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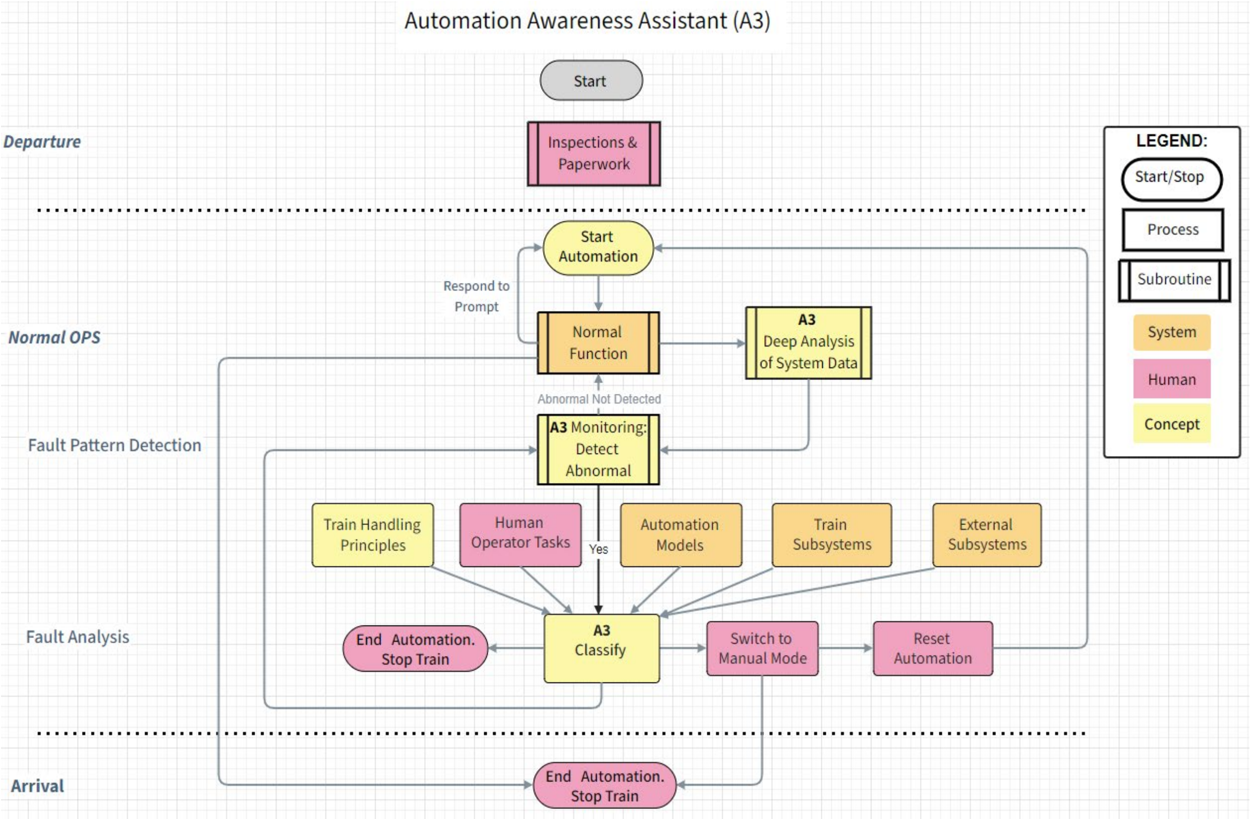
User-Centered Design for Railroad Automation: Phase I



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14. ABSTRACT

This document is the final report for Phase I of a two-phase research project, "User-Centered Design for Railroad Automation (UCD-Rail)," to develop and demonstrate an improved interface between human operators and advanced automation in rail systems. Applying user-centered design methodology, Phase I offers a new rail systems user interface concept called the Automation Awareness Assistant (A3). A3 will improve human operator situation awareness of automated rail functionality and suggest what actions to take if a possible system failure is detected, especially under conditions of high operator workload. A3 will be designed for locomotive cabs, but the A3 user interface concept can be applied and extended to other related rail and transportation systems.

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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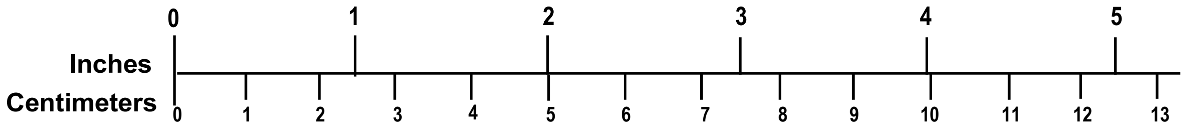
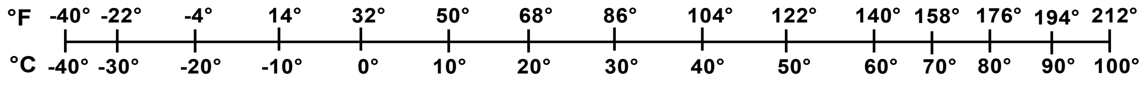
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

This report summarizes Phase I of a two-phase research project, "User-Centered Design for Railroad Automation (UCD-Rail)," which aims to develop and demonstrate an improved interface between human operators and advanced automation in rail systems. The project addresses the need for improvements in human-system integration in railroad systems.

The Federal Railroad Administration's (FRA's) research mission is to ensure the safe, efficient, and reliable movement of people and goods by rail through applied and developmental research. A primary objective is to increase safety by reducing both the likelihood and severity of accidents. Interactions between human operators and automated railroad equipment are an area of concern. Human error is a known contributing or causal factor of accidents in all transportation modes. FRA accident data show that human factors continue to be an element in rail incidents and accidents with automation onboard.

New system capabilities are often layered onto legacy systems to meet evolving requirements. While this approach may make sense from a business perspective, it may not adequately consider the operator's perspective.

This project seeks to adapt human-system integration engineering methods that are known to mitigate risks to augment and enhance human operator performance. The focus in this project is the design of an operator interface for emergent safety and energy management systems in the locomotive cab.

Phase I of this project represents the first iteration of a tailored, spiral development process that applies user-centered design (UCD) methodology. UCD is an agile design process with an iterative approach. This contrasts the "big design upfront" process in which a system is described in a series of requirements and specification documents and then built in stages to meet those requirements (Cowen et al., 2014). Instead, UCD proposes designs in smaller increments with multiple iterations. UCD recognizes up-front requirements, but by creating fast iterations through demonstration of design concepts, the requirements become further refined via the process of prototype validations. Initial concepts may be kept or discarded during the refinement process (Cowen et al., 2014).

In Phase I, the UCD-Rail project team examined human operator rail system touchpoints (i.e., interactions with automated systems) to find the critical tasks specific to human operator awareness of automated functions status. The task and workflow analyses performed here identified key human tasks and activities related to potential automation elements that must be considered when designing new human-machine interface (HMI) options to meet evolving railroad enterprise capabilities and goals. Task and workflow analyses suggest that the human operator needs situation awareness (SA) support to detect, classify, and handle abnormalities when the train is controlled by automated functions, especially under conditions of high operator workload. In Phase I, the authors offer a concept of employment (CONEMP; Appendix A) for the Automation Awareness Assistant (A3), an HMI feature. This new rail systems capability will improve driver SA and suggest what actions to take if a fault is detected. The CONEMP will serve as the baseline for a mature HMI design of A3 in Phase II.

1. Introduction

This project, "User Centered Design for Railroad Automation (UCD-Rail)," aimed to develop and demonstrate an improved interface between human operators and advanced automation in rail systems. The Federal Railroad Administration's (FRA's) research mission is to ensure the safe, efficient, and reliable movement of people and goods by rail through applied and developmental research. A primary objective is to increase safety by reducing both the likelihood and severity of accidents. Interactions between human operators and automated railroad equipment are an area of concern. Human error is a known contributing or causal factor to accidents in all transportation modes. FRA accident data show that human factors continue to be a factor in rail accidents even when automated system are in place. Inappropriately designed automated systems can lead to operator confusion about system functions which can result in human error.

The research team applied the user-centered design (UCD) process to develop and demonstrate a locomotive cab console human machine interface (HMI). The HMI will provide necessary situation awareness (SA) of rail systems states and processes and the operational environment so the human operator can adapt to unexpected situations. UCD, a human task-centered approach, organizes system information and controls in a human activity-centric manner such that normal workflows are efficient (Cowen et al., 2014). Like many multi-display vehicle control legacy systems, the current locomotive cab displays data across multiple console elements without integrating or organizing it by human operator job tasks (see Figure 1). The UCD approach to human interface design helps build operational consoles that help human operators make sense of displayed information.

Figure 1. Locomotive Control Stand with Trip Optimizer

The UCD design process described in this report led the project team to the conclusion that a fundamentally new approach is needed to integrate advanced automation into railroad systems. In Phase I, this project developed a concept of employment (CONEMP; Appendix A) for an HMI feature. The new rail systems capability, called the Automation Awareness Assistant (A3), will improve operator SA and offer suggestions for actions to take if a fault is detected.

1.1 Organization of the Report

This report summarizes Phase I of the UCD-Rail project. The report is organized to explain the concept and development of the A3 display. Section 1.2 details the design and development process. Section 1.3 provides background to the project. Section 1.4 outlines the project objectives. Section 1.5 describes the overall approach and scope of Phase I. Section 1.6 presents the findings, and Section 1.7 provides a discussion and the conclusion of the report.

1.2 Design/Development Process

The UCD-Rail project had two phases; this report is a description of the Phase I effort. Phase I represents the first iteration of a tailored, spiral development process (see Figure 2) that applies UCD methodology. UCD is an agile design process with an iterative approach. This contrasts the "big design upfront" process in which a system is described in a series of requirements and specification documents and then built in stages to meet those requirements (Cowen et al., 2014). UCD is a human task-centered process; it involves conducting a series of iterative testing evolutions to evaluate the user interface and using the results to design and implement usability improvements. UCD involves frequent user interactions to support spiral development of working software to increase relevant functionality and improve usability with each iteration. This is accomplished by eliciting and addressing user needs that are not well-supported, leading to a more intuitive user interface (UI).

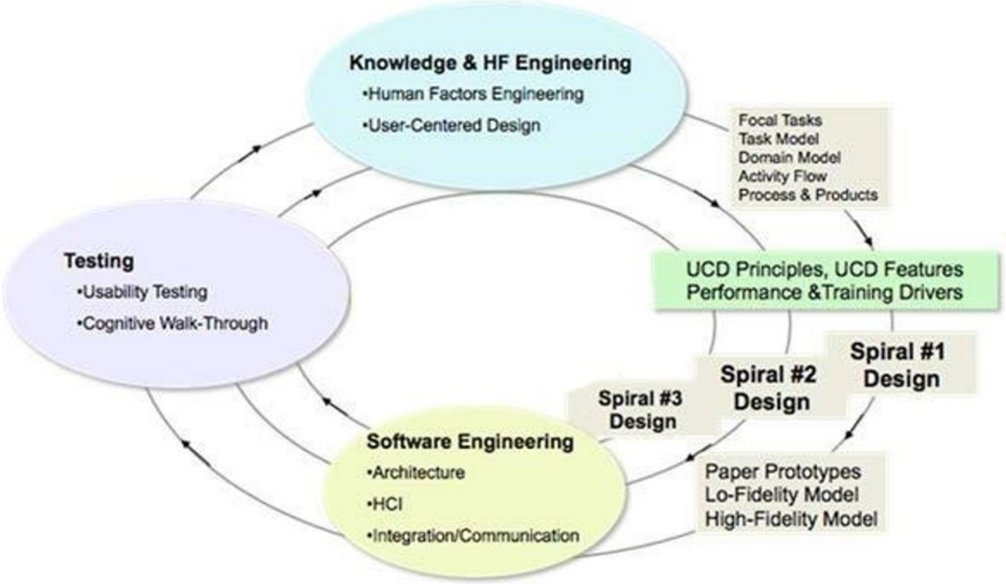

Figure 2. Monterey Technologies, Inc. (MTI) Rail System UI UCD Process

UCD employs agile methods to create and build interactive prototypes tailored to the identified technology advances. This approach enables an iterative design cycle that supports innovation and focuses on critical stages in the decision sequence that enable the task domain. As Figure 2 illustrates, the approach presumes an iterative process that provides an initial prototype that is successively refined and tuned to a specific purpose. This project uses a top-down approach, defining the task domain and user roles to enable system operations.

In UCD, information is "brought to the task" (Cowen et al., 2014) instead of requiring the end user to synthesize information from separate sources. UCD for train operation and control involves the trade-off of function allocations between the human operator and the automated system for executing task steps. The research team explored user interface concepts to support the monitoring and control of automated locomotive capabilities and functions. UCD-Rail's primary objective is to design a locomotive engineer operator console concept that will display the right information and functionality at the right time to manage, adapt to, or override possible unsafe automated rail equipment control options.

This project is tailored from the general process outlined below to meet specific goals to demonstrate both the product and the process.

- Phase I
    - System Domain Definition and Analysis
    - Heuristic Review
    - Trade-Off Analysis
    - HMI Design Concept
- Phase II
    - Initial Prototype
    - Usability Testing
    - Refine Prototype

When both phases are complete, an initial prototype will be available for demonstration and evaluation in simulated locomotive applications, along with preliminary specifications for transition to the operational environment.

UCD-Rail uses a formal system engineering architecture framework called TRAK (2022), derived from a United Kingdom Ministry of Defense project called Ministry of Defense Architecture Framework (MODAF), tailored for rail applications. The project is building a command and control (C2) model of human supervision including direct actions to manage, adapt to, or override possible unsafe or inefficient automated rail equipment control options. Functions and capabilities identified in this project are comprehensive because they are traceable backward to both human and machine components in the rail control systems and forward to enterprise goals suitable for executive decisionmakers in the acquisition process. These functions and capabilities are principled in that the core ideas are derived directly from fundamentals of control theory. They are documented in diagrams and models that conform to the TRAK architecture framework.

In Phase I, the researchers examined human operator rail system tasks to find the critical tasks specific to human operator awareness of automated functions status. UCD-Rail's task and workflow analyses identified key human tasks and activities related to potential automation elements that must be considered when designing new HMI options. The task and workflow analyses suggest that the human operator will need SA support to detect, classify, and handle abnormalities when the train is controlled by automated functions, especially under conditions of high operator workload.

