

# Improvement of ATCS Operational Safety and Efficiency Through Human Factors Applications

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Successful implementation of any advanced computer system depends on its usage. Users—in this case, enginemen—will not be enticed to use advanced train control systems because these systems have sophisticated software structures and complex hardware configurations. Rather, they will use the systems only if useful information can be obtained through simple man-machine interface (MMI) procedures. Human factoring methods can be used to develop MMI and related displays for the locomotive on-board terminal and to promote safe, efficient, and reliable train operation.

North American railroad companies, in a joint venture, have developed specifications for an advanced train control system (ATCS). These specifications emphasize standardization of ATCS structure and functions while allowing railroad companies and vendors to decide how various functions will be provided at the on-board terminals installed on locomotives.

Several railroad companies have developed subsystems and components with which they can test, on a limited scale, some ATCS functions. These railroad companies are satisfied with the results of their experimental equipment and now want to build pilot ATCSs. The pilot ATCSs are expected to have most or all of the functions and possibly some additional functions or features that individual railroad companies would like. A typical pilot ATCS would be installed on 50 to 100 locomotives and used over a few hundred miles of track.

The pilot ATCS's on-board terminal equipment and functions will probably be designed according to the North American railroad industry's ATCS Specification 320, Locomotive Displays and Control. This specification lists the information that should be available for display at the terminal's screen. The specification also identifies numerous functions—each of which can be requested through the terminal's keyboard. Furthermore, individual railroad companies will probably require additional information and functions, for example, operational instructions ("take siding" and "hold main"), locomotive health monitoring (locomotive load and brake pressure), and operational information (brake and throttle settings, time, direction, and distance to stop). The large amount of information expected to be available at the terminal and the many functions provided for selection at the terminal will pose a serious challenge to the designer—how to design an on-board terminal that is capable of displaying desired information presented in a useful format and how to design man-

machine interface (MMI) procedures in a manner that makes them simple and easy to use.

On-board terminals are supposed to help enginemen operate trains. If an on-board terminal is difficult to use or has displays that do not provide useful information, or the information cannot be easily read, then enginemen will have difficulty using the terminals. In extreme cases, enginemen may be overwhelmed by the complexity of the MMI procedures or by the amount of irrelevant information shown. This could result in operational errors.

Useful information is available only when different displays that support different operational needs or different ATCS functions are provided. The format and content of each display must be geared toward a specific operational need. Each display must be quickly and easily accessible. For this to happen, simple and efficient MMI procedures are needed.

Proper design and successful implementation of the ATCS on-board terminals can be achieved only if the design is supported by suitable human factors activities.

Successful implementation of human factors activities will depend on the following:

- Use of a detailed human factors plan for the design, development, and evaluation of the enginemen's terminals;
- Use of suitable human factors guidelines;
- Careful evaluation of proposed design; and
- Use of human factors specialists who are experienced in design, design evaluation, and follow-up evaluation of MMI equipment and related displays for a variety of advanced computer systems.

The following sections include recommended human factors activities for the development of suitable human factors plans and guidelines and for the evaluation of the proposed design of the on-board terminal.

## HUMAN FACTORS PLAN

Human factors tasks for a specific ATCS project are defined in an ATCS human factors plan document. These tasks are intended to do the following:

- Analyze engineman role, engineman information needs, and the new operational procedures,
- Develop a human factors guidelines document, and
- Evaluate a prototype terminal design and perform a long-term operational evaluation.

Figure 1 shows a typical outline of the scope and contents of an ATCS human factors plan. The following paragraphs describe the scope and contents of each section of the ATCS human factors document outlined in Figure 1.

**Purpose.** This section describes the purpose and scope of the proposed plan and the project for which the plan is designed.

**Reference documents.** This section identifies documents that support plan implementation.

**Plan overview.** This section describes the organization, schedule, resources, and responsibilities necessary to perform the ATCS human factors tasks.

**Analysis efforts.** This section describes the specific human factors analysis tasks for the ATCS project. The following types of analyses are performed:

- Definition of engineman role, including definition of data needed by the enginemen to support their duties, identification of data critical to train operation safety, and identification of data of secondary importance to train operation safety;
- Preparation of specifications, including descriptions of those functions used by the enginemen in a manner that shows the intended train operational procedures;
- Analysis of engineman informational needs, including identification of data items needed to support each major operational task, definition of groups of data items to be available for display at the terminal, and evaluation of the available backup information for use when the ATCS or the terminal fails; and
- Integration of operational procedures, including evaluation of the new train operational procedures proposed to support the ATCS system, evaluation of whether the new operational procedures are effectively integrated into the existing

operational procedures, and verification that the proposed new operational procedures are accepted by the enginemen.

