and the effects of grade. Most importantly, *predicted* train speeds (white box, mentioned earlier) which violated authority, work block or speed limits resulted in an automatic penalty brake application which required a full stop to reset.

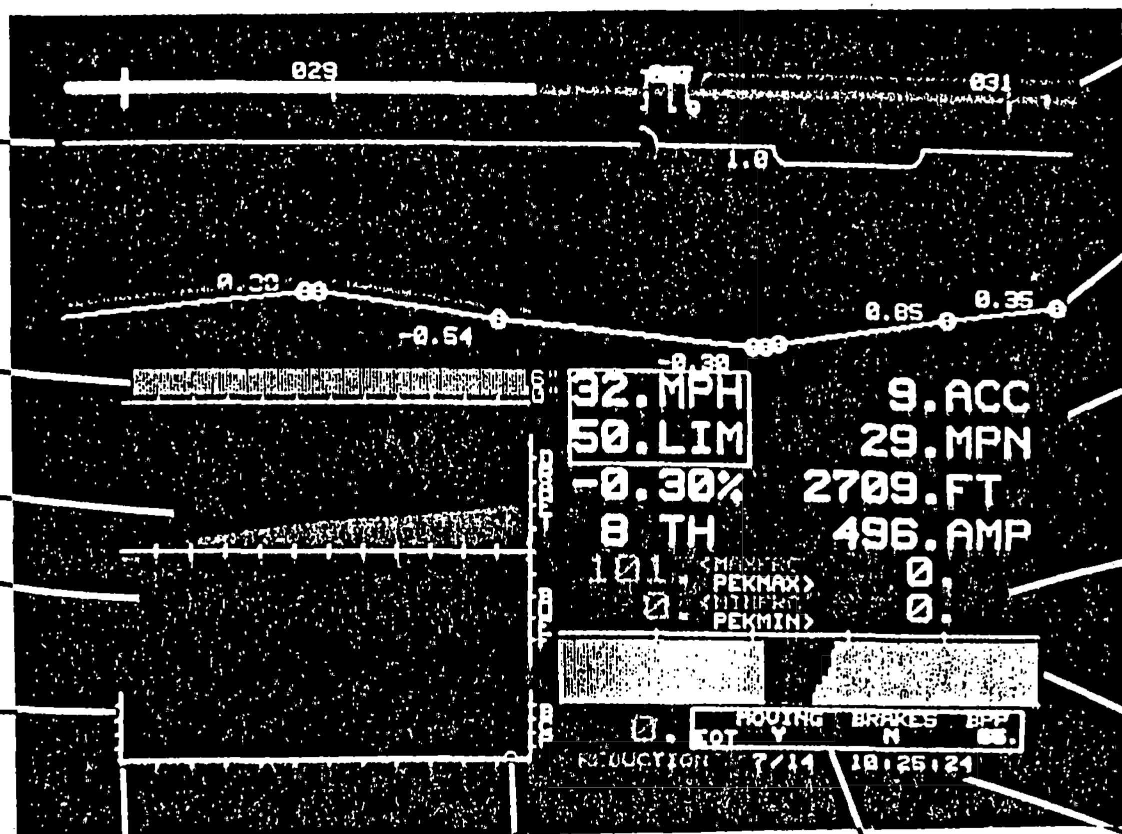


ATCS Level 30 Graphic Display

APPENDIX B

This appendix contains a representation of the IITRI "all in one" or "77 display" used in the study. The alternative display represents feedback on the track crossings, braking systems, coupler slack, and train forces not found in the ATCS 320 display used in the study. The alternative display was included as a contrast or cross-check to the ATCS display. For example, the alternative display does not include pacing information, track authorities, or work block information. The expectation was that the alternative display would be more likely to influence subject management of in-train forces than the ATCS display and less likely than the ATCS display to influence compliance with speed limits or movement authorities. Study findings were consistent with this expectation.