The CONEMP (Appendix A) is a narrative of how the A3 HMI capability is expected to work for a normal trip. A normal trip is a typical train operational timeline from yard departure, traveling in normal operations (OPS), to yard arrival for a train. A3 supports the human operator cognitive monitoring requirements to maintain awareness of train automation; it also supports recognition of anomalies in both system performance and operational situation, leading to risk assessment and mitigation. A3 supports achieving and maintaining automation awareness, supporting the broad capabilities required to meet railroad enterprise goals. The CONEMP also provides enough detail to specify a set of functional requirements for the human rail operator to drive a train safely and efficiently with advanced automated functionality. This CONEMP will serve as the baseline for a mature HMI design of A3 in Phase II.

Embedding the A3 design in the TRAK-based architecture framework ensures that the A3 HMI concept can be used to generate requirements for emerging systems of systems, the function automation, and the HMI to support the addition of new automated functionality into existing and future rail systems. UCD-Rail and its A3 concept are focused on human operational tasks in the locomotive cab with the goal of reducing operator workload and improving operator performance to increase train safety.

1.3 Background

Integrating independently developed automated systems (new and legacy) is a significant challenge, as is integrating the HMI for such systems. During the last 20 years, the rise in applications of information technologies has included increasing levels of automation. Manual legacy train protection and separation practices have evolved toward the development of commercial products to automate control functions in response to the application of information technology to reduce risk of human operator error.

The main train protection product categories are Automatic Train Control (ATC), Positive Train Control (PTC), and Energy Management. ATC can have three subsystems: Automatic Train Operation, Automatic Train Supervision, and Automatic Train Protection. PTC systems (per the Rail Safety Improvement Act of 2008) are designed to prevent train-to-train collisions, over-speed derailments, incursions into established work zones, and the movement of a train through an incorrectly positioned switch. PTC accomplishes this by using technology to monitor train speed and train locations, provide warnings for the train crew to act, and automatically initiate braking if the traincrew does not act.

Trip Optimizer is a train automation energy management product developed to save fuel and simplify train handling (Brooks et al., 2017; Figure 1). This product line is a train operator speed control system that considers terrain, locomotive/car profile, speed restrictions, and operating conditions, automatically controlling throttle and brakes to reduce fuel consumption while maintaining optimal train handling. As shown in Figure 1, the current acquisition approach of adding stove-pipe automation functionality quickly crowds the human operating compartment. Improved human-centered systems integration must be prioritized. Currently, there are no standard solutions to integrate automation product lines with the required Association of American Railroads (AAR) control stand HMI (the AAR-105), resulting in potential information display discrepancies, function activation confusion, and loss of operator SA.

FRA conducts research to develop and demonstrate advanced technologies to reduce risk and increase rail safety. For example, recent research demonstrated new head-up display capability in the locomotive cab, testing advanced energy management capabilities in simulated environments and implementing new information display concepts such as the moving map. These projects are often conducted in coordination with research on new sensors and other components of rolling stock, locomotive, or dispatch/central control systems, in addition to ongoing research into emerging intermodal systems. The present project complements other FRA work by focusing on the underlying systems architecture to manage information flow between human operators and their systems. The resulting A3 concept, once fully developed and demonstrated in Phase II, will be interoperable with other advanced control and display technologies produced by these complementary projects.

1.4 Objectives

The research team's objective is to apply a UCD human factors design and development process to build a cab console HMI, thus providing necessary SA of locomotive cab systems' states and processes and the operational environment so the train human operator can adapt to unexpected situations. The concept will support the monitoring and control of current-generation and future automated locomotive capabilities, features, and functions. The primary objective is to design a locomotive engineer operator display that will show the right information and functionality at the right time to manage, adapt to, or override possible unsafe automated rail equipment control options.

1.5 Overall Approach and Scope

The research team applied a total systems performance approach (Booher, 2003) to UCD-Rail HSI. HSI will ensure that the design of products, software, tasks, and procedures for use in locomotive cabs are compatible with the sensory, perceptual, and cognitive attributes of the personnel who will operate, maintain, and provide training and support for the systems (see Melnik et al., 2018). The project approach is also principle-based. Human-machine function allocation (see Fitts, 1951) is a core element of this work; it is key to the appropriate use of automation in complex human-machine systems.

1.5.1 A3 Architecture Framework

The goal of the product design is to provide operational functionality with simple, intuitive, and familiar interfaces that will enable operators to manage workload and maintain adequate SA. The project team carefully documented this effort in a generic rail enterprise architecture using the TRAK system engineering framework. This approach enables future industry rail systems acquisition authorities to understand how the demonstrated research products contribute to system design goals.

The TRAK metamodel conforms rigorously to ISO/IEC 42010. A distilled human view of the metamodel is illustrated in Figure 3. Though different railroads' enterprise goals may vary, a generic set of goals (along with components such as resources and capabilities) is depicted as TRAK diagrams to conform to the TRAK model.

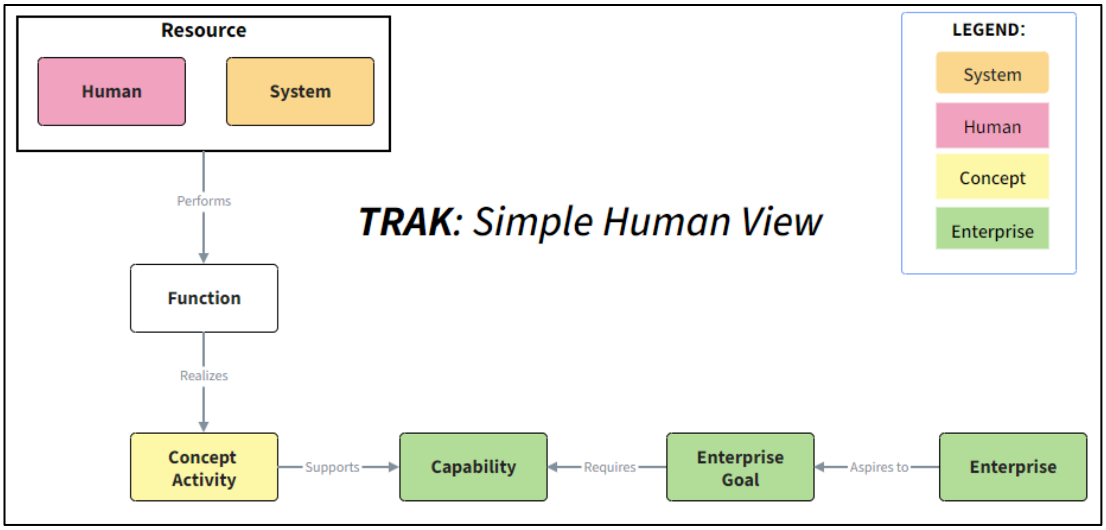

Figure 3. Distilled Simple Human View of TRAK Metamodel

Figure 4 shows a notional example of enterprise goals for a railroad and depicts the specification of enterprise goals from organizational leaders. Resources, functions, capabilities, and design elements are captured in the TRAK model and traced forward to enterprise goals (circled). Enterprise goals tailored for any railroad would likely be similar, at least to the level of description shown in Figure 4. Note the specified relationships among goals and other model elements, as specified in TRAK. For example, Figure 4 illustrates that a function (the salmon-colored boxes on the edges of the figure) realizes a capability. The terms and colors used in subsequent diagrams of A3 and other diagrams developed during the project correspond to this framework. Hence, using the TRAK framework, it is possible to trace the impact of a given system technical feature to enterprise goals, to engineering requirements for low-level onboard subsystems, and to external systems, such as intermodal system safety capabilities.

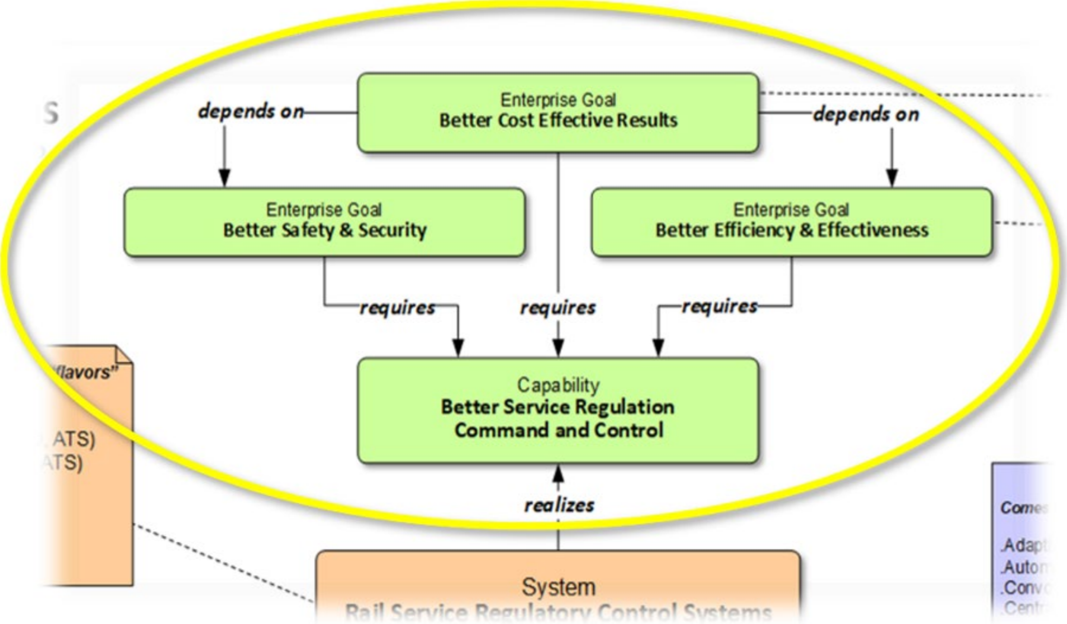

Figure 4. Example Enterprise Goals for a Railroad

1.5.2 Principle-Based Human Factors

An important aspect of system design is further demonstrated in this project through the application of a principle of human-machine function allocation first identified by Fitts (1951), and subsequently elaborated by Sheridan (2000) and Harris and Narkevicius (2016). Many automated functions serve to monitor and control elementary components of complex systems. An HMI is designed to display the available information in a way that can ensure the human operator has the appropriate level of insight into system performance and operational context (e.g., weather, track conditions, intrusions) and can exercise appropriate control authority. To ensure appropriate design, it is essential to understand the structure of the decision-making problem facing the human user. The problem of reasoning from sensor readings to diagnose a system and determine what caused those readings is fundamentally a problem of induction. There is no closed-form solution to the problem of "making sense" from sensor readings, based on several foundational mathematical theorems. This must be considered when devising any automation management system intended to intercede between the human and the controlled elements of the system.

Whether a problem is amenable to solution by deduction (i.e., computation) or by induction (or abduction, a distinct variant of induction recognized by some researchers), depends on the structure of the problem; it is not a choice made by the system designer. Since there is no closed-form solution to problems of induction, solutions cannot be computed with certainty. The final choice of a solution to those problems must be left to human operators with support from deduction machines. Thus, the design challenge is to figure out how to enable and facilitate human induction in real-time control systems. The process taxonomy and general architecture of the solution to this design challenge are well-documented (see Sheridan, 2000; Harris and Narkevicius, 2016). These constructs underpinned the concept development in Phase I and will be realized in a mature design in Phase II. The goal is to devise an HMI to ensure human control and authority over automation and enable the human operator to continually assess the train's situation with the aid of information from automated systems. Automated systems alone are limited in situation assessment by sensor capability and algorithm development.

1.5.3 User Centered Design (UCD)

HSI for rail system and subsystem acquisition requires a formal HMI analysis for automated control capability per 49 CFR 236 Subpart I §236.1013 and 49 CFR 236 Subpart I §236.1015 (see Part 236 appendices – HMI Design). Designers must consider the following human factors issues:

- Reduced operator SA and over-reliance
- Expectation of predictability and consistency in product behavior and communications
- Human operator cognitive limitations to remember and process information

UCD-Rail builds on recent and ongoing FRA-sponsored research (Roth et al., 2020; Brooks, 2020) in operator intent modeling, rail system control, and predictive UIs to tailor and demonstrate a task-centered UI solution for UCD-Rail. The project integrates the data functions (including automated functions) to support display of the right information and functionality at the right time to manage, adapt to, or override possible unsafe automated rail equipment control decisions. This will bring needed information to the activity at hand, reducing operator workload for data searching and entry and function activation.

2. Findings

Implications from the task and workflow analyses suggest that the human operator will need SA support to detect, classify, and address abnormalities when the train is controlled by automated functions, especially under conditions of high operator workload. A3 supports the human operator cognitive monitoring requirements to maintain awareness of train automation, recognition of anomalies, risk assessment and mitigation. The CONEMP also provides enough detail to specify a set of functional requirements for the human rail operator to drive a train safely and efficiently with advanced automated functionality. This CONEMP will serve as the baseline for a mature design of A3.

2.1 Discussion

While increasing automation brings the promise of increasing safety, it may have unintended consequences. The obvious challenge for designers of new rail products is illustrated in Figure 5. The upper illustration (Kaye et al., 2003) depicts the familiar interaction between a human (pink) and a machine (yellow). The system displays information to the human operator, who senses it, processes it, and responds to it by manipulating controls. This process iterates continuously in real-time, interrupted occasionally when the human operator is distracted, or otherwise not in, on, or out of the control loop. The iterative process can be characterized in the time domain as a frequency or latency.

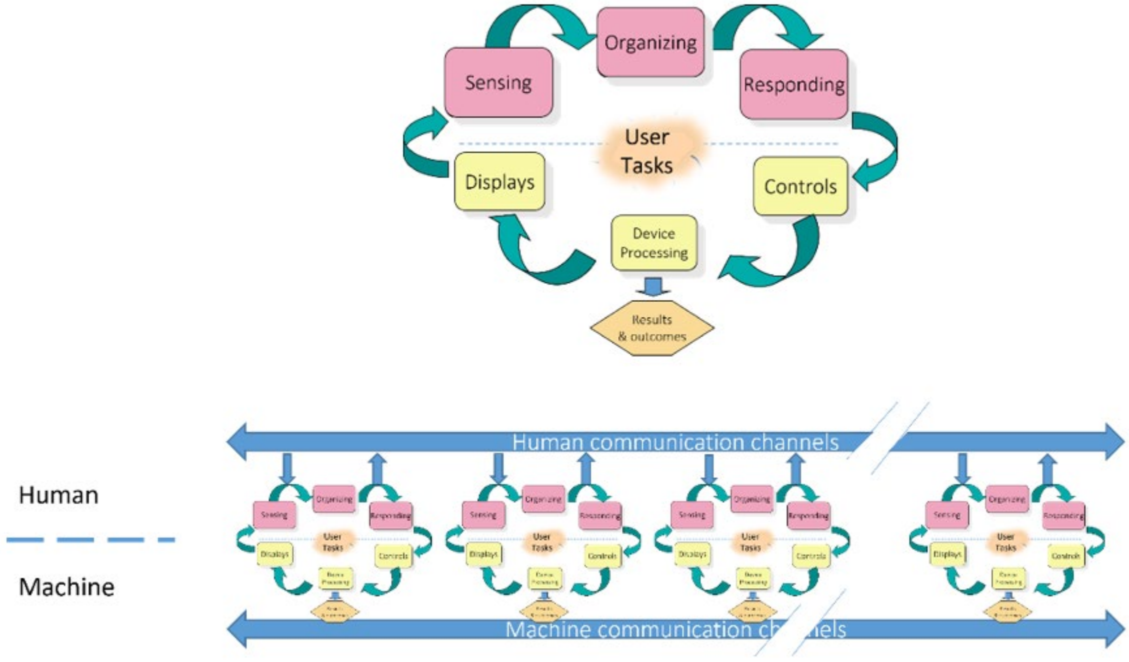

Figure 5. Schematic View of Human-Machine Dyads in Real-Time Control

The limiting factor in this iterative process is often the human operator, who must monitor numerous channels of information, make sense of that information, and create a plan of action. Human information processing takes time and is constrained by cognitive limitations. The capacity to process large amounts of information can easily be overwhelmed by poorly organized displays and controls. The information flows between the human and the machine should be organized around the user tasks at hand. Hence, Phase I focused mostly on identifying critical work tasks and analyzing related workflows.