**Design efforts.** This section provides a detailed plan of human factors tasks associated with the terminal design. The tasks are developing a human factors guidelines document and human factors design support.

**Evaluation efforts.** This section provides a detailed plan of the human factors evaluation tasks associated with the terminal development. These tasks are human factor design evaluation of a prototype terminal specifically installed for that purpose in a locomotive and long-term operational evaluation of terminals associated with a pilot ATCS installation.

**Administrative procedures.** This section describes the following human factors administrative procedures: deficiency reporting and resolution; configuration management procedures; and standards, practices, and policies.

## HUMAN FACTORS ANALYSIS EFFORTS

Human factors analysis activities that are performed during the design of the on-board terminal's MMI equipment and displays are defined in a human factors plan document. There are four categories of these activities:

1. Definition of engineman's role. Definition of the engineman's responsibilities and the manner in which the new ATCS can support these responsibilities is an important part of the initial ATCS design activity. The engineman's train-operating responsibilities are identified concurrent with the crew's information needs. The following must be defined: train-operating crew's role and responsibilities with respect to ATCS use, type of information enginemen need to support their duties, information critical to train-operation safety, and information of secondary importance to train-operation safety.

2. Participation in the functional specification preparation. Functions used by enginemen should be described in terms of intended train operational procedures.

3. Engineman's interface analysis. MMI equipment and displays that are poorly designed increase the probability of engineman errors and thus increase the probability of negative operational consequences. To ensure effective user interface, the following types of analysis are suggested: definition of information that would be displayed on the locomotive's on-board terminal, identification of information that meets engineman-required or task-required needs, and evaluation of available back-up information when the ATCS or terminal fails.

4. Procedures integration. Integration of the ATCS's related operational procedures with established train operational procedures reduces the potential for engineman errors. Furthermore, procedure integration reduces training requirements and improves the probability of the enginemen's acceptance of ATCS. The following activities are to be performed: identifying movement authority and speed restriction procedures supported by the new terminals on board the locomotives, integrating the new ATCS operating procedures with the existing train operation procedures, and verifying that the proposed new operating procedures associated with the ATCS's on-board terminals are accepted, from a human factors point of view, by the enginemen who evaluate them.

1. PURPOSE
2. REFERENCE DOCUMENTS
3. PLAN OVERVIEW
  - 3.1 Organization
  - 3.2 Schedule
  - 3.3 Resources
  - 3.4 Responsibilities
4. ANALYSIS EFFORTS
  - 4.1 Definition of Engineman Role
  - 4.2 Participation in Specification Preparation
  - 4.3 Analyzing Engineman's Informational Needs
  - 4.4 Evaluating New Operational Procedures
5. DESIGN EFFORTS
  - 5.1 Developing a Human Factors Guidelines Document
  - 5.2 Design Support
6. EVALUATION EFFORTS
  - 6.1 Design Evaluation
  - 6.2 Long Term Operational Evaluation
7. ADMINISTRATIVE PROCEDURES
  - 7.1 Deficiency Reporting and Resolution
  - 7.2 Configuration Management Procedures
  - 7.3 Standards, Practices, and Policies

**FIGURE 1** Scope and contents of the human factors plan document.

## HUMAN FACTORS GUIDELINES DOCUMENT

A human factors guidelines document for the on-board terminal's MMI equipment and related displays must be developed by human factors specialists. The guidelines should include a description of human factors principles and criteria. The guidelines should address areas where human factors principles should be taken into consideration when designing terminals. These guidelines will support the design and the design review process. Figure 2 shows an example of a table of contents for a human factors guideline document developed for the ATCS on-board terminal. As can be observed, this document addresses large numbers of human factors aspects associated with the terminals.

Human factors guidelines will be used in: (a) assessing what hardware will be needed to support the terminal; (b) designing display screen, keyboard, and data displays for the prototype terminal; (c) reviewing the terminal design specification document against human factors criteria; (d) reviewing the human engineering suitability of the prototype terminal installed on a locomotive; and (e) evaluating terminal usefulness based on long-term operational experience.

For the human factors guidelines to be effective in supporting the design review process, each human factor criterion should be supplemented by an evaluation questionnaire arranged in a checklist format. The questionnaire will help ascertain whether the aspects of human factors principles associated with each criterion have been adhered to. Figure 3 shows an example of a section taken from a human factors guidelines document. This example contains an evaluation questionnaire presented in a checklist format.