TYPICAL ALL-IN-ONE TRAIN INFORMATION DISPLAY
(120 CARS)



APPENDIX C

This appendix contains the track warrants (or authorities) and example of the track profile type used with the subjects. The first group relied on the ATCS display for this information. The second group relied on the alternative display for the track profile information (including speed limits) but used the warrants for authority to move. The third group used both the track warrants and the track profile which are shown here. All groups communicated with track foremen and a dispatcher role played by a certified supervisor of locomotive engineers.

SOO LINE RAILROAD

TRACK BULLETIN FORM D

No ______________

LOCATION	DATE

TO ______________________________

OK	COPIED BY	DISPATCHER

SOO LINE RAILROAD

TRACK BULLETIN FORM B

No B 206

LOCATION	DATE
Davis Jct	Today

TO C & E Extra 2006 East

ON ______________________________ BE GOVERNED BY RULE 455 WITHIN THE FOLLOWING LIMITS:

LINE VOID	LINE NO.	LIMITS MP	TO MP	FROM	UNTIL	TRACK (S)	FOREMAN OR GANG NO.	STOP
	1	74.9	75.0	12:01A	11:59P	MAIN	WESLEY	
	2	50.0	50.1	12:01A	11:59P	MAIN	ROHTER	
	3	37.9	38.0	12:01A	11:59P	EASTWRD	GRAYDON	
	4							
	5							
	6							
	7							
	8							
	9							
	10							

OK	COPIED BY	DISPATCHER

SOO

TRACK WARRANT

NO. 88 Today 19 92

TO: C & E Extra 2006 East AT: MP80

1. ☐ TRACK WARRANT NO. ________ IS VOID.
2. ☒ PROCEED FROM MP80 TO MP59 ON MAIN TRACK.
3. ☐ PROCEED FROM ________ TO ________ ON ________ TRACK.
4. ☐ WORK BETWEEN ________ AND ________ ON ________ TRACK.
5. ☐ NOT IN EFFECT UNTIL ________.
6. ☐ THIS AUTHORITY EXPIRES AT ________.
7. ☐ NOT IN EFFECT UNTIL AFTER ARRIVAL OF ________.
   AT ________.
8. ☒ HOLD MAIN TRACK AT LAST NAMED POINT.
9. ☐ DO NOT FOUL LIMITS AHEAD OF ________.
10. ☐ CLEAR MAIN TRACK AT LAST NAMED POINT.
11. ☐ BETWEEN ________ AND ________.
    MAKE ALL MOVEMENTS AT RESTRICTED SPEED. LIMITS OCCUPIED BY TRAIN OR ENGINE.
12. ☐ BETWEEN ________ AND ________ MAKE ALL MOVEMENTS AT RESTRICTED SPEED AND STOP SHORT OF MEN OR MACHINES FOULING TRACK.
13. ☒ DO NOT EXCEED 20 MPH BETWEEN MP72.1 AND
    MP 71.9.
14. ☒ DO NOT EXCEED 30 MPH BETWEEN MP67 AND
    MP66 HEAD END ONLY.
15. ☒ PROTECTION AS PRESCRIBED BY RULE 99 NOT REQUIRED AGAINST FOLLOWING TRAINS ON THE SAME TRACK.
16. ☒ TRACK BULLETINS IN EFFECT B206, ____, ____, ____, ____, ____, ____.
17. ☐ OTHER SPECIFIC INSTRUCTIONS: ________

OK NOW DISPATCHER WFT

RELAYED TO ________ COPIED BY Any Body

LIMITS REPORTED CLEAR AT ________ BY ________

FORM 1258 (5-88)

(Mark"X" in box for each item instructed.) C-3

SOO

TRACK WARRANT

NO. 89 Today 19 92

TO: C & E Extra 2006 East AT: MP 59

1. [X] TRACK WARRANT NO. 88 IS VOID.
2. [X] PROCEED FROM MP59 TO MP50 ON MAIN TRACK.
3. [ ] PROCEED FROM ______ TO ______ ON ______ TRACK.
4. [ ] WORK BETWEEN ______ AND ______ ON ______ TRACK.
5. [ ] NOT IN EFFECT UNTIL ______.
6. [ ] THIS AUTHORITY EXPIRES AT ______.
7. [ ] NOT IN EFFECT UNTIL AFTER ARRIVAL OF ______.