The lower portion of Figure 5 illustrates that a control system comprises many such human-machine dyads, all of which communicate information through both machine-mediated and human-mediated channels. The design of such systems requires careful consideration of the various tasks by job role, the functions required to do the tasks, and how those task functions support a capability to realize an enterprise goal. Human-system function allocation decisions made in this context have significant impact on system effectiveness and mission performance. The goal of the analysis of human-machine interactions shown in Figure 5 is to identify functional requirements for providing the user with the right information at the right time.

2.1.1 Introduction to A3

The final deliverable from the project Phase I effort is the CONEMP, illustrated as a TRAK viewpoint in Figure 6. This diagram will serve as the starting point for a detailed design and prototype development and demonstration to be completed in Phase II.

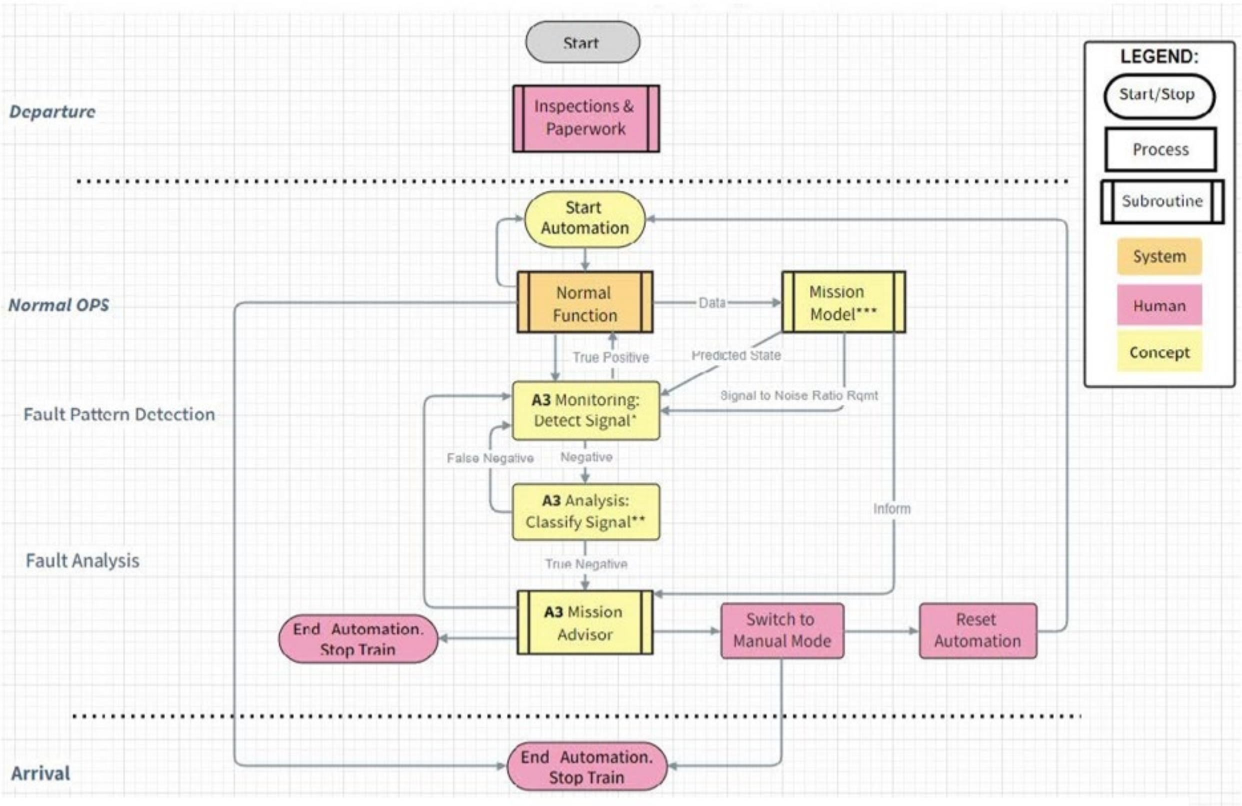

Figure 6. CONEMP for A3

The CONEMP depicts an essential story scenario describing a normal train operational timeline from yard departure, traveling under OPS, to yard arrival for a very long train. The CONEMP follows UCD guidance detailed in the HSI Plan organizing rail operational timelines, required data, and functions in a human activity-centric manner such that a UCD-Rail Phase II A3 HMI design can be easily created.

An innovative component shown in Figure 6 is the Mission Model. This data construct will be maintained by A3 as a current representation of the phase of the trip, including geographic location and extent of the train, consist, schedule and traffic information, and other information to assess whether the train is performing as expected and facilitate operator executive control of automated systems. The A3 monitoring and detection components integrate and maintain data that provide an estimate of system state including indicators of onboard systems as well as environmental factors.

Generally, these components summarize the train's mission and provide an estimate of the state of the system (i.e., the status of capabilities for the human operator to achieve the mission). Figure 6 depicts the final Phase I CONEMP view of the principal components of the A3 capability and the interactions among those components. Detailed treatment of these elements depicted in Figure 6 and the analysis form the architecture of A3.

2.2 Phase I Summary

Phase I represents a total systems human factors design and development process to create a cab console HMI to provide necessary awareness of the operational environment and the rail system's processes/status so the operator can override or adapt to the rail system in unexpected situations. UCD-Rail applies a C2 approach to integrate existing rail systems architectures to address compressed cycle times and more demanding workloads in the rail operational environment. UCD-Rail Phase I is an important step in the design process to develop a human control authority solution to mitigate the risks associated with human-on-the-loop rail system vulnerabilities, where machine errors and brittle automation (Cowen et al., 2021; Hooey et al., 2021) could lead to cascading failures.

Phase I analyzed rail human operator tasks and existing rail system artifacts, including system of systems architectural diagrams. Phase I identified how to address the effects of automation to support design strategies that will make the human operator more aware of deviations from the trip plan, changes to the rail system state, and pending automated courses of action. The system analysis, critical task analysis, and workflow analysis provided the fundamental structure to develop a CONEMP for an HMI technical solution to improve human operator awareness of automated train behaviors for safe and efficient locomotive control. The critical task analysis, workflow analysis, and CONEMP provided a path, visualized in system engineering views, to support the generation of human interaction requirements as rail system automation progresses from human in/on/out of the loop, defining how the human operator will reassert control and retain decision-making while minimizing function activation delays.

3. Conclusion

The locomotive engineer needs HMI assistance to manage surges in workload from unexpected automation behaviors and to make sense of large amounts of rail systems data. The decision support feature being developed by the UCD-Rail team will be able to help manage and display automation status notifications under high signal density situations, integrating information from a variety of train and external sources, to improve SA to support overall mission objectives. A3 will support the operator in getting the right information or affordance to detect and classify faults occurring under automated control, a process that may include alerting and remediation. This can be traced to the rail system not accurately knowing what the human operator is thinking or needs at that moment. The primary challenge for Phase II is designing a role- and task-based HMI to support better decisions without overwhelming the human operator with notifications or losing the capability to simply activate system functions. The following A3 HMI design questions will be addressed in UCD-Rail Phase II:

- How much alerting is needed (depending on the workload)?
- When it is needed, how is it provided and spatially displayed?
- How can status notification algorithms be used to keep the locomotive engineer informed so that the execution cycle is continuous?

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Appendix A.
Concept of Employment (CONEMP)

Document published by Monterey Technologies, Inc.

1. Concept of Employment Deliverable Objective

Previous User Centered Design (UCD) efforts by Monterey Technologies Inc (MTI) in defense and other domains have demonstrated that UCD is key to developing HMI solutions that will reduce driver workload while increasing intelligent vehicle performance (Jimenez, 2017). In this technology demonstration project for the Federal Railroad Administration (FRA), MTI's UCD-Rail team is applying their human factors design and development process to build a prototype cab console human machine interface (HMI) to provide necessary SA (Endsley, 1999) of rail systems' states/processes in the operational environment so the train operator can adapt to unexpected situations. Specifically, the MTI UCD-Rail team is designing and developing a user interface (UI) concept to support the monitoring and control of automated locomotive capabilities, features, and functions. The UCD-Rail overall objective is to design a locomotive engineer operator console dashboard that will display the right information and functionality at the right time to manage, adapt to, or override possible unsafe automated rail equipment control behaviors.

This deliverable presents the UCD-Rail concept of employment (CONEMP), a high-level description and narrative of an HMI solution to improve train operations. A CONEMP provides enough detail for engineers and analysts to specify a set of functional requirements for what the human operator needs to do to drive the train safely and efficiently. This document will serve as the baseline for the design of an initial automation control UI feature for UCD-Rail. Our previous deliverables, the Critical Task Analysis (CTA[1])and the Workflow Analysis (WFA), have provided the fundamental structure to develop a CONEMP (this deliverable) for an HMI console option to meet UCD-Rail project objectives.

Applying formal methods of analysis, our CTA provided a high-level description of function allocation between humans and systems. From the CTA, workflows were then developed to describe users' activities, decision-making circumstances, and steps users take to accomplish critical work tasks essential to meeting mission goals. UCD-Rail methodology follows a human task-centered approach, organizing system information and controls in a human activity-centric manner such that critical workflows are efficient and task products can be easily created (Cowen et al, 2014). In a user-centered design, information is "brought to the task." This approach significantly reduces operator workload by eliminating tasks that require the end user to collect, gather and synergize information from separate sources. Our WFA included an analysis of workload, identifying potential surges in human operator workload along the workflow, a key consideration in the CONEMP on what assistance maybe required to perform under complex or degraded conditions.

Our CONEMP is the final step in the CTA/WFA to UI concept evolution. This Appendix is the reporting of additional paragraphs to the Analysis (Section 7) and Discussion (Section 8)

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[1] Not to be confused with the rail cognitive task analysis described in the Systems Analysis.

headings of the CTA/WFA. Sections 2 through 6 (background topics) are the same. The CONEMP, the CTA, and the WFA will be inputs to the UCD-Rail HMI design plan.

2. Background

Federal Railroad Administration (FRA's) research mission is to ensure the safe, efficient, and reliable movement of people and goods by rail through applied and developmental research. A primary mission objective is to increase safety by reducing both the likelihood of accidents and the amount of loss if there is an accident. Human error is a major cause of accidents. An area of increasing concern is the interaction between the human operator and automated railroad equipment. How do we improve rail safety when automated back-end rail network, sensor, and function activation are not necessarily consistent with what the human operator is trying to get done?

During the last 20 years, the rapid acceleration in applications of information technologies has been led by increasing levels of automation. Manual legacy train protection and separation practices, in response to application of information technology to reduce human operator error, have evolved to the development of commercial products to automate control functions to drive trains safely and efficiently. The main product lines roughly fall into Automatic Train Control (ATC), Positive Train Control (PTC), and Energy Management. ATC can have three subsystems Automatic Train Operation (ATO), Automatic Train Supervision (ATS), and Automatic Train Protection (ATP). PTC systems (Rail Safety Improvement Act of 2008) are designed to prevent train-to-train collisions, over-speed derailments, incursions into established work zones, and the movement of a train through a switch left in the wrong position. PTC accomplishes this by using technology to monitor train speed and train locations, provide warnings for the traincrew to act, and automatically initiate braking if the traincrew does not take action. A recent study of PTC close calls (Hooey et al, 2021) reported that 68% of all respondents indicated that PTC did not work as advertised, noting that in some instances "PTC failed to enforce a stop indication, which is a fundamental requirement for PTC systems."

Rapid advances in train automation are taking place. For example, Train Automation Energy Management products are being developed such as Trip Optimizer (see Brooks et al 2017) to save fuel and simplify train handling. This product line is a train driver speed control system that considers terrain, locomotive/car profile, speed restrictions and operating conditions automatically controlling throttle and brakes to reduce fuel consumption while maintaining optimal train handling. This current acquisition approach of adding stove-pipe automation functionality will quickly clutter the human operating compartment. In the long run, human-centered systems integration will be significantly more effective in achieving true automation than the current accretion approach. Currently, there are no standard solutions nor concepts of operation to integrate automation product lines with the required Association of American Railroads (AAR) control stand HMI, resulting in potential information display discrepancies, function activation confusion, and loss of operator SA.

3. FRA Human Factors Research

The MTI UCD-Rail team is building on recent and ongoing FRA-sponsored research (Brooks et al, 2020, Jones 2022; Mathews et al, 2020; Roth et al, 2020) in operator intent modeling, rail system control, and predictive UIs to tailor and demonstrate a task-centered UI/user experience (UX) solution to reduce risks associated with unreliable automation. The solution will integrate the data elements and functions (including automated) to support actions to display the right information and functionality at the right time to manage, adapt to, or override possible unsafe automated rail equipment control decisions, bringing needed information and agility to the activity at hand, and reducing operator workload to do data searching and entry, and function activation.

A recent study, utilizing the Cab Technology Integration Lab (CTIL), by FRA and General Electric Research about ways to better automate and manage railroad trip functionality (Brooks et al 2017 & 2019) found that the operator's main priority was to achieve awareness of: "Train state, train rules and regulations, train location and extent, track conditions, topography, long term/intermediate train handling plans, new slow orders, overall integrity of the system, safe speed, nearby traffic, state and limitation of the automation system." Maintaining awareness involved comprehending and managing the following general rail system functions: "Train Speed, Braking Systems, Train Forces, Signal Violation, Signal Uncertainty, Dispatcher Communication, Crew Agreement, Stability of Work Environment, Train Location Uncertainty, Work Location Uncertainty, Track Encroachment Uncertainty, Mode of Automation System, Verbal Records, Warning Systems, Track Defects Detection, and Maintenance Crew Communication."