## REVIEW PROCESS

The human factors review process consists of three phases: the design, the design evaluation, and the long-term evaluation. The review process, especially during the design and the design evaluation phases, is interactive. It provides an opportunity to resolve problems before the manufacture and installation of the pilot ATCS on-board terminals begin. The design and design evaluation phases are performed in a multi-pass process. (See the feedback pass in Figure 4.)

The first phase of the review process, the design phase, begins by defining the ATCS functions that will be provided at the enginemen's terminals. From this information, the on-board terminal's physical characteristics are specified and candidate displays are defined in sketches or drawings.

During the second phase of the review process, the design evaluation phase, the terminal design specification as well as a prototype terminal installed on a locomotive are evaluated for human engineering suitability. The evaluation proceeds from a review of the suitability of the on-board terminal's MMI procedures for simple and effective use; an evaluation of the display's formats and contents for compatibility with the enginemen's assigned duties; and a determination of the understanding of the displayed information by the enginemen to an empirical assessment of the effectiveness of the displays in helping the enginemen operate the train in a safe and efficient manner.

The third phase of the review process is the long-term operational evaluation of the on-board terminals installed on locomotives selected for the pilot ATCS. These terminals are evaluated by their initial operational experience.

The following sections provide additional details about the specific human factors activities recommended for each of the three phases of the review process.

### Design Phase

During the design phase, candidate displays for the on-board terminal are defined, and the hardware components of the terminal's MMI equipment are listed. During this phase, display objectives and MMI procedures should be considered.

The specific human factors design activities are as follows:

- Recommending specific display format(s) and display contents. When designing a locomotive's displays, it is necessary to establish a format for data presentation that allows the enginemen to rapidly access the point to which they must direct their attention. The format can be textual or graphic. The display format should contain vital information permanently located in a specific area of the screen, thus allowing enginemen to rapidly view the train's primary or most pressing operational needs. Additional operational data may be presented outside this area. This additional data should supply detailed information and explanations for specific operational situations.

- Recommend MMI equipment layout and user procedures.

The display objectives should emphasize their required information content and the choice of optimal techniques to enhance information displayed (e.g., character size, inverse video, blinking, color, intensity, etc.).

MMI equipment must be specified in terms of its physical dimensions, performance characteristics, and environmental suitability. MMI procedures deal with the methods enginemen use to dialogue with the terminal, the on-board computer's response time, and ergonomic considerations.

The candidate displays and MMI equipment should be described in detail in the terminal design specification document. This document should include information about each of the proposed displays (e.g., the display purpose, list of applicable train operating data, and schematic illustration of the proposed display).

The on-board terminal design could be outlined by the railroad's engineering group, the railroad's operating group, or by the on-board terminal supplier's engineering group. The actual design efforts will probably be performed by members of the supplier's engineering group. When, and if needed, these individuals can be assisted by the railroad's engineering or operation personnel.

### Design Evaluation Phase

The terminal design specification document should be reviewed against human factors criteria and design objectives