   AT ______.
8. [X] HOLD MAIN TRACK AT LAST NAMED POINT.
9. [ ] DO NOT FOUL LIMITS AHEAD OF ______.
10. [ ] CLEAR MAIN TRACK AT LAST NAMED POINT.
11. [ ] BETWEEN ______ AND ______.
    MAKE ALL MOVEMENTS AT RESTRICTED SPEED. LIMITS OCCUPIED BY TRAIN OR ENGINE.
12. [ ] BETWEEN ______ AND ______ MAKE ALL MOVEMENTS AT RESTRICTED SPEED AND STOP SHORT OF MEN OR MACHINES FOULING TRACK.
13. [ ] DO NOT EXCEED ______ MPH BETWEEN ______ AND ______.
14. [ ] DO NOT EXCEED ______ MPH BETWEEN ______ AND ______.
15. [ ] PROTECTION AS PRESCRIBED BY RULE 99 NOT REQUIRED AGAINST FOLLOWING TRAINS ON THE SAME TRACK.
16. [ ] TRACK BULLETINS IN EFFECT ______, ______, ______, ______, ______, ______, ______.
17. [ ] OTHER SPECIFIC INSTRUCTIONS: ______

OK Now DISPATCHER WFT

RELAYED TO ______ COPIED BY Any Body

LIMITS REPORTED CLEAR AT ______ BY ______

FORM 1258 (5-86) (Mark "X" in box for each item instructed.) C-4

SOO

TRACK WARRANT

NO. 91 Today 19 92

TO: C & E Extra 2006 East AT: MP 52

1. [X] TRACK WARRANT NO. 89 IS VOID.
2. [X] PROCEED FROM MP 52 TO MP 44.6 ON MAIN TRACK.
3. [X] PROCEED FROM MP 44.6 TO MP 35.6 ON ESTWRD TRACK.
4. [ ] WORK BETWEEN ______ AND ______ ON ______ TRACK.
5. [ ] NOT IN EFFECT UNTIL ______.
6. [ ] THIS AUTHORITY EXPIRES AT ______.
7. [ ] NOT IN EFFECT UNTIL AFTER ARRIVAL OF ______.
   AT ______.
8. [ ] HOLD MAIN TRACK AT LAST NAMED POINT.
9. [ ] DO NOT FOUL LIMITS AHEAD OF ______.
10. [ ] CLEAR MAIN TRACK AT LAST NAMED POINT.
11. [ ] BETWEEN ______ AND ______.
    MAKE ALL MOVEMENTS AT RESTRICTED SPEED. LIMITS OCCUPIED BY TRAIN OR ENGINE.
12. [ ] BETWEEN ______ AND ______ MAKE ALL MOVEMENTS AT RESTRICTED SPEED AND STOP SHORT OF MEN OR MACHINES FOULING TRACK.
13. [X] DO NOT EXCEED 40 MPH BETWEEN MP 47 AND
    MP 46.
14. [ ] DO NOT EXCEED ______ MPH BETWEEN ______ AND
    ______.
15. [X] PROTECTION AS PRESCRIBED BY RULE 99 NOT REQUIRED AGAINST FOLLOWING TRAINS ON THE SAME TRACK.
16. [X] TRACK BULLETINS IN EFFECT B206, ______, ______, ______, ______, ______, ______.
17. [ ] OTHER SPECIFIC INSTRUCTIONS: ______