4. Previous UCD-Rail Deliverables

System Analysis

The UCD-Rail System Analysis (previous deliverable) reviewed existing human operator task analyses along with rail system of systems (SoS) architectural diagrams related to the movement of trains with automated functionality. The SoS architectural diagrams were reviewed to determine which operational, system, and technical views need to be considered to generate requirements to design an HMI that provides human operator awareness of automated functions status to safely control train movements. In this deliverable, we examined human operator rail systems interactions (e.g., touch points) to locate and describe the critical tasks specific to human operator awareness of automated functions status to safely and efficiently control train movements, with the objective to meet Enterprise Goals (see TRAK, 2022) considering rail system elements that have the most potential to reduce mission risks related to possible points of automation failure.

Trade-Off Analysis

In the trade-off analysis (previous deliverable) we examined rail systems' components and connections to generate a trade space strategy to optimize rail stakeholder and customer goals (e.g., safety, performance, security, convenience, cost) by considering rail system elements that have the most potential to cause enterprise risks related to possible points of automation failure. Our trade space design offers a flexible approach to the identification and study of potential brittle connections and components that will be addressed by balancing HMI design options. Automation that can rapidly fail is referred to as 'brittle,' because dependable feedback loops break suddenly and without warning. Where applicable, this analysis follows Human Factors best practices and principles on how to allocate tasks between humans and machines (Fitts *et al*, 1951; Harris and Narkevicius, 2016; Hoffman, *et al*, 2002; de Winter and Dodou, 2014). In this deliverable, we will identify key human tasks related to potential brittle automation elements that may impact enterprise goals, requiring necessary mitigation via HMI design solutions.

5. System of Systems Perspective: Command & Control

The purpose of Command & Control (C2)[2] is to enable the effective transfer of information between and among systems and operators to gain situation awareness, make decisions and execute of appropriate courses of action (Cowen & Kaiwi, 2010). "PTC systems are integrated command, control, communications, and information systems for controlling train movements with safety, security, precision, and efficiency (FRA, 2019)." C2 system architectures, because of advances in information technology, have evolved to encompass communications, computers, cybersecurity, intelligence, surveillance, and reconnaissance. The cybersecurity element is a recent, explicit, and necessary addition for robust C2 architectural development (Snyder, 2021). Our system analysis employed this broader perspective to evaluate human operator decision-making to realize safe and efficient rail activation of larger enterprise capabilities (TRAK, 2022). A major thrust of Human Factors is to research concepts and develop tools to facilitate the effectiveness and ease of knowledge management, information foraging and exchange, collaboration, and decision-making in current networked command environments. It is essential that C2 architectures consider how to effectively integrate the human operator with information/network technologies that have automated functions. C2 implies a total systems performance approach (Booher, 2003). The overall Human Factors benefit of applying a principle-based system of systems approach is to ensure (along with doing traditional single system analysis) that the design of products, software, tasks, and procedures intended for implementation in locomotive cabs are compatible with the sensory, perceptual, and cognitive attributes of the personnel who will operate, maintain, provide training, and support the systems (see Melnik et al, 2018). The goal of the HMI product design is to provide operational functionality with simple, intuitive, and familiar interfaces that will enable rail personnel to manage workload and maintain adequate SA.

A system of system approach to select automated and autonomous options to control rail movements requires incorporating Human Factor's methodology (as suggested by Melnik et al, 2018). Assured human control authority over automation is critical to the overall trip management systems performance. Following Human Factors principals, our critical task analysis will help identify control points. Application of human factors engineering (HFE) will be in concert with the trip management software development planning for automated features. Trip management HFE focuses on the system characteristics and features that require HFE methods, guidance, best practices, and standards to enable effective human system performance. For trip management to be effective, the HMI design process considers display mode (visual or auditory), display format, display interactions, and the potential for distraction or interference with concurrent tasks. It also incorporates the workflow of locomotive engineer, conductor, and dispatcher tasks, the sources of data, what the operator must do with the data, where the data goes, and the relationship among tasks that different users must perform. The intended relationship among different users' tasks is being defined in terms of an operational dialogue with associated user cues and information requirements to ensure interoperability from the user's perspective. When designing the HMI, HFEs consider the capabilities of operator roles, the

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[2] The technical components of advanced C2 systems encompass Command and Control (C2) capabilities together with communications, computing, cybersecurity, intelligence, surveillance, and reconnaissance capabilities. The generally recognized acronym for these systems is C5ISR (Snyder, 2021). For purposes of this effort, we mean the term C2 to encompass those related capabilities. Future work will address how these additional capabilities may be considered in the context of rail operations.

interaction of trip management with other rail systems, and the operational requirements for system maintainers and for training. UCD-Rail is utilizing and build on existing FRA resources, notably CTIL, to demonstrate and evaluate evolving HMI concepts. In addition, UCD-Rail HMI development is leveraging multiple defense related C2 products developed previously by MTI.

6. Human Factors in C2 Rail Architectures

As described in the UCD-Rail systems analysis and trade-off deliverables, the human operator tasks related to activating or monitoring rail functions to drive the train have already been studied and described in sufficient detail to generate HMI design requirements for individual cab console displays. As mentioned previously, the current rail freight configurations rely upon user recall and cognitive processing of standard procedures, searching and aggregating data across disparate displays with no decision support. The current cab displays data across multiple console elements without the data being integrated or organized by human operator job tasks. In effect, the human operator must read between the lines and fuse information from multiple sources to assess the present situation, identify trends and calculate appropriate actions. These current confusing configurations are the result of a data-centric systems engineering process that does not deal with overall C2 goals and human task considerations as specified 49 CFR 236 Subpart I §236.1015, only satisfying the usability goals for functional validity.

C2 rail systems architectural diagrams were reviewed to determine which operational, system, and technical views need to be considered to generate requirements to design an HMI that provides human operator awareness of automated functions status to safely control train movements. The UCD-Rail team is examining these architectural views for system of systems potential safety risks related to automated control of train movement as part of the critical task analysis (this deliverable). Relationships within and among the architectural views are being analyzed to identify potential brittle connections. We have also proposed a trade-off strategy to evaluate options to mitigate possible system failures related to unreliable automation components and connections.

A review of current Human Factors research supporting C2 decision-making supports naturalistic decision-making (NDM) approaches when developing human factors technologies that will better anticipate the decisions and data needs for both the console operator and the supervisor. NDM is the model of how people actually make key decisions in real-world settings under conditions of time pressure and uncertainty (Zsambok & Klein, 1997). Expert decision-makers in naturistic settings recognize patterns and don't tend to compare options. They evaluate an option by imagining how it would play out. Morrison et al (1996) proposed some initial designs on how use implications of NDM to support tactical decision-making and has created a program of research to revolutionize and apply these prototypes to other tactical domains and operational warfare. His team's decision support innovations were based on an understanding of case-based reasoning, storytelling, and macro-cognition, counter to the controlled experimental study of decisions that looked at optimizing ways to choose among clear-cut options. Human operators and their supervisors decide by recalling similar situations (pattern recognition) in the past and then adapting the decision to the problem at hand, typically pursuing a single feasible option, rather than creating and comparing multiple alternatives. His method investigated executive decision-maker heuristics, information biases and reasons for poor performance (e.g., tunnel vision, impulsive action, non-transparency, isolation) and he pursued tangible solutions on how to resolve information bias and poor tactical performance. Warner, Letsky & Cowen (2005) developed a macro-cognitive model of team command decision-making to augment these solutions exploring individual mental model construction, individual task knowledge development, and individual visualizations of meaning to create shared understanding in the operational environment.

7. Critical Tasks for Supervision of Rail Automation

Utilizing the TRAK (2022) system engineering architectural framework, we are building a TRAK model of human supervision to control automated train functions safely and efficiently. In this deliverable we examined human operator rail systems touchpoints to locate and describe the critical tasks specific to human operator awareness of automated functions status. Our critical task analysis identifies key human tasks related to potential brittle automation elements that will be addressed by constructing and balancing HMI design options to meet enterprise goals.

The UCD-Rail critical tasks are described in TRAK viewpoints flowing from higher level railroad enterprise goals and capabilities. TRAK provides a way of describing systems for a work domain through architectural models. Architectural models "provide a means to develop an understanding of the complex relationships that exist between organizations, systems, and systems-of-systems and enable the analysis of these systems to ensure that they meet the expectations of the user community (OMG, 2022)." Because of increasing complexity and rising costs, it is important to ensure that systems within and between work domains can communicate/operate with each other (i.e., interoperability) and meet the overarching capabilities that they were intended to achieve. TRAK is an evolving architecture framework developed specifically for use within the British rail industry in support of rail systems acquisition processes[3].

The TRAK enterprise architecture metamodel is shown in Figure G-1. The node and connector elements used to make the TRAK diagrams are defined by the TRAK Metamodel. The TRAK views that contain these elements are defined by TRAK Viewpoints (again, see TRAK, 2022). The TRAK Viewpoint of the Enterprise Perspective (see Figure G-1) describes the enterprise and its high-level goals. Example common enterprise goals in the TRAK trade space include affordability, reliability, security, and convenience. Similarly, specific emerging enterprise goals for rail (derived from the UCD-Rail system analysis) are rail safety, performance (including efficiency), security (both C2 and cargo), and cost. Prospective overarching capabilities to accomplish rail systems enterprise goals are in the areas of vehicle movement, configuration, protection, maintenance, and networks (both information and rail traffic).

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[3] The TRAK architecture framework was originally derived and tailored from more complex frameworks to support British rail programs and procurements. TRAK is routinely employed in transit rail in the US and elsewhere.

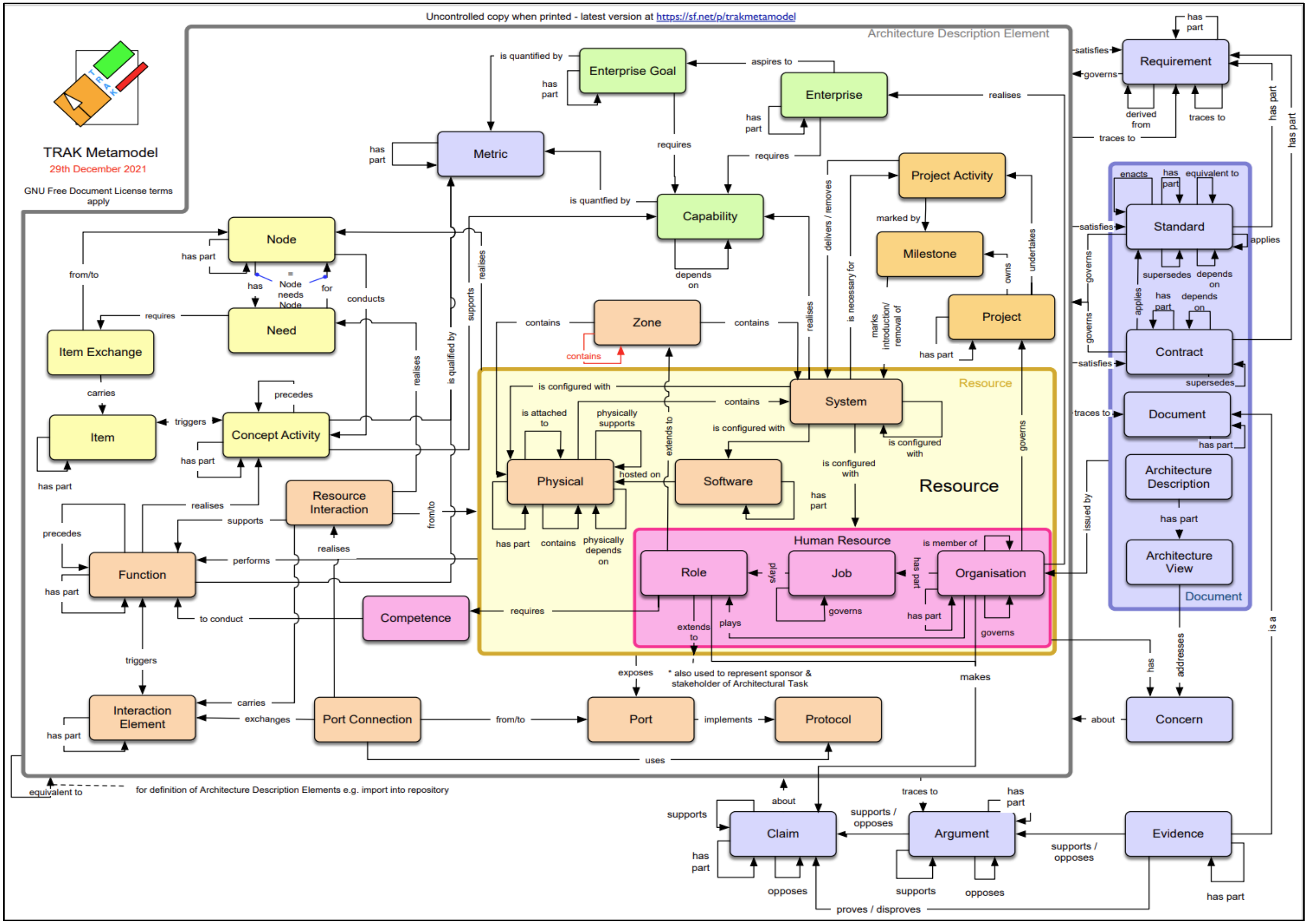

Figure G-1. TRAK Metamodel.

