Technical Article

# Human Machine Interface Systems for *Cockpits in Rail Applications*

Rolling stock for passenger, freight, and switching duty are complex electromechanical systems. Control areas in Locomotives, Electric Multiple Units (EMUs), Diesel Multiple Units (DMUs), Light Rail, and Streetcars can be referred to as the cab, cockpit, driver or operator compartment, control desk, driver area, control cab, or hostler panel (a hostler panel controls railway cars in maintenance yards during coupling and uncoupling operations, and provides manual operation in case of an emergency on the main line). A typical control panel generates information on the availability and status of a variety of critical subsystems. How control cab personnel interact with and respond to this information affects the efficiency, safety, and reliability of rolling stock, with potentially significant impacts on uptime availability and operating costs.

**EMU**

The rail market is experiencing a growth phase after weathering the global economic recession with limited damage. This is likely due to the long lead times and bidding processes for projects around the world. In addition, growing economies in China, India, and Brazil, which fared well during recent years, are modernizing their rail infrastructures. 85% of the market volume is attributed to EMUs, with most operated in Japan, the UK, Germany, France, and Italy, as well as the United States. The leaders in the manufacture and sale of EMUs are Bombardier, Hitachi, Kawasaki, Tokyo Car, Nippon Sharyo, Alstom, Stadler, Siemens, Hyundai Rotem, CAF, and AnsaldoBreda. Market drivers include:

- Demand for mobility in urban areas
- Infrastructure development
- Fleet disposals and replacements
- Availability of financing

**Competition**

The United States is the most important North American market for EMUs with more than 90% of the total installed base. Because of the Buy American Act, many international companies have production operations located in the U.S. Procurement programs to replace aging fleets are expected to continue for the long term.

**DMU**

Worldwide deliveries of DMUs have decreased over the past five years. Top manufacturers include Bombardier, Alstom, and Siemens. The top market drivers for DMUs include:

- Replacement of locomotives with DMUs in Western Europe and Asia;

# The two most important factors are working conditions and the incorporation of information technology into a clear and easy-to-use Human Machine Interface—*Conclusion by the Federal Rail Authority.*

*"One clear contributor to assuring locomotive performance and safety is the attention the industry has given to human factors in the design and evaluation of new and existing rail cabs."*

*"In Europe the UIC Leaflet 612-0 has defined the driver/machine interface for electric and diesel multiple units, locomotives, and driving trailers as functional and system requirements for a driver's cab to be understood and executed as a harmonised human/machine interface."*

**The design of an effective HMI cockpit system begins with the definition of the designer, operator, and passenger.**

- Demand for mobility with increasing passenger volumes;
- Vehicle operation must comply with new, strict environmental standards;
- Increasing competition.

Funding for rail projects in North America was $7.28 billion in 2009, and an additional $10.5 billion in 2010, as well as the recent announcement of an additional $8 billion in funding from the American Recovery and Reinvestment Act. Much of this expenditure will be dedicated to infrastructure and controls, but will most certainly lead to purchases of rolling stock and an increase in New Start Funding. U.S. Transportation Secretary Ray LaHood has already announced $1.58 billion for 28 public transit items. Rail transit projects account for 16 items with more than $1.33 billion in funding. For instance, in early 2010, AMTRAK stated it plans to invest approximately $11 billion over the next 14 years (starting in 2009) on 780 single level cars, 420 bi-level cars, 70 electric locomotives, 264 diesel locomotives and 25 high speed train sets. Its plans for a 15 to 30 year timetable were similarly aggressive.

To operate trains more efficiently and contain sky-rocketing operational costs, railroad managers are making use of HMI Systems that increase productivity. New locomotives, EMUs, and DMUs cost $1.75 million or more and have a life expectancy of about 30 years, while maintenance costs can range from $35,000 to as high as $100,000 a year. Normal maintenance costs plus repair or replacement of failed parts may exceed the initial cost of a locomotive over its lifetime. These clearly are investments that require constant attention to achieve optimum performance and service life.

To meet safety and performance objectives, crews need to be assured that locomotives, EMUs, and DMUs are in proper working order before leaving the yard and while in operation. One clear contributor to assuring locomotive performance and safety is the attention the industry has given to human factors in the design and evaluation of new and existing rail cabs. The need for improvement has been closely examined by the Federal Railroad Administration (FRA) in its assessment of standards developed by the Association of American Railroads on crash-worthiness and working conditions that affect safety and productivity.