OK Now DISPATCHER WFT

RELAYED TO ______ COPIED BY Any Body

LIMITS REPORTED CLEAR AT ______ BY ______

FORM 1258 (5-88) (Mark "X" in box for each item instructed.) C-5

ELGIN SUB

WESTWARD ↓ — EASTWARD ↑

Milepost Location	Station Numbers	Siding Length	STATIONS	Distance from Pingree Grove	Rule 6(A)
15.5	9500		BENSENVILLE YARD	28.9	BKRTY
			1.5		
17.0	9504		TOWER B 17	27.4	IY
			0.2		
17.2	9506		BENSENVILLE	27.2	
			1.9		
19.1	9508		WOOD DALE	25.3	
			1.9		
21.0	9510		ITASCA	23.4	
			2.0		
23.0	9512		MEDINAH	21.4	
			0.9		
23.9	9514		ROSELLE	20.5	
			2.6		
26.5	9516		SCHAUMBURG	17.9	
			1.9		
28.4	9518		HANOVER PARK	16.0	
			1.7		
30.1	9520		BARTLETT	14.3	
			2.6		
32.7	9522		SPAULDING (EJE Crossing)	11.7	IPT
			2.5		
35.2	9524		TOWER B 35 (CNW Crossing)	9.2	IP
			0.8		
36.0			(East End of DT) NATIONAL ST.	8.4	
			0.6		
36.6	9526		ELGIN	7.8	BKRY
			3.2		
39.8			BIG TIMBER RD.		Y
			4.6		
44.4	9525		PINGREE GROVE	93.9	
			6.5		
50.9	9530		HAMPSHIRE	87.4	
			8.3		
59.2	9532	20694	GENOA	79.1	
			20.7		
79.9	9560	21666	(Jct. Janesville Sub) DAVIS JCT. (BN Crossing)	58.4	ATY

SPEED RESTRICTIONS

MAXIMUM SPEED 50

All trains through crossovers at the following locations: 40

Tower B 12 — Roselle

Tower B 17, Third crossover East of Tower — Spaulding, crossover within interlocking

Tower B 35, through turnouts

MAXIMUM, on sidings Genoa, Davis Jct., ... 25

MAXIMUM thru turnout at Pingree Grove 25

BLOCK SYSTEM LIMITS

ABS is in use between Tower A 5 and Pingree Grove. Between Tower A5 and Tower B 17, Rule 255 is in effect. Between Tower B 35 and Pingree Grove, Rule 251 is in effect. Rule 97 does not apply between Tower B 35 and Pingree Grove.

ABS is in use between Pingree Grove and Savanna

CTC is in use between Tower B 17 and Tower B 35, controlled by the operator at Tower B 17.

YARD LIMITS

West Location		East Location
MP40.0	Elgin	Tower B 35

APPENDIX D

This appendix contains the subject consent form used in the study.

IIT RESEARCH INSTITUTE CONSENT FORM

ADVANCE TRAIN CONTROL SYSTEM STUDY

I, ______________________________, consent to be a subject of the research program described below.

1. The purpose of this experiment is to evaluate the effect of two forms of Advance Train Control System displays on the performance of locomotive engineers in comparison with conventional methods of conveying route information. The experiment will be conducted on the locomotive/train simulators at the IIT Research Institute (IITRI).

   I have been selected for this study because I am a certified Train Service Engineer under current FRA regulation.

2. I understand that I will be asked to serve as the human subject for the evaluation.

3. During the evaluation, I will be required to complete a simulated heavy freight run of approximately two hours duration following one hour of orientation (a total of approximately three hours).

4. I understand that my services will be compensated at the firm fixed price of $250 and that no other compensation will be provided.

5. I understand that I may contact any of the following individuals with any questions that I may have about this study or my participation in it as a research subject:

   Name: George Kuehn Title: Principal Investigator

   Organization: Transportation Technology

   Telephone No: 567-4148

6. I understand that any questions I have regarding this research or my rights as a volunteer will be fully answered by George Kuehn or his/her designate. Further, I understand that I am free to withdraw my participation in the project at any time without penalty.

7. I understand that, in the unlikely event of a physical injury, medical emergency treatment will be provided. I also understand that neither George Kuehn nor IITRI will be financially responsible for injuries not due to the negligence of George Kuehn or IITRI which

may be sustained by me while, or as a result of, participating as a subject in this research program.

I have read and understand the various aspects of my participation in this study, all of my questions have been answered, and I voluntarily agree to participate.

Name:______________________________ Name:______________________________

Subject (Print) Witness (Print)

Signature:__________________________ Signature:__________________________

Date:______________________________ Date:______________________________

Advanced Train Control System Evaluation,
George I Kuehn, 1992 -06-Signals, Control &
Communications