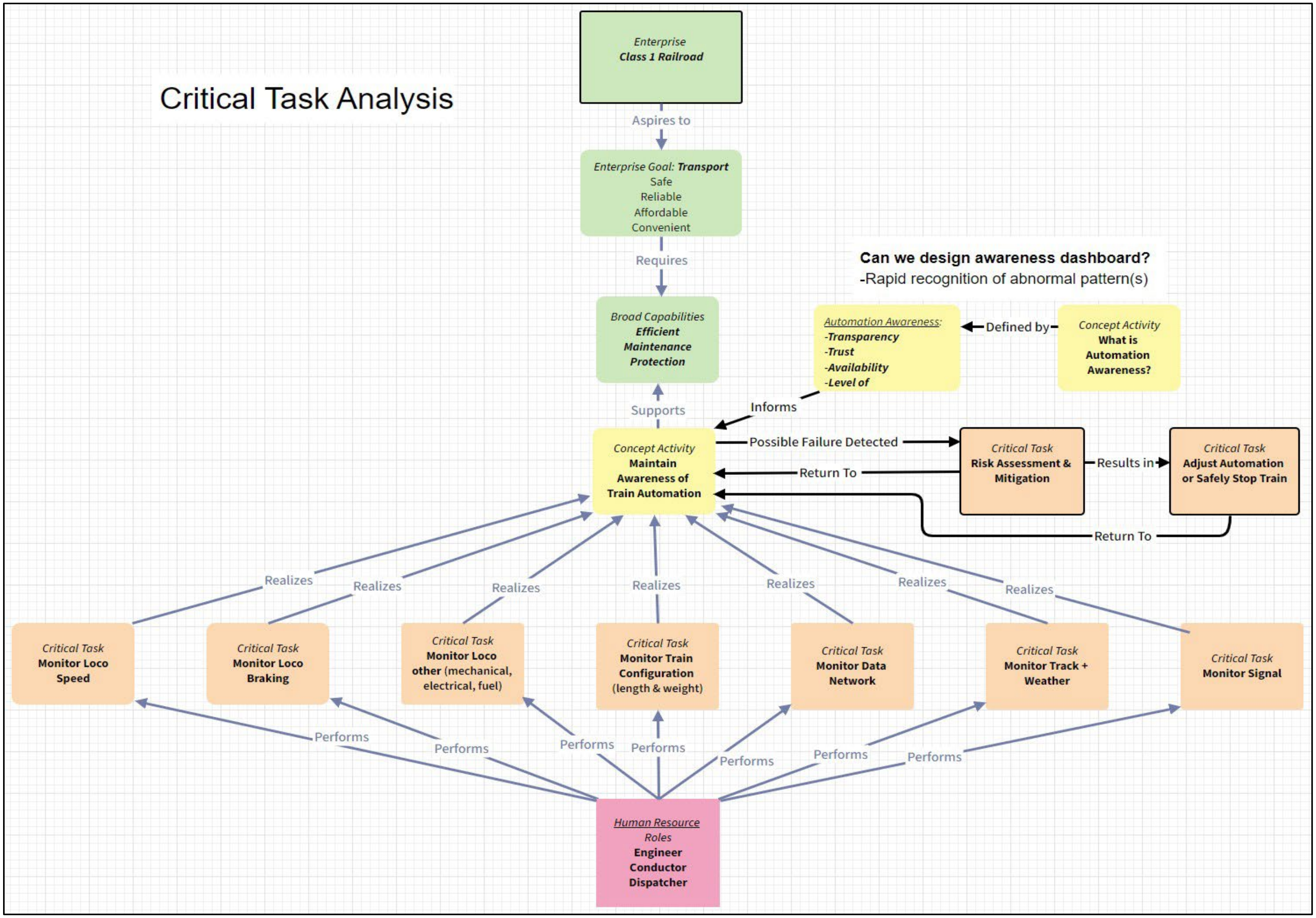

Figure G-2. UCD-Rail Critical Task Analysis Expressed as a TRAK Systems View: Maintain Awareness of Train Automation.

The TRAK architecture views can be built and arranged to describe human operator tasks that support enterprise goals. TRAK diagrams have been found to be useful in analyzing work roles, "especially in the initial phases of exploring allocation of functions across human and technological system elements. Using TRAK in conjunction with other HF techniques (paper prototyping, scenario walkthroughs) is likely to be a strong combination to support automation system design (Lowe, 2010)." Following Lowe's suggestion, we explored human functions required for automation awareness and we built a TRAK systems human view (see Figure G-2) of functional activities for operator situation awareness of automation behaviors that may require human-in-the-loop supervision to meet enterprise safety and efficiency goals. This methodology reflects a new approach of formal methods applied to conventional human factors engineering to build a model of critical human tasks to generate workflows and HMI requirements. Optimizing human-system integration requires UCD-Rail to employ a principle-based approach to systems engineering at the outset that will inform a rigorous, iterative design-development process (Harris & Narkevicius, 2016).

Our TRAK human view (Figure G-2) models the cognitive monitoring requirements to maintain awareness of train automation and specifies the critical tasks for automation awareness, recognition of anomalies, risk assessment and mitigation. The flow of the TRAK critical tasks system view propagates from the human resource (divided into roles) performing sets of functional activities, referred to as focal tasks (Osga et al, 2002) or factors. Function activation of these factors realizes the concept activity (maintain automation awareness) supporting the broad capabilities required to meet enterprise goals. The view also includes a functional task flow for defining automation awareness and what to do if a possible automation failure is detected (risk assessment and mitigation).

Monitoring, as used in the critical task analysis, denotes a complex task that entails continuous assessment of the current state of a complex system with respect to one or more goals, where goals (in this context) represent desired or required system states. Monitoring can be thought of as assessing whether the constantly changing trajectory of the system in a multivariate space is consistent with one or more trajectories that are likely to lead to a predetermined system goal state. Monitoring may also be thought of as assessing whether a pathway through a multidimensional maze is likely to lead to the desired goal state. Such multivariate monitoring requires solution to both deductive and inductive problems. Deductive monitoring processes (i.e., monitoring in the usual sense contemplated in engineering of systems) concern determining whether the projected system state (e.g., in movement orders) is consistent with the observed state (e.g., what the speedometer says). While such operations are easily performed by a computer, the presumption in such circumstances is that sensors are operating correctly, and that the observed and predicted states are both consistent with the system/enterprise goals.

By contrast with deductive monitoring, the determination whether an observed or predicted state is consistent with enterprise goals is an inherently inductive process. For example, an unexpected obstruction of the railway, or weather not consistent with forecasts, or an unusual hardware or software failure will impact complex train operations in incalculable ways. Because there is no closed-form solution to inductive problems, this question is beyond the capabilities of machines, and hence is assigned to the human. Review of a specific critical task, such as Monitor Loco Speed (Figure G-2), thus entails analysis of both inductive and deductive components that matter for the eventual design of hardware and software.

One aspect of the UCD-Rail trade-space strategy (previous deliverable) is to better understand how existing rail system roles and human tasks can be evaluated to optimize enterprise goals**.** As reported in the UCD-Rail Systems Analysis, human operator roles and tasks related to operating locomotives with automated functionality has been extensively studied (see Brooks et al 2017 & 2019). In these studies, the human activities of the locomotive engineer, the conductor, and the dispatcher were described in great detail and analyzed. Both a basic and hierarchical human task analyses were evaluated as well as operator concept maps and cognitive tasks. The level of detail reported is more than sufficient to build hierarchical lists of rail systems' elements for finding the focal tasks (factors) that could be used to form an HMI technical solution to improve human operator understanding to better manage, adapt to, or override possible unsafe automated rail equipment behaviors. From our system and trade space analysis, we extracted the following human monitoring factors for maintaining awareness of train automation: speed, braking, train configuration, data network, railroad tracks, and signals. We also added an "other" category for awareness of other important subsystems (e.g., mechanical, electrical, fuel, etc.) data. We found that the relationships among the roles (the locomotive engineer, the conductor, and the dispatcher) and the factors are complex and, in some cases, redundant so we have combined the roles into a single human resource to simplify the TRAK human view.

The TRAK human view also defines automation awareness and a cognitive process, rapid pattern recognition, to detect a possible automation failure. A review of the human automation interaction research from our trade space deliverable along with a recent *Journal of Cognitive Engineering and Decision-Making* special issue on human automation teaming (Endsley et al, 2022) suggests four facets to gain automation awareness: transparency, availability, trust, and level required. Is there enough automation transparency to support levels of SA (Endsley, 1999) required to adjust the automation or safely stop the system: What is it doing? When does it do it and why?

Transparency is the amount of data visibility required to design and develop a console display to support epistemological concerns about what the end-user needs to know about how the rail automation works, enough to be able to intervene if the automation is not working right (Karn et al, 2014). Availability is system transparency related to automation mode (on/off), possible human intervention, automation triggers, and redundancy. Automation trust, which has been extensively studied, pivots around reliability, human experience including work arounds, and automation complacency. Automation complacency is the condition that occurs when users tend to trust the automation results and disregard other possible contradictory information. Factors that contribute to complacency include long periods of stable operations with few critical decisions, monotony, fatigue, and boredom.

Our TRAK human view also suggests what the human operator should do (i.e., risk assessment and mitigation) if a possible automation failure is detected. TRAK views can be built to visualize system component vulnerability as a way to assess threats that may pose risks to normal function activation (TRAK, 2022). Figure G-3 shows our TRAK human view of critical tasks required for risk assessment and mitigation: Where is the potential fault? Is it a harmless quirk or a known vulnerability? Does the pattern suggest that the human operator adjust the automation or just safely stop the train?

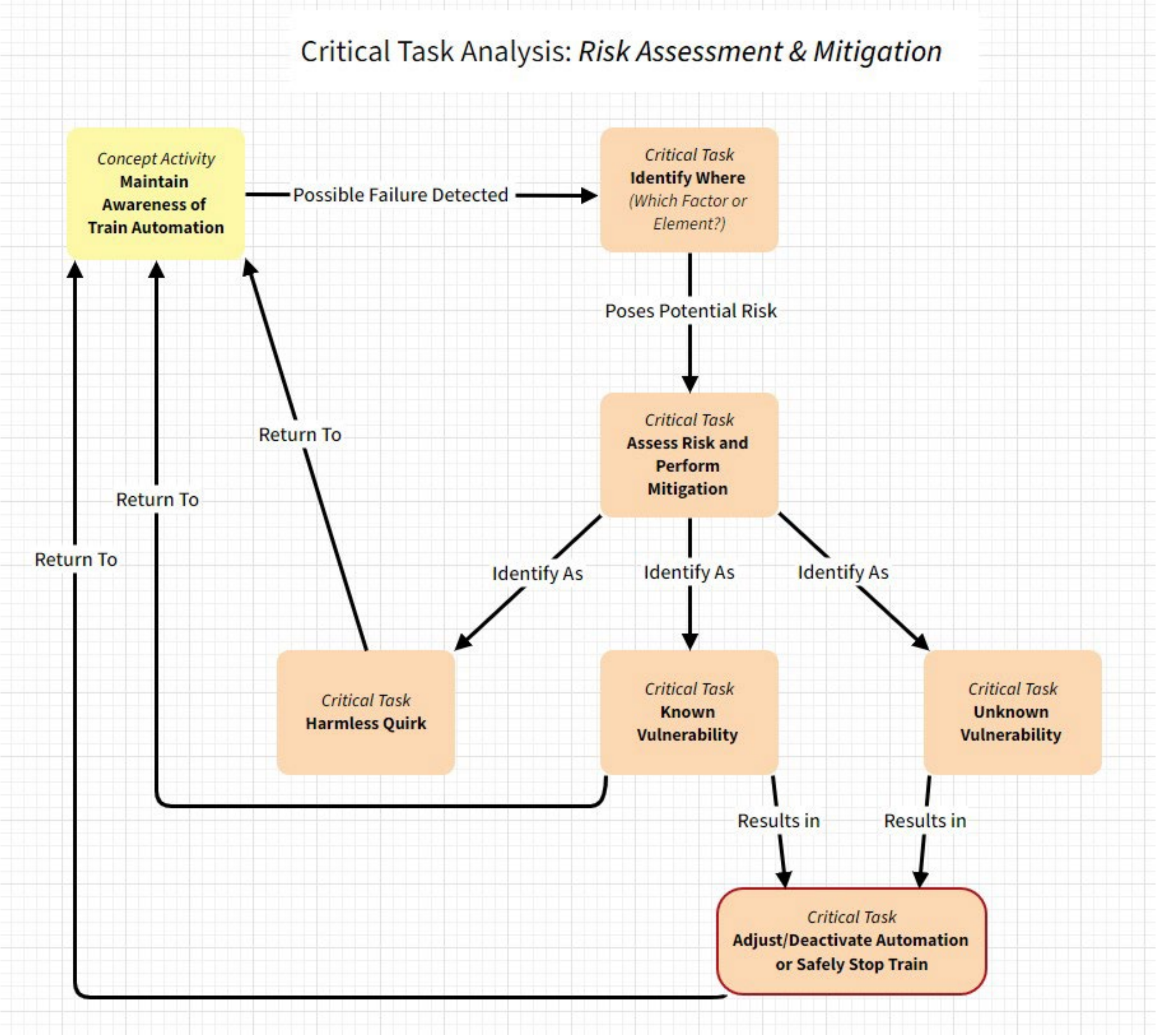

Figure G-3. TRAK Risk Assessment and Mitigation: Critical Tasks

Workflow Analysis

Utilizing the TRAK (2022) system engineering architectural framework, as described in the CTA, we are building a TRAK model of human supervision to control automated train functions safely and efficiently. Our CTA identified key human tasks related to potential brittle automation elements that will be addressed by constructing and balancing HMI design options to meet enterprise goals. In this deliverable we describe human operator rail systems interactions as workflows to locate and describe the identified critical tasks specific to human operator awareness of automated functions status.

Workflows for CTA use cases are described in TRAK viewpoints: One use case is diagramed for Positive Train Control (PTC) and one for Trip Optimizer (TO). See Figures G-4 & G-5. Note that workflow symbology follows American National Standard Institute (ANSI) guidelines with TRAK augmentations.