The FRA's conclusion is that the two most important factors are working conditions and the incorporation of information technology into a clear and easy-to-use Human Machine Interface.

In addition to the FRA conclusions, in Europe the UIC Leaflet 612-0 has defined the driver/machine interface for electric and diesel multiple units, locomotives, and driving trailers as functional and system requirements for a driver's cab to be understood and executed as a harmonized human/machine interface.

# There are several factors in the rail industry that will increase the demand for new and improved cab control HMI Systems—*Safety and standardisation are among the most important.*

*"Design engineers working on rolling stock applications are developing modular HMI Systems with easily recognisable colours, symbols, groupings, and orientation to increase efficiency and improve workflow and productivity."*

*"The PTC deadline of December 15, 2015, is one of factors driving trend towards HMI Systems that are both easier to use and understand and, at the same time, capable of more sophisticated control."*

**Modular HMI Systems can drop-in can be dropped in to existing cut-outs during a rail refurbishment project.**

**Trends in HMI Systems for driver compartment controls**

There are several factors in the rail industry that will increase the demand for new and improved cab control HMI Systems. These include:

- Political pressure to develop high speed rail lines with improvements to certain corridors across the country;
- Standardization is moving closer to being mandatory;
- Buy American will encourage purchases from domestic suppliers;
- Green initiatives will promote trains that are more fuel efficient;
- Safety improvements through better control systems, including technologies such as Positive Train Control (PTC) systems that require advanced HMI Systems and communications.

Lines that carry passenger rail or toxicby-inhalation (TIH) materials have a PTC deadline of December 31, 2015. These factors are also driving industry trends toward HMI Systems that are both easier to use and understand and, at the same time, capable of more sophisticated control.

Trends in cockpit control include:

- Exacting ergonomic standards for control systems and switching;
- Increased use of display technology for visualization and control;
- Alarm and status signals/indicators that are integrated;
- Efficient system indicator panels with rapid push-to-test;
- Modular design to save money and speed-up replacement;
- High reliability components;
- Regulatory influences from the FRA, UIC and other bodies;
- Easy connection with existing wiring harnesses.

According to studies undertaken by the FRA, train control systems that have been designed with human-centred design principles in mind (i.e. systems that keep human operators as the central active component in the system), are more likely to result in improved safety. As increased automation of systems and controls continues with initiatives like PTC, human-centred design features become more important. One of the goals for the FRA is to ensure that the HMI Systems in the cab keep the operator engaged.

**Design considerations**

The design of an effective HMI cockpit system begins with the definition of the designer, operator, and passenger. While the HMI system designer must keep aesthetics, functionality, ergonomics and safety in mind, they also need to understand how they are different for each user. While the designer receives specific information on the system or subsystem for an application, the operator is waiting to receive information from the system to perform an operation, from driving the train, to maintenance, to repair of the system. According to the FRA, the overriding design concern is to keep the operator from becoming a passive participant. A passive operator

# Time is of the essence for retrofit projects.

## *Replacing rocker switches with modern flush-mounted push-buttons in the operator control console is a quick HMI solution with significant advantages.*

*"The cab interior design layout is specified to accommodate operators in the range of the U.S. 95th percentile for males (six feet, one inch tall) and U.S. 5th percentile for females (five feet tall)."*

*"The HMI System will also offer advance warning as a means of preventing operator overreaction in an emergency. This warning assistance is most important during high workload periods."*


**Modern flush-mount pushbutton controls within a train cockpit.**

is less alert to what the system is doing, more apt to rely too much on the system, and becomes less capable of reacting properly when the system requires the operator's attention.

In every customer design project, a Technical Specification type of document stipulates what the customer wants inside the cab. All required pushbuttons, switches, and other functional components to be installed on the dash assembly are typically specified. It is usually the task of the design team to properly organize and place all the components within the operator's ergonomic reach, with the more important controls closest to the operator. The cab interior design layout is specified to accommodate operators in the range of the U.S. 95th percentile for males (six feet, one inch tall) and U.S. 5th percentile for females (five feet tall).

**Operational/functional requirements**

Part of the design of an HMI System for a rail cockpit application should include a human factors analysis, usually as part of a formal Product Safety Plan. This analysis is gauged at determining how the design performs the following functions:

- Improves operator situational awareness;
- Meets the operator's expectations for consistency and predictability;
- Minimizes the operator's information processing load;
- Anticipates possible human errors;
- Presents information that accurately predicts system states.

Improved awareness is key in reducing operator over-reliance on the system.