1.0	DATA ENTRY-KEYBOARD	8.0	MESSAGES AND WARNINGS
1.1	Numeric Keys Arrangement	8.1	Types Needed
1.2	"Hard" Function Keys Arrangement	8.2	Error Messages
1.3	"Soft" Function Keys Arrangement	8.3	Feedback Messages
1.4	Key Dimensions	8.4	User Guide Messages
1.5	Labeling and Nomenclature	8.5	Message Contents
1.6	Key Displacement and Resistance	8.6	Visual Versus Auditory Presentation
1.7	Positive Key Actuation Indication	8.7	Intensity and Frequency
1.8	Keyboard Slope	9.0	GRAPHIC SYMBOLS AND HIGHLIGHTING
1.9	Separation of Keys	9.1	Use of Graphic Symbols
1.10	Key Type	9.2	Use of Color
2.0	TERMINAL'S RESPONSE TIME TO ENGINEMAN ENTRIES	9.3	Use of Highlighting
2.1	Key Activation	9.4	Blinking of Symbols
2.2	Error Feedback	9.5	Inverse Video
2.3	Response to Switch Status Inquiry	10.0	DISPLAY CONTENTS
2.4	Request for Switch Control Function	10.1	Content Density
2.5	Response to "Execute" of Switch Control Function	10.2	Content Integration
3.0	ENGINEMAN USER'S GUIDES	10.3	Format Orientation
3.1	Terminal Operating Procedures	10.4	Cognitive Fidelity
3.2	Train Operating Procedures	10.5	Information Needs
4.0	DISPLAY SCREENS	10.6	Display Layout and Contents
4.1	Display Readability	11.0	USER CHARACTERISTICS
4.2	Reflected Glare	11.1	Anthropometrics
4.3	Screen Luminance and/or Contrast	11.2	Visual Activity and Color Perception
4.4	Display Resolution	11.3	User Experience with Respect to Train Operation
4.5	Refresh Rate	11.4	Age (Cognitive Capacity, Visual System Degradation)
4.6	Display Controls	11.5	Time Available for Viewing the Displays (Work Load)
4.7	Flicker/Movement	11.6	User Response Time
4.8	Viewing Angle	12.0	USER TASKS
4.9	Gray Scale/Color Ability	12.1	Entering Data into the Terminal
4.10	Image Quality	12.2	Train Operation
4.11	Color Quality	12.3	Voice Communication
4.12	Low Light Conditions	12.4	Train and Track Surveillance
4.13	Sunlight Readability	12.5	Managing Problems
5.0	ENGINEMAN-DISPLAY RELATIONSHIP	13.0	TRACK AND ENVIRONMENTAL FACTORS
5.1	Viewing Distance	13.1	Day and Night Operation
5.2	Viewing Angle	13.2	Sunlight Readability
5.3	Screen Location	13.3	Ambient Noise Levels
5.4	Visibility of Data	13.4	Existing Alarms and Warnings
6.0	DATA PRESENTATION FORMAT	13.5	Temperature
6.1	Usefulness of Data	13.6	Humidity
6.2	Lists	13.7	Vibration
6.3	Tabular Information	13.8	Abrasive Environments
6.4	Headings	14.0	LOCOMOTIVE CHARACTERISTICS
7.0	SCREEN LAYOUT AND STRUCTURE	14.1	Available Mounting Locations (i.e., Console Cabs and Traditional Cabs)
7.1	Location of Data Groups	14.2	Cab Seat Feature and Location
7.2	Location of Instructions	14.3	Location of Windows, Doors, Walkways in Cab
7.3	Messages Area	14.4	Foot Rests
7.4	Alarms Area	14.5	Other Display and Controls Used by the Enginemen (e.g., Auxiliary Speedometer, Emergency Brake Valve, Radio, etc.)
7.5	Screen Loading		

**FIGURE 2** Table of contents for a human factors guidelines document.



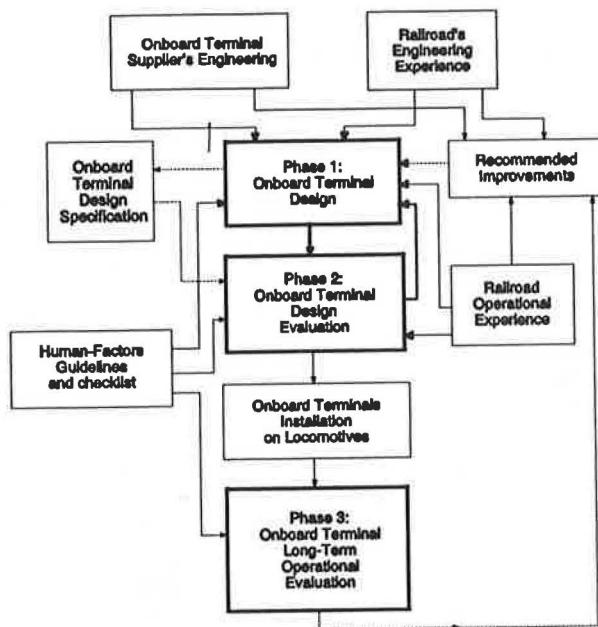


FIGURE 4 On-board terminal design review process.

(i.e., Have the operational needs been adequately addressed? Is the design practical from the enginemen's point of view? Are unforeseen problems in seemingly unrelated aspects of train operation produced by the information included in the enginemen's terminal?) Human factors guidelines and the evaluation checklist should be used to facilitate systematic and consistent evaluation of the proposed on-board terminal.

The design evaluation process should include a review of a prototype on-board terminal, preferably a terminal that was installed for this purpose on a locomotive. The on-board terminal could then be evaluated under "real" conditions.

At least four separate reviews of the on-board terminal design specification document and the prototype terminal should be performed. These reviews could be performed by the railroad's operational representatives. Enginemen, the ultimate users of ATCS, should comment on the proposed terminal's design and evaluate the MMI equipment and related displays by the simplicity of its procedures and by the usefulness of the information accessed, the railroad's engineering representatives, independent individuals from the supplier's engineering group (i.e., individuals other than those who created the terminal design specification document), and human factors specialists.