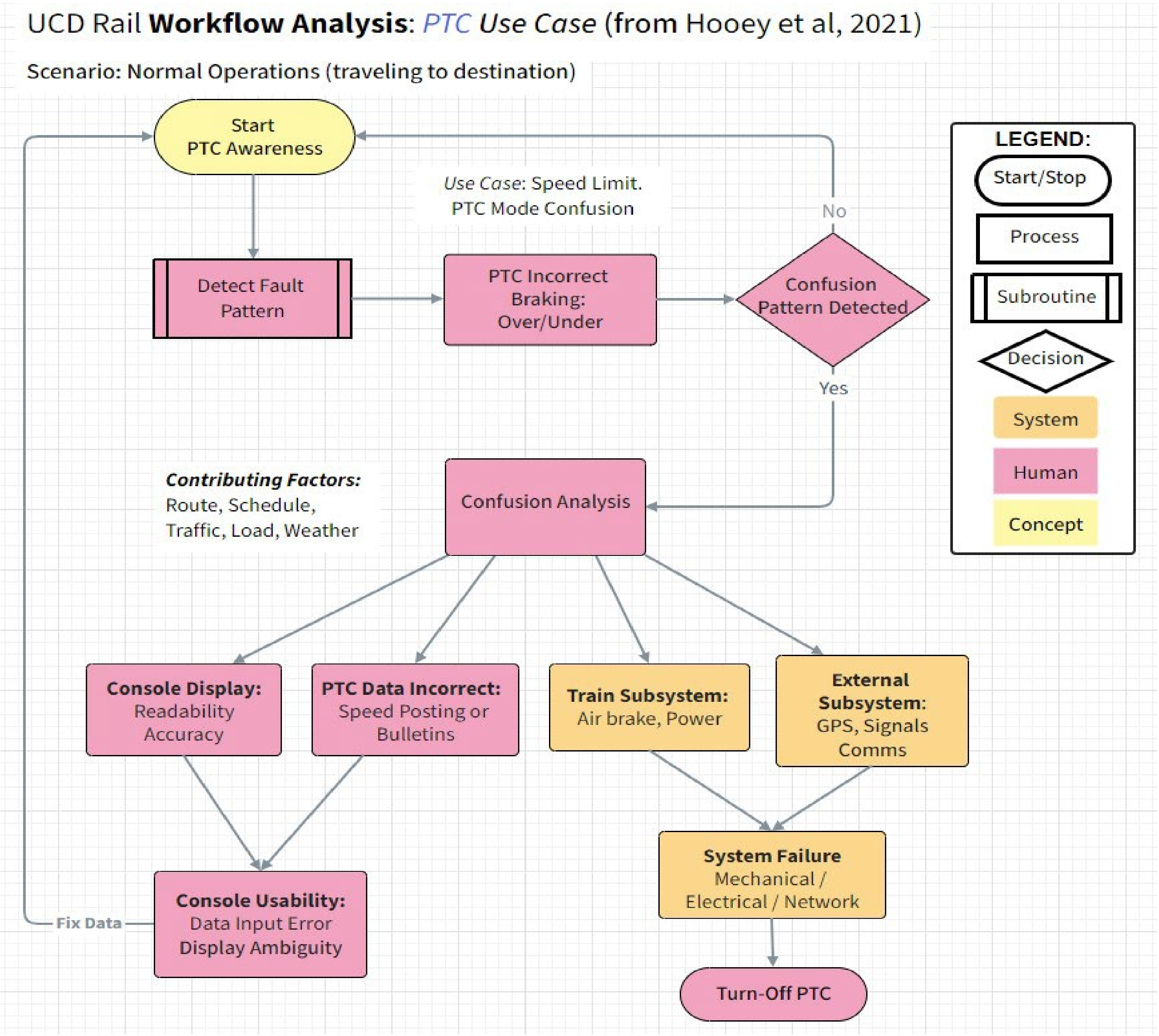

Figure G-4. UCD-Rail Workflow: PTC Use Case.

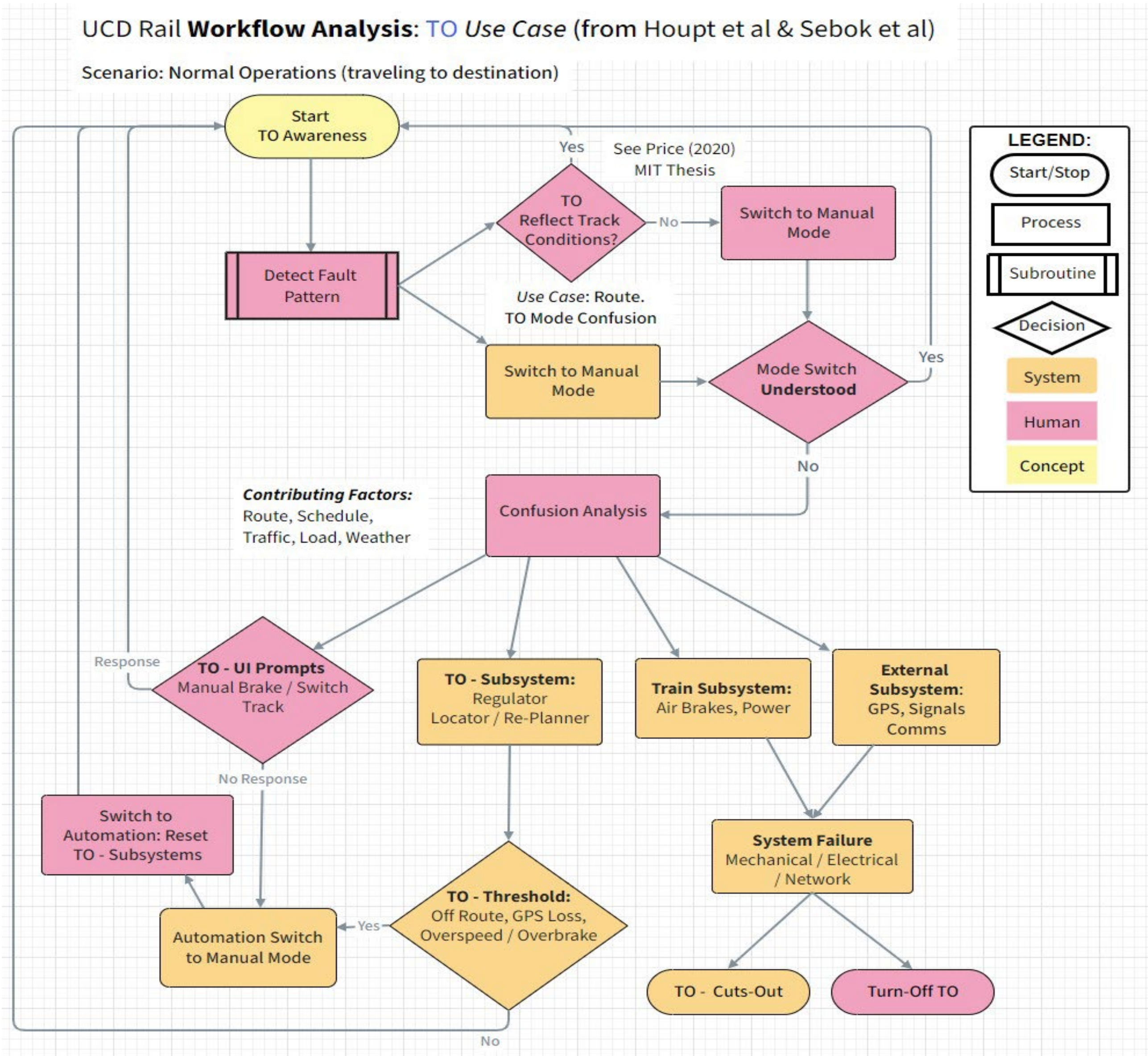

Figure G-5. UCD-Rail Workflow: TO Use Case.

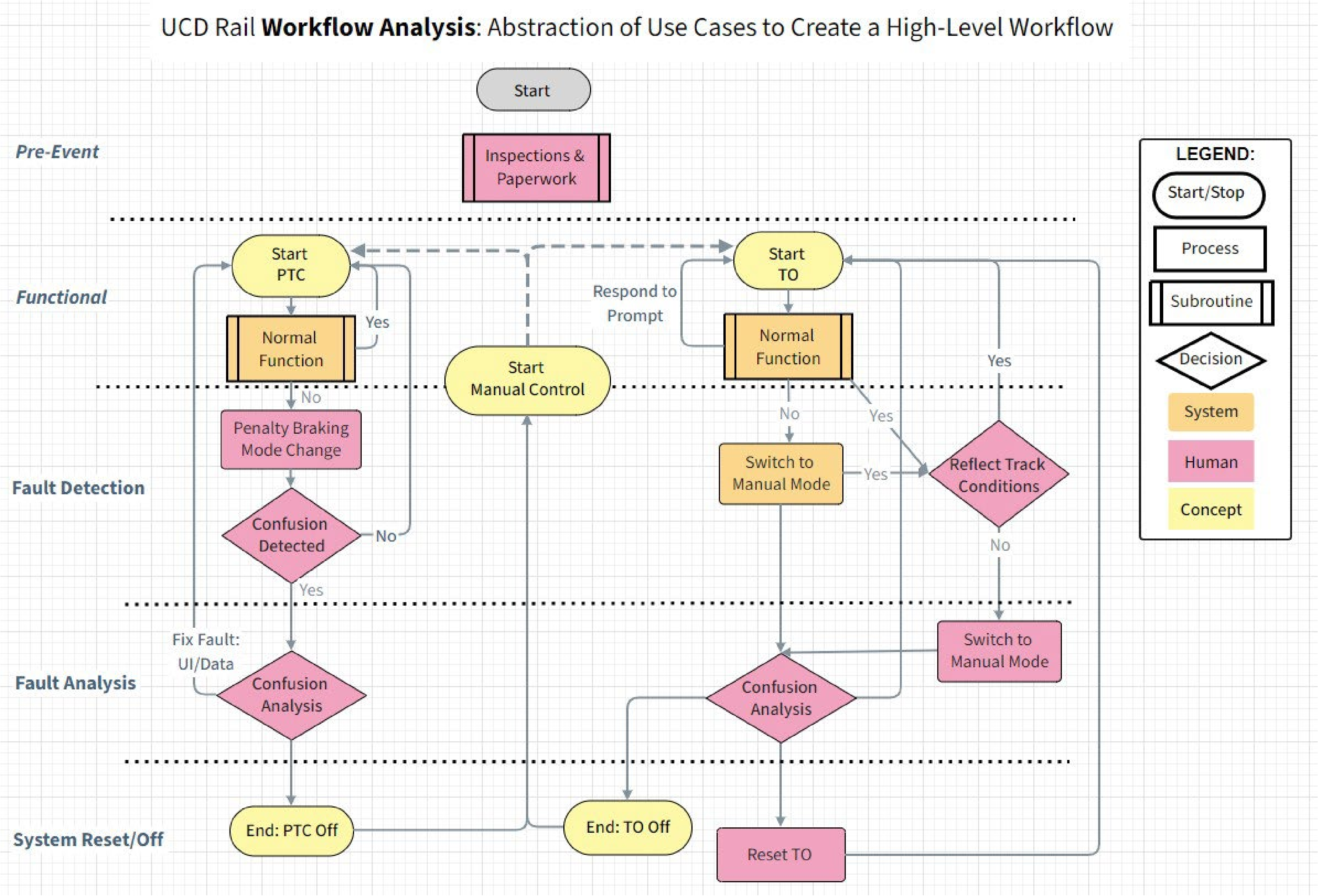

Figure G-6. UCD-Rail Workflow: PTC + TO Combined

TRAK provides a way of describing workflows for a systems domain through architectural diagramming tools. This provides "a means to develop an understanding of the complex relationships that exist between organizations, systems, and systems-of-systems and enable the analysis of these systems to ensure that they meet the expectations of the user community (OMG, 2022)." Because of increasing complexity and rising costs, it is important to ensure that workflows within and between system domains can communicate/operate with each other (i.e., interoperability) and meet the overarching capabilities that they were intended to achieve.

As mentioned in the CTA, our TRAK human view (Figure G-2) models the cognitive monitoring[4] requirements to maintain awareness of train automation and specifies the critical tasks for automation awareness, recognition of anomalies, risk assessment and mitigation. The flow of the TRAK critical tasks system view propagates from the human resource (divided into roles) performing sets of functional activities, referred to as focal tasks (Osga et al, 2002) or factors. Function activation of these factors realizes the concept activity (maintain automation awareness) supporting the broad capabilities required to meet enterprise goals. The view also includes a functional task flow for defining automation awareness and what to do if a possible automation failure is detected (risk assessment and mitigation).

Our diagrammed workflows (in TRAK/ANSI format) follow the human system interaction flow of train automation awareness (from the CTA) detecting a possible fault pattern then deciding whether to turn off the automation. For PTC (See Figure G-4) the use case is whether or not PTC is correctly braking to stay under the track speed limit and how the locomotive driver sorts out the inconsistency through a confusion analysis process. Here, the human operator could detect a data inconsistency on the console and then fix or update the PTC data to get PTC working right and then the PTC awareness process continues (start of flow). Incorrect braking could also be caused by an internal or external systems failure in which case the human operator must turn-off the PTC. [PTC is always on as per train regulations]. The outcome of the confusion analysis is to find PTC elements that can be fixed in real time by driver, else shutdown the PTC automation.

For TO (see Figure G-5) the use case is slightly more complicated: The human operator detects a fault pattern where TO could be switched to manual mode based from the driver's judgement[5] of track conditions or from the TO's underlying optimization algorithm. If the mode switch is understood by the driver, then TO awareness process continues (start of flow). If the driver does not understand the mode switch to manual, then driver sorts out the inconsistency through another confusion analysis process. Mode confusion could be traced to three events: (1) TO may have prompted the driver to perform some action and the driver did not respond. In this case, the driver needs to respond to the prompt and then the TO awareness process continues. (2) External disturbances and large deviation from planned TO inputs and other factors change TO mode to manual. The driver here can re-set TO (to do replanning) and then the TO awareness process continues. (3) In could also be that, similar to what might be happening during PTC, there is an internal or external systems failure in which case TO shuts down by itself or the human operator must turn it off. Contributing factors to mode confusion for TO (and PTC) are heavy train loads and complex locomotives/cars make-up, and the routes, traffic, weather and schedules. How

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[4] A more in-depth discussion of cognitive monitoring can be found in the CTA.

[5] A discussion of reasons why the locomotive engineer may disable TO can be found in Price (2020, 2021).

these factors affect automation reliability will be discussed in more detail in the UCD-Rail CONEMPS (next deliverable).

The use case workflows were combined and simplified to create a high-level workflow (see Figure G-6) for CONEMPS development. The high-level workflow follows a trip timeline where there are pre-trip events followed by normal functioning trip operations (OPS). The workflow shows the typical closed loop between normal OPS and train automation awareness except when an irregular mode pattern (potential fault or failure) is detected by the human operator who then must do a confusion analysis to turn off the automation or fix what is wrong (or let it be). The human operator may have trouble detecting mode fault patterns under conditions of high workload.

Workload
The relationship between safe vehicle driving and task workload has been extensively studied (Kantowitz & Simsek, 2001). As it relates to human control of a machine, workload can be generally defined by the amount information and actions required to do a set of operational tasks measured by the amount of cognitive processing used to accomplish each task including unexpected work demands. Groshong (2016) has been able to model the operational tasks for driving a freight train and found a method to predict workload for task functions allocated to the engineer, conductor, or the automation. The effect of high workload on train safety has been experimentally tested by requiring the locomotive engineer to deal with secondary tasks (i.e., real-world distractions) while performing the primary driving task (Sebok et al, 2017). Specifically, Sebok et al (2017) found that TO prompts were ignored under a condition of high workload, resulting in a "failure to notice a request for information from the TO, and failure to detect the change to manual mode." High workload is another contributing factor to our workflow analysis and the effects of high operator workload on the human management of automated rail systems behaviors will be addressed in the CONEMP.