The HMI System must promote operator action to maintain awareness and engagement with the system. The operator is required to perform actions from time-to-time as an indication that he/she and the system are in good status and ready mode. The HMI System therefore needs to operate under a management-by-consent versus management-by-exception guideline. In addition to remaining "in-the-loop" for at least 30 minutes at a time, the HMI System must provide the operator timely information on the system's automated functions, as well as immediate notification on any of the operator's manual actions. The HMI System will also offer advance warning as a means of preventing operator overreaction in an emergency. This warning assistance is most important during high workload periods.

As humans can only effectively process one or two streams of information at a time without losing information (called selective attention) the HMI System must reduce an operator's processing load through information integration and a format that allows for clear presentation. An effective format provides information of the highest importance clearly and boldly, avoids presenting too much detail in text, and designs warnings that correlate to the level of risk for the situation. Data should be "chunked" according to importance and function so

*Information needs to be presented in a consistent and predictable manner, so that similar objects/warnings/actions are always presented in a similar manner. There should be a logical and consistent relationship between actions and results.*

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that it is easier to comprehend and process.

In addition, information needs to be presented in a consistent and predictable manner, so that similar objects/warnings/actions are always presented in a similar manner. They should behave similarly when an operator acts upon them. There should be a logical and consistent relationship between actions and results.

Finally, the HMI System design should anticipate possible human error and catch the error before it goes through the system.

**Controls**
Design elements that should be considered in the creation and arrangement of controls include:
- Locating displays adjacent to the controls that affect them;
- Analysis of the operator's normal position to locate displays and controls;
- Minimizing the need for the operator to change positions;
- Arrangement of controls according to their expected order of use and grouping similar controls together;
- Safety-critical controls should require more than one positive action to operate;
- Controls allowing for fast and easy recovery from error.

According to EU UIC 612, design elements that should be considered for information display include:
- Emphasizing the relative importance of information;
- Compliance with ANSI/HFS 100-1988 standard;
- Minimum display contrast of 3:1, with 7:1 preferred, with the brightness and contrast adjustable;
- Displaying only information necessary to the operator;
- Using short, simple text but without abbreviations where possible;
- Placing design elements in a consistent location on all displays;
- Displaying critical information in the centre of the operator's field of vision;
- Grouping items that go together;
- Limiting the number of colours used.

Key information for the operator must be displayed and includes:
- Knowledge of the train's location relevant to relevant entities;
- Knowledge of the type and importance of relevant entities;
- Understanding of the evolution of a situation over time;
- Knowledge of the roles and responsibilities of the relevant entities;
- Knowledge of the expected actions of relevant entities.

**HMI technology, component selection, and panel layout**
The panel layout should be designed to provide the operator functional groups of related information in a predictable and consistent manner. In addition, the system must require an operator to initiate action and keep them informed by providing timely

## Master controllers are complex electromechanical assemblies that enable the safe operation of rolling stock through a precise construction of limit switch and electronic sensors. *They are the most widely evaluated HMI component due to their critical nature.*

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*"Rotary switches also can be used for an application requiring multiple positions, such as driver compartment cab control, temperature, or wiper control."*


**Short-travel keypad technologies are finding their way into subsystem controls, often located adjacent to a visualization display.**

feedback on those actions. The layout should be organized so that the operator is clearly prompted in advance when the next operator action is required.
The panel will incorporate:

- Human factors, workflow analysis, and ergonomics
- Electromechanical assembly
- Ergonomic design
- Durable construction LED illumination

HMI technology and component selection could include a wide variety of components.

**Complex master controller for main train control**

Master controllers are complex electromechanical assemblies. They control the safe operation of rolling stock through a precise construction of limit switch and electronic sensors. They incorporate contact closures with pulse width modulation (PWM) outputs. They are the most widely evaluated HMI component due to their critical nature. They are typically reviewed in the design phase by operators, engineers, and suppliers to provide a balance between safety and control. They are the main interface between human and machine, providing ready control between all operational modes from automated operation to critical train line functions, such as emergency brake activation.

**Switches (pushbutton, rocker, slide, keylock, rotary, etc.)**

Pushbutton switches provide the best option with the ability to flush mount, offering improved up-time operation, positive tactile feedback, and a source of intuitive LED illumination to indicate a quick visual status feedback. Rotary-switch and keylock technologies serve best when the application requires position indicators. Keylocks provide an additional layer of security to the application. Rotary switches also can be used for an application requiring multiple positions, such as driver compartment cab control, temperature, or wiper control.