Design evaluation is vital to the development of an acceptable on-board terminal because it provides an opportunity to detect and correct deficiencies in the proposed design before the pilot on-board terminals are built and installed on locomotives. The design evaluation may indicate a need to modify the keyboard layout, keyboard arrangement, number of keys, screen size, screen type, character size, display contents, displays formats, terminal location, etc. If changes are made, the review process returns to the first phase—the design phase. When the terminal design specification document and the prototype terminal are successfully evaluated, manufacturing and installation of pilot terminals can begin.

The final version of the "as-built" pilot terminals and their displays should be documented in the final version of the terminal design specification document. This document should include a cover sheet that contains the approval signatures, the design specification, and the appropriate technical information showing all relevant data being presented at the on-board terminals.

### Long-Term Operational Evaluation Phase

There should be more than one evaluation. The first evaluation should be done upon completion of the design phase (design evaluation). The second evaluation should be done following installation and initial operation of the pilot ATCS on-board terminals (long-term evaluation).

Long-term acceptance by the enginemen and usefulness in long-term routine operation cannot be addressed during the limited time available in the earlier design evaluation phase. The feedback loop from the "long-term operational evaluation" of the pilot system to "recommended improvements" (see Figure 4) indicates that long-term operational experience is part of the total on-board terminal evaluation. The long-term evaluation may precipitate changes that could then be implemented in a review process similar to the one used for the initial design and implementation of the on-board terminals. Change originators may be the railroad's operational group, the railroad's engineering group, or the supplier's engineering group. Change implementation will be performed by either the supplier or the railroad's engineering group.

### CONCLUSION

During the terminal development phase, several different methodologies should be employed to define the human factors plan; to formulate design requirements; to evaluate terminals based on human factors criteria; and to resolve human factors deficiencies. Among those methods are these four:

- Use of existing human factors literature (this provides data on past research efforts);
- Use of experienced human factors and railroad industry specialists;
- Evaluation of the terminal's design specification document and a prototype terminal installed on a locomotive [this evaluation will be performed by human factors specialists and candidate users (enginemen)]; and
- Long-term operational evaluation of pilot ATCS terminals installed on locomotives (this evaluation will be conducted by human factors specialists, railroad industry specialists, and enginemen).

The performance of ATCSs and, in particular, their on-board terminals, will depend on matching terminal design with the capabilities and limitations of the human users (i.e., enginemen). Users' performance levels will be measured in terms of their ability to meet their task demand. The readability of displays, usefulness of information, ease of locating desired information, proper highlighting of emergency situations, and simplification of MMI procedures are all important perfor-

mance factors. If ATCS are to be viable operational tools, then task demand must match the ability of the enginemen. Human factors considerations influence users' ability to meet task demand. They are, therefore, an important part of the ATCS design.

Systematic evaluation of human factors issues in relation to ATCS requirements is essential in terminal design. When human factors are considered early in the design process, it is probable that design deficiencies will be corrected before the ATCS is operational. In contrast, when attention is focused only on some other components of the ATCS design (e.g., verification and validation and extensive testing) it is possible that operational problems could arise in human factors areas not considered.

## SUMMARY

The human factors engineering process described in this paper is provided for the following:

- Planning human factors methods that support the design, design evaluation, and long-term operational evaluation phases;
- Use of human factors principles and criteria when designing the prototype on-board terminal;
- Evaluation of the prototype terminals based on human factors principles and criteria using a questionnaire arranged in a checklist format; and
- Use of evaluation results to correct human factors deficiencies.

Keyboard layout and key arrangement, display format and contents, legibility of the display device, and simplification of

MMI procedures are all important design factors. Furthermore, the information shown at the on-board terminal's displays must be integrated into the train operation procedures.

The importance of human factors activities in ATCS design cannot be underestimated. Emphasis on effective on-board terminal equipment and displays is expected to increase partially because of the frequency and the severity of the accidents experienced within the railroad industry and partially because of the awareness within the railroad industry of the additional costs incurred as a result of human errors.

A human factors plan should be developed and then implemented during the design and development of on-board terminals. The plan should provide the framework for the application of human factors principles and criteria during the progressive stages of ATCS on-board terminal development. It should summarize present state-of-the-art methods of human factors planning, analysis, design, and evaluation efforts related to ATCS on-board terminal development.

The proposed methods for applying human factors principles should be geared to meet the specific needs of the railroad industry and should provide railroad management, consulting engineers, system suppliers, and the railroads' design teams with procedures and criteria that will help improve train operation safety and efficiency through human factors applications.

The human factoring knowledge used when designing on-board terminals is as important as that used by military, aerospace, and nuclear industries. Although the railroad industry can take pride in its improving safety record, the adverse public reaction to accidents caused by human error makes it essential that on-board terminals be optimized from a human factors point of view.