8. CONEMP Description

Utilizing the TRAK (2022) system engineering architecture framework, as described in the CTA, we are building a TRAK model of human supervision to control automated train functions safely and efficiently. Our CTA identified key human tasks related to potential brittle automation elements that will be addressed by constructing and balancing HMI design options to meet enterprise goals. In the WFA deliverable we described human operator rail systems interactions as workflows to locate and describe the identified critical tasks specific to human operator awareness of automated functions status. Our workflow analysis concluded that the human operator will need HMI support to detect abnormal patterns related to automated train control, and what to do when a possible automation fault is detected, especially under conditions of high workload. Workflows for CTA use cases were diagrammed as TRAK viewpoints (See Figures G-4, G-5 & G-6): A Positive Track Control (PTC) workflow, a Trip Optimizer (TO) workflow, and a combined PTC/TO workflow. [Note: our symbology follows American National Standard Institute (ANSI) guidelines with TRAK augmentations].

Our workflow analysis identified an emerging need for a new rail systems capability, an HMI feature to be developed by the UCD-Rail Team, called the Automation Awareness Assistant (A3). In this deliverable we offer a CONEMP for A3. This CONEMP is a narrative of how A3 is expected to work during a typical trip. Analysts call this typical trip an *essential story*. The essential story scenario will be a normal train operational timeline from yard departure, traveling in normal operations (OPS), to yard arrival for a very long train. Our CONEMP follows UCD guidance detailed in our Human Systems Integration Plan (previous deliverable), organizing rail operational timelines, required data and functions in a human activity-centric manner such that a UCD-Rail Phase II A3 HMI design can be easily created where information and control is "brought to the task" (Cowen et al, 2014) as opposed to requiring the user to collect, gather and synergize information from separate sources to do function activation.

Our proposed CONEMP, diagrammed as TRAK viewpoints, is shown in Figures G-7 and G-8. Figure G-7 is a high-level description of A3 following the essential story described above. This diagram is a workflow following a trip timeline where there are pre-trip events followed by normal OPS during the journey. This workflow shows the typical closed loop between normal OPS and train automation awareness (see previous figures in the WFA) except when an irregular mode pattern (potential fault or failure) is detected by the human operator who then must do a classification computation that will suggest whether to turn off the automation or fix what is wrong (or let it be). A3 will provide situation awareness (SA) assistance to the human operator during this workflow by examining low-level system data (A3 Deep Analysis), not typically consumed by the human operator, to increase the probability of detecting a fault (A3 Monitoring) that may lead to a system failure. If an abnormality is detected A3 would classify (A3 Classify) the severity of the fault by determining what triggered the abnormality (from the functional analysis shown in Figure G-2. Our CONEMP simplifies the system awareness elements into five broad categories of function control: train handling principles, human operator tasks, the automation models, train/locomotive subsystems, and external (non-train) subsystems. A more detailed description of rail system elements and functions can be found in our System Analysis deliverable. If A3 classifies the fault as minor, such as incorrect speed posting (see discussion of Figure G-4), then A3 can suggest that the error be simply fixed with the input of correct speed limit and to continue with the journey with automation engaged. If the fault is a symptom of a potentially serious automation failure (again, see the WFA), A3 may suggest turning off the automation or stopping the train in the case of a system or safety critical failure.

Figure G-8 expands the CONEMP in Figure G-7 adding a Mission Advisor and a Mission Model to the A3 CONEMP. Implicit in the Mission Model is a system state estimator (i.e., current system performance) which is compared to Mission Model expectations such that the Mission Model can request the human operator to adjust the mission or the system to meet enterprise goals. The structure, functions, and actions for the Mission Model, the system state estimator, and the Mission Advisor will be developed in the next Phase of the UCD-Rail project.

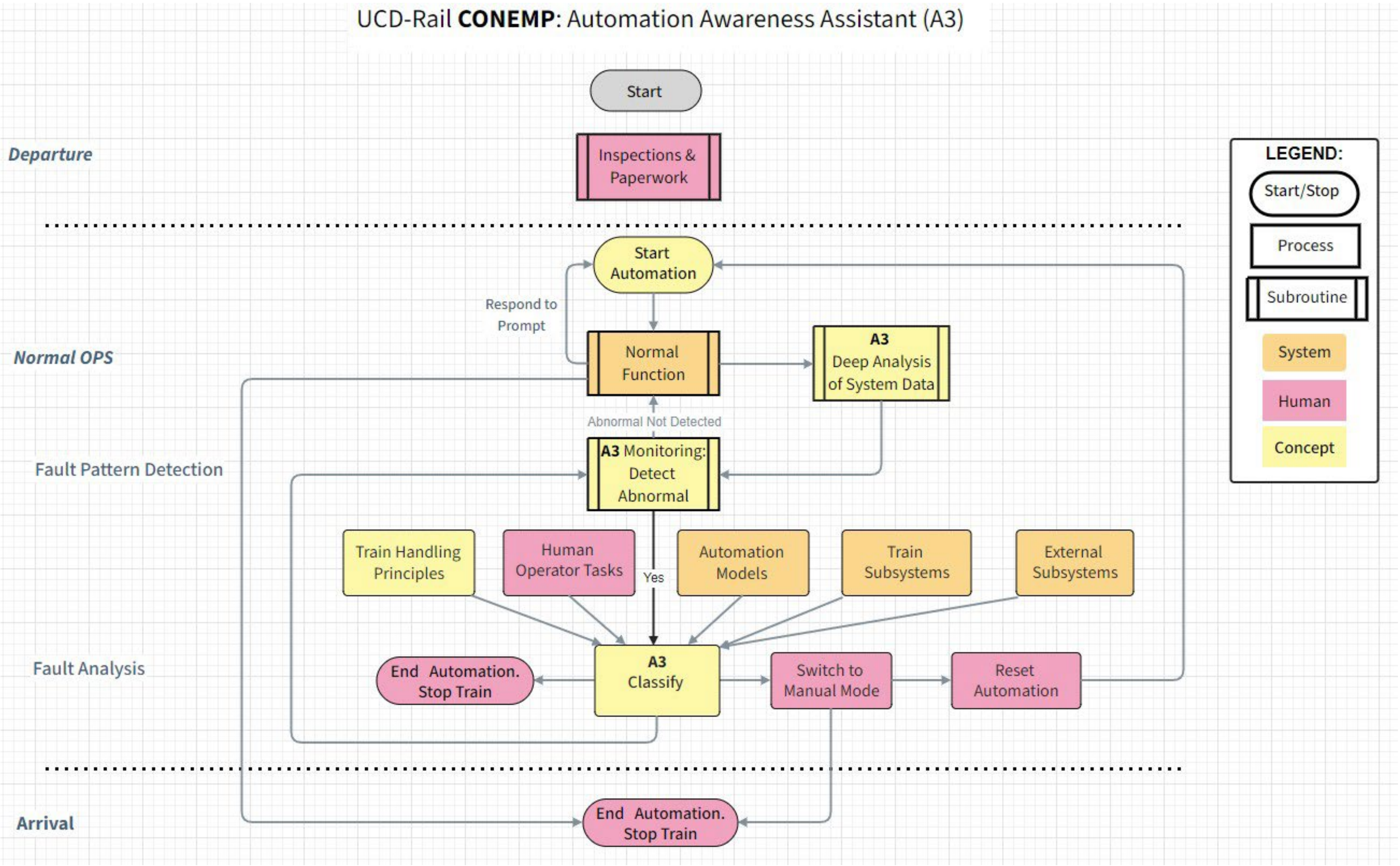
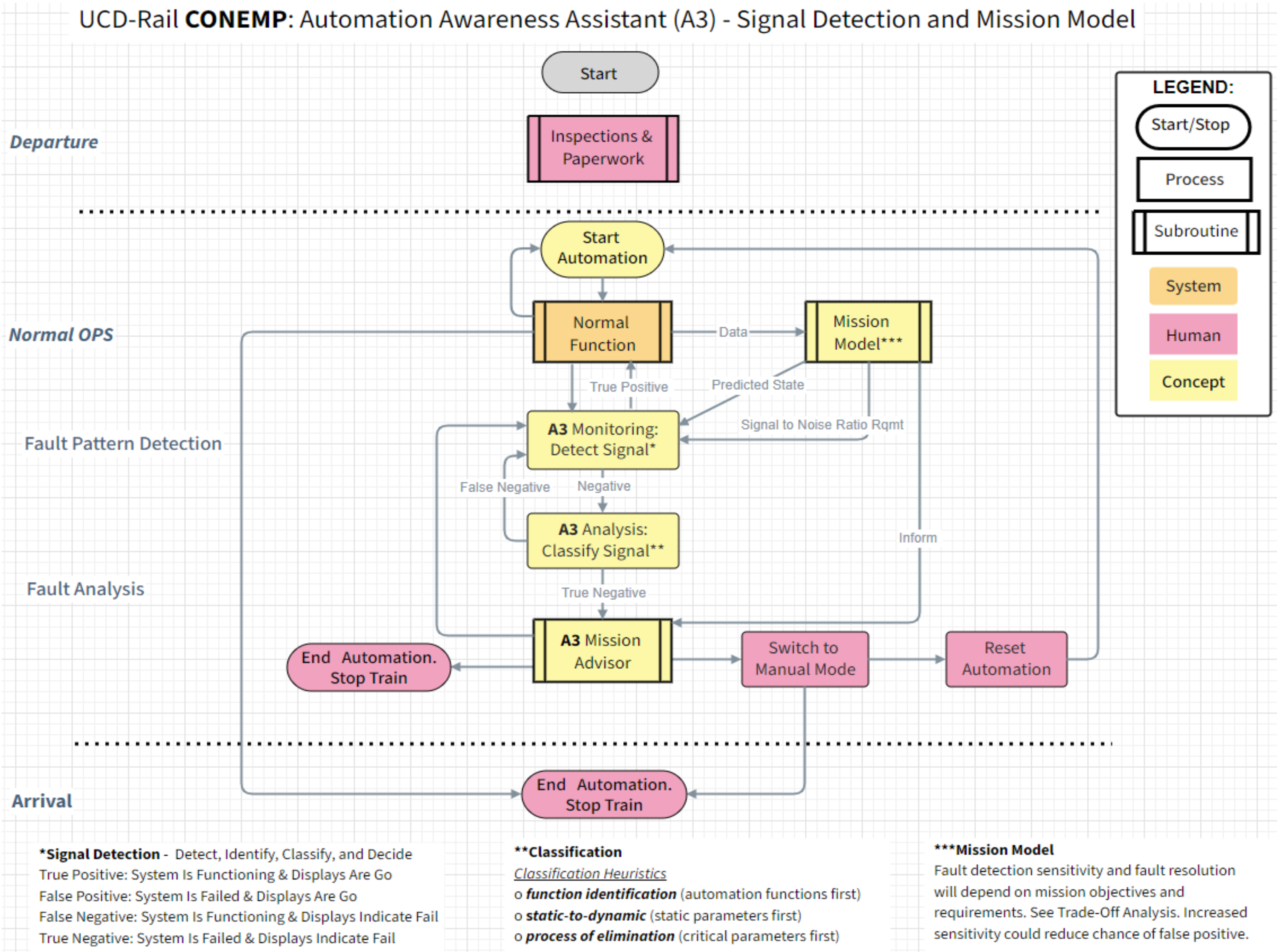


Figure G-7. UCD-Rail CONEMP: A High-Level Description of the Automation Awareness Assistant (A3)



***Signal Detection** - Detect, Identify, Classify, and Decide
True Positive: System Is Functioning & Displays Are Go
False Positive: System Is Failed & Displays Are Go
False Negative: System Is Functioning & Displays Indicate Fail
True Negative: System Is Failed & Displays Indicate Fail

****Classification**
Classification Heuristics
o ***function identification*** (automation functions first)
o ***static-to-dynamic*** (static parameters first)
o ***process of elimination*** (critical parameters first)

*****Mission Model**
Fault detection sensitivity and fault resolution will depend on mission objectives and requirements. See Trade-Off Analysis. Increased sensitivity could reduce chance of false positive.

Figure G-8. UCD-Rail CONEMP: A Description of A3 with Signal Detection Strategies Advised by a Mission Model

Figure G-8 also adds a signal detection process to the CONEMP. Following signal detection theory as applied to human system interactions (Parasuraman & Wisdom, 1985), the goal of the A3 Monitoring and A3 Classify is to detect an abnormality as a signal (or to verify no irregular pattern) representing one of four system states (see bottom of Figure G-8):

- True Positive: System Is Functioning & Displays Are Go
- False Positive: System Is Failed & Displays Are Go
- False Negative: System Is Functioning & Displays Indicate Fail
- True Negative: System Is Failed & Displays Indicate Fail

As shown in the diagram in Figure G-8, the intent of the A3 monitoring is to detect a signal (for our CONEMP signals can only be negative, possible fault) and determine if the signal is a False Negative or a True Negative via A3 classification analysis. If A3 detects no signal, A3 assumes a True Positive, but signal-to-noise sensitivity can be increased to reduce the probability of a False Positive, a sudden system failure. Increasing sensitivity, however, will increase the likelihood of a False Negative.

A3 signal detection sensitivity is controlled by the Mission Model[6]. The Mission Model is a description of how the trip will meet enterprise goals (TRAK, 2022). For freight rail, this is typically transporting cargo and there are representations in mission model for trip criticality, train building, route challenges, and a pre-departure to post-arrival timeline. A more detailed description of rail mission elements can be found in our Trade-Space deliverable which contains a Rail Functional Hierarchy, Rail System of Systems (SoS) Hierarchy, and a Rail Operational Timeline Hierarchy. For example, contributing factors for accurate signal detection and classification could be heavy train loads, complex locomotives/cars make-up, high operator workload, difficult routes, traffic, weather, and schedules. Fault detection sensitivity and fault resolution will depend on mission objectives and requirements. If A3 classifies the signal as a True Negative, the Mission Model will inform the A3 Mission Advisor as to what actions should be considered (by the driver) to ensure that the trip will meet railroad mission and enterprise goals.

9. Discussion

Guided by the UCD-Rail system analysis, we extracted critical tasks specific to human operator awareness of automated functions status, mostly from prior FRA sponsored studies having to do with train operator activities (including operator concept maps and cognitive tasks) and from C2 rail systems architectural diagrams. As part of the critical task analysis, we examined these artifacts for potential safety and performance risks related to automated control of train movements. Utilizing the TRAK (2022) system engineering architectural framework, we identified and described key human tasks related to potential brittle automation elements that will be addressed by constructing HMI design options. Our critical task analysis, as a TRAK viewpoint, provides the blueprint to generate workflows and develop a concept of employment that will drive HMI designs. We are building an enterprise TRAK model that will describe how to supervise automated train movements to meet enterprise goals.