**Short travel technologies (conductive rubber, membrane, keyboard, keypad, etc.)**

Short travel technology can include cost effective, conductive rubber keys in a typical keyboard, dome keys under an overlay, or a multi-layer membrane. These technologies are finding their way into subsystem controls, often located adjacent to a visualization display.

**Touch and switching technologies, (Piezo, capacitive, high frequency, etc.)**

Piezo, capacitive, and high frequency technologies all offer rugged switch technology with long life cycles and low maintenance costs. Piezo products can use virtually any top layer material, including stainless steel, aluminium, silicon rubber, or plastic with either tactile or non-tactile activation.

Capacitive, or high-frequency signals, electronically activate an on/off function by changing capacitive load. Capacitive/high-frequency technologies require the use of non-conduc-

## Hard-wired systems require no special tools and are simple, visible, and easy to understand, especially where the HMI interface controls a single operation, for example, in power distribution. *This means HMI System connections must fit into standardized wire harnesses.*

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*"IRIS (International Railway Industry Standard) Rev. 02; ensures products meet globally recognized quality levels."*

A Japanese tram cockpit fitted with EAO pushbutton controls.

tive front panel materials which can be up to 15 mm thick, for example those operating under protective glass, within hazardous environments. These modern technologies are in limited use in train control applications.

**Display technologies (LCD, active matrix, OLED, FED, plasma, etc.)**
Display technology choices are dictated by the HMI System environment and its degree of ambient illumination, as well as by colour requirements. Active matrix LCD technologies are commonly used for colour functionality, while legacy LCD technology is used in applications where monochromatic feedback is sufficient. OLEDS, organic (carbon-based) light-emitting diodes can currently support smaller displays.

**Motion control**
Motion control most often employs joystick technology for applications requiring macro control, such as a linear lever for positioning. Motion control applications usually work with proportional output, where the joystick or lever is interfaced with a sensor or array of sensors for directional control. An N, S, E, W arrangement of Hall Effect cells positioned around a central magnet provides low-cost, and stable directional control that is often used in video games or for security surveillance cameras, where motion resolution need not be that fine.

**Connecting/communicating with an HMI System**
Typically, communication/connection on rolling stock is hard-wired. Hard-wired systems require no special tools and are simple, visible, and easy to understand, especially where the HMI interface controls a single operation, for example, in power distribution. Hard-wired controls require that the HMI System connections usually fit into standardized wire harnesses that are use across a rail fleet.

**U.S. and industry standards and test methods by application**
ISO (International Standards Organization): 9000, Quality Management

IRIS (International Railway Industry Standard) Rev. 02; ensures products meet globally recognized quality levels. The goal of IRIS is to develop and implement a global system for the evaluation of companies supplying to the railway industry with uniform language, uniform assessment guidelines, and mutual acceptance of audits, which will create a high level of transparency throughout the supply chain.

EN 50155 develops standards for electronics on railway passenger vehicles

The Federal Railroad Administration (FRA, under the U.S. Department of Transportation) is responsible for defining standards covering safety issues

49 CFR Appendix B to Part 238 – Test Methods and Performance Criteria for the Flammability and Smoke Emission Characteristics of Materials Used in Passenger Cars and Locomotive Cabs

ASTM (under ANSI) and other

*Working with an experienced HMIS supplier can ensure that the system meets all standards and provides the successful and safe operation of locomotives. A supplier must understand the applications, environment, user of the equipment, and the nature of their usage.*


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organizations specify testing procedures in transportation. A range of ASTM standards provide methodology and performance specifications for testing FRA regulations flammability testing

ASTM E 162-02A – Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source

ASTM E 662-03 – Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials

Boeing BSS 7239 – Gas Toxicity Test

Bombarier SMP 800-C Toxic gas generation

Americans with Disabilities Act (ADA)

European Technical Specifications of Interoperability for Persons with Reduced Mobility (TSI-PRM) Standards

American National Standards Institute (ANSI)

Institute of Electrical and Electronics Engineers (IEEE)

UIC 612 for European Guidelines to driver desk design and ergonomics

**Summary**


The effectiveness of the HMI System — and consequent effectiveness of its use — depends upon an exacting design process that incorporates all technical, ergonomic, and communication requirements. For cockpit control in rail applications, working with an experienced HMIS supplier can ensure that the system meets all standards and provides the successful and safe operation of locomotives. Working with a supplier that understands the applications, environment, user of the equipment, and the nature of their usage is critical to the successful implementation of an effective and aesthetically pleasing HMI System for rail cockpit applications.