A recent paper (Cowen et al, 2021) by MTI on human automation interaction discuss the comparison among Human-in-the-Loop (HITL), Human-on-the-Loop, and the progression to

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[6] Signal sensitivity: Are actual vs expected system states sufficiently divergent to represent a signal?

Human-Out-of-the-Loop. The paper discusses the supervisory human control authority capabilities, requirements, and issues implicit in each human in/on/out of the loop architecture to safely activate functions as cycle time approaches zero to reduce the probability of a mishap. There exist many rail system tasks that the locomotive engineer or the conductor must accomplish that are time-critical with life-or-death outcomes. In this context, human performance must be supported with well-designed console features to make the right decision, but no amount of training can compensate for poor human factors, and confusing user displays that obfuscate automation status or return human control at the worst possible moment when the operator is not ready to deal with a sudden hazard.

MTI’s previous investigations offer three human engineering factors that could improve human interaction with automation to prevent locomotive accidents: graceful degradation, task--centered design (TCD), and automation complacency. Graceful degradation is an automation supervisory control technique that we propose to explore. Automation features are needed that sense, analyze, and react to vehicle environmental conditions and equipment status and can adjust rail subsystems to maintain normal operations. Problems occur in the human-system supervisory loop if the adaptations suddenly cross a tolerance threshold wherein the system rapidly fails. Automation that can rapidly fail is referred to as ‘brittle,’ because it breaks suddenly and without warning. Graceful degradation is needed whereby the human supervisors of the automation are informed and aware that automated features are compensating for performance deviations. If a console display dedicated to graceful degradation is not achievable, then users must be trained to view and interpret challenging vehicle status information.

TCD organizes system information and controls in a user activity-centric manner such that normal workflows are efficient and task products can be easily created. When function allocation design decisions are made, UI constructs can be created to deliver capability as cycle time approaches zero. This can include shared system-user task states and awareness of past, current, and planned tasks explicitly listed. A TCD UI construct can include the explicit display of tasks which are triggered based upon trip objectives. UCD is a TCD approach.

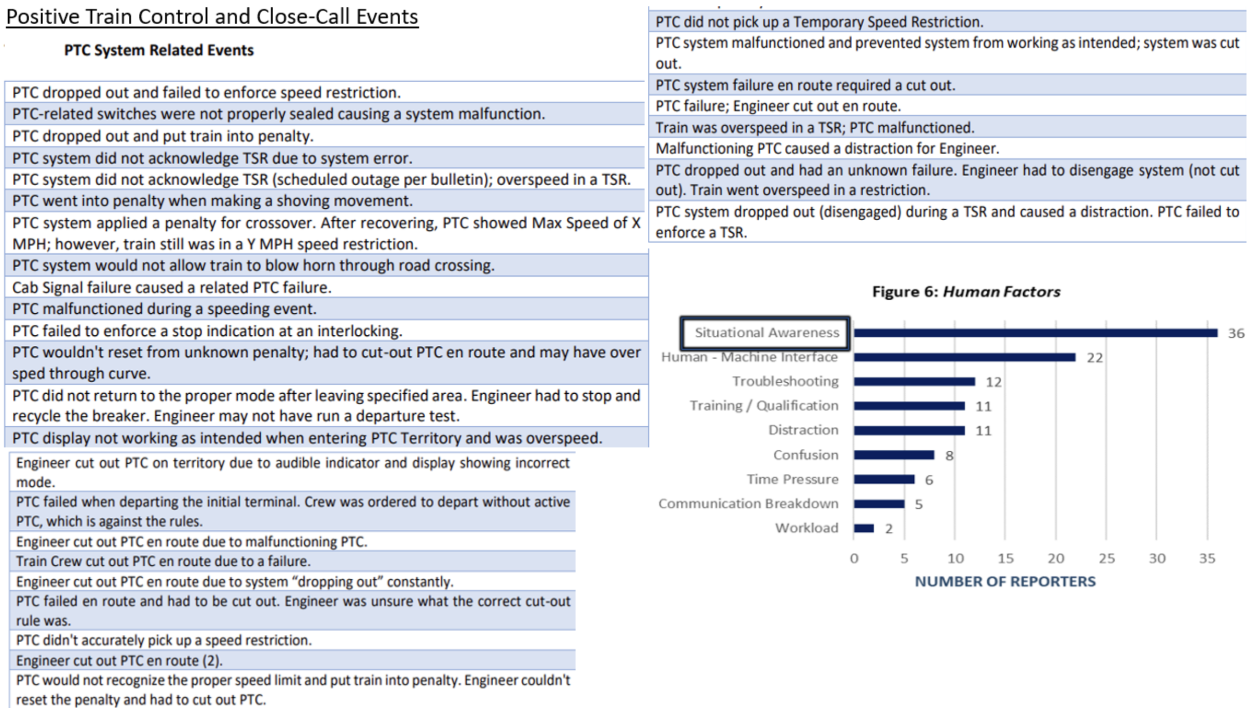
As mentioned earlier, automation complacency (aka, automation bias) is when human operators trust automation outcomes and disregard other possible contradictory information. Complacency tends to occur when there are extensive periods of routine handling with little human machine interaction, which make cause fatigue and monotony. Mitigation strategies can include tasks and activities designed to keep operators alert, diligent, and vigilant. Simulated events and recurring practice and activities with critical events can also reduce negative issues related to complacency. Endsley’s (2017) model of autonomy oversight recognizes the ‘decision-biasing effect’ of operator dependence on automated decision aids. Human operators tend to supervise automated systems using approaches that require the least cognitive effort when seeking and sharing process details, believing that automation has superior analytical ability. Rail system HITL architectures should consider decision process designs that grant active human ‘management by consent’ versus reactive ‘management by exception’ to mitigate automation bias by requiring the human operator to remain actively engaged. The effects of automation bias will be greatly reduced by explicitly displaying decision elements/steps, and then compelling the user to engage in the decision process with critiquing what-if, and contingency planning paradigms.

When mitigating the effects of automation bias, the decision process to support ‘management by consent’ or ‘management by exception’ must also be able to manage cognitive biases of human information processing, especially under conditions of high workload. These biases have been found to be the underlying cause for most errors in human judgement and have been extensively studied (Lewis, 2016). HITL architectures must address potential human judgement errors in the supervision of rail tasks and workflows, most notably confirmation bias, availability bias, and illusory correlations. As with automation bias, the best way to reduce judgement bias is to explicitly (and in an operationally relevant manner) display layers of information and data that both support the decision process and engage the user.

Rapid Recognition of Key Patterns

Our TRAK human view considers a cognitive process, pattern recognition, to detect automation anomalies (Klein et al, 2021): How much transparency is needed for rapid recognition of abnormal system functioning related to automated behaviors? As mentioned earlier, NDM approaches to C2 suggest that expert human operators in naturistic settings can quickly recognize atypical patterns and then rapidly work the functions at hand to identify and solve, typically pursuing a single feasible option. Expert operators have a “richer idea of how a system works, how it fails (including how to break it), and how to make it work and manage it (Klein et al, 2021).” What sort of decision support (details, warning, alert, etc.) can the HMI simply provide to help the human operator to detect and understand rail patterns that indicate a potential automation failure?

As an example, train automation failures have been found for various installations of PTC. PTC systems are designed to prevent train-to-train collisions, over-speed derailments, incursions into established work zones, and the movement of a train through a switch left in the wrong position. PTC accomplishes this by using technology to monitor train speed and train locations, provide warnings for the traincrew to act, and automatically initiate braking if the traincrew does not take action. As mentioned previously, a recent study of PTC close calls (Hooey et al, 2021) reported that 68% of all respondents indicated that PTC did not work as advertised, noting that in some instances “PTC failed to enforce a stop indication, which is a fundamental requirement for PTC systems.” Other reported PTC malfunctions are shown in Figure G-9. Human factors analysis of responses (see figure) shows that these glitches can affect human operator situation awareness of the rail network (where other trains or hazards might be), a potential safety concern. A recent study by the Transit Advisory Committee for Safety (TRACS, 2020) reported automation errors to control train movements could be caused by equipment, track, or information network malfunctions not understood by the human operator. The study recommended that a secondary warning system be added to the cab console configuration.



Positive Train Control and Close-Call Events

PTC System Related Events
PTC dropped out and failed to enforce speed restriction.
PTC-related switches were not properly sealed causing a system malfunction.
PTC dropped out and put train into penalty.
PTC system did not acknowledge TSR due to system error.
PTC system did not acknowledge TSR (scheduled outage per bulletin); overspeed in a TSR.
PTC went into penalty when making a shoving movement.
PTC system applied a penalty for crossover. After recovering, PTC showed Max Speed of X MPH; however, train still was in a Y MPH speed restriction.
PTC system would not allow train to blow horn through road crossing.
Cab Signal failure caused a related PTC failure.
PTC malfunctioned during a speeding event.
PTC failed to enforce a stop indication at an interlocking.
PTC wouldn't reset from unknown penalty; had to cut-out PTC en route and may have over sped through curve.
PTC did not return to the proper mode after leaving specified area. Engineer had to stop and recycle the breaker. Engineer may not have run a departure test.
PTC display not working as intended when entering PTC Territory and was overspeed.
Engineer cut out PTC on territory due to audible indicator and display showing incorrect mode.
PTC failed when departing the initial terminal. Crew was ordered to depart without active PTC, which is against the rules.
Engineer cut out PTC en route due to malfunctioning PTC.
Train Crew cut out PTC en route due to a failure.
Engineer cut out PTC en route due to system "dropping out" constantly.
PTC failed en route and had to be cut out. Engineer was unsure what the correct cut-out rule was.
PTC didn't accurately pick up a speed restriction.
Engineer cut out PTC en route (2).
PTC would not recognize the proper speed limit and put train into penalty. Engineer couldn't reset the penalty and had to cut out PTC.
PTC did not pick up a Temporary Speed Restriction.
PTC system malfunctioned and prevented system from working as intended; system was cut out.
PTC system failure en route required a cut out.
PTC failure; Engineer cut out en route.
Train was overspeed in a TSR; PTC malfunctioned.
Malfunctioning PTC caused a distraction for Engineer.
PTC dropped out and had an unknown failure. Engineer had to disengage system (not cut out). Train went overspeed in a restriction.
PTC system dropped out (disengaged) during a TSR and caused a distraction. PTC failed to enforce a TSR.

Figure 6: *Human Factors*

Figure G-9. PTC and Close Call Events.

Implications

Increasing levels of automation bring the promise of increasingly safe, efficient, and reliable movement of people and goods by rail, but also bring risks that may lead to deadly consequences. We are offering a total systems human factors design and development process to create a cab console HMI to provide necessary awareness of the operational environment and the rail system's processes/status so the operator can override or adapt to the rail system in unexpected situations. We are applying this variable autonomy approach to existing rail systems architectures to address compressed cycle times and more demanding workloads in the rail operational environment. This deliverable is an important step in the design process to develop a human control authority solution to mitigate the risks associated with human-on-the-loop rail system vulnerabilities, where machine errors and brittle automation (Hooey et al, 2021) could lead to cascading failures.

This study of the rail systems' critical human operator activities considered existing job task analyses and rail SoS architectural artifacts. We found sufficient detail in these artifacts to do a critical task analysis that will lead us to requirement generation for an HMI technical solution to improve human operator awareness of automated train behaviors to do safe and efficient locomotive control. This deliverable identifies and describes the critical tasks to carefully address the effects of brittle automation to support design strategies that will make the human operator more aware of deviations from the trip plan, changes to the rail system state, and pending automated courses of action. Our critical task analysis has provided a path visualized in system engineering views to support the generation of human interaction requirements as rail system automation progresses from human in/on/out of the loop, defining how the human operator will reassert control and retain decision-making while minimizing function activation delays.

The objective of the UCD-Rail HMI design process is to create a cab console HMI to provide necessary situation awareness of rail systems' processes, states, and status in the real-time operating environment so the human driver can manage, adapt to, or override possible unsafe automated rail equipment control options. HMI design in rail has not matured at the same pace as automated and autonomous machines in other domains and, as a result, current freight rail control HMI's do a poor job supporting the operator's SA of system processes, status, and operational context. New system automation capabilities are being added to existing console elements and operator tasking without proper integration with legacy rail systems. As noted above, adding automation can introduce unique problems of their own. This problem can be compounded in unpredictable ways when the new systems are layered onto older legacy control systems with increasingly complex mission or performance requirements. Conflicting indicators among systems can materially reduce human operator SA. There is an emerging trend to make freight trains longer on tighter schedules (Machalaba, 2018) with automation managed by artificial intelligence (*The Seattle Times*, 2020). Unanticipated interactions among new and legacy systems and processes can result in emergent failure modes (Harris and Narkevicius, 2016). A human operator with reduced SA may not adapt to unexpected circumstances, risking catastrophic failure. As rail systems become more automated and autonomous, operator requirements will shift away from physical tasks and lean more heavily on complex decision making and managing risk across several interrelated factors and variables, many of which are abstract. Traditional HMI design approaches that are typical of rail systems acquisition have not accommodated this shift and struggle to keep pace with automated and autonomous system development. An outcome of this project is to create a C2 systems engineering architecture incorporating a Human Factor's approach to rail systems integration that enables and supports assured human control authority over advanced automation.

Implications of our critical task analysis suggest designing and developing a console display to support epistemological concerns about what the end-user needs to know about how the rail automation works (especially for closed-loop subsystems), enough to be able to intervene if the automation is not working right (Karn et al, 2014). The HMI design also needs to support when to intervene and how to intervene without having to needlessly search, remember, or deduce system automation information and processes. This will involve the trade-off of function allocations between people and systems for executing operational task steps and accomplishing goals. To this end, we are following our UCD approach to organize system information and functions around and consistent with human work activities and intentions to easily "bring information to the task (Cowen et al, 2014)."

CONEMP

Implications from our workflow analysis suggest that the human operator will need HMI situation awareness support to detect, classify and deal with abnormalities when the train is controlled by automated functions, especially under conditions of high operator workload. Here, we offer a CONEMP for an HMI feature, new rail systems capability, called the **Automation Awareness Assistant** (A3) that will improve driver SA during the journey and offer suggestions as to what actions to take if a possible fault is detected. Our CONEMP is a narrative of how A3 is expected to work for a normal trip, a typical train operational timeline from yard departure, traveling in normal OPS, to yard arrival for a very long train. A3 supports the human operator cognitive monitoring[7] requirements to maintain awareness of train automation, recognition of anomalies, risk assessment and mitigation. A3 supports achieving a critical TRAK concept activity, maintaining automation awareness, supporting the broad capabilities required to meet enterprise goals. Our CONEMP also provides enough detail (see Figures G-7 & G-8) to specify a set of functional requirements of what the human rail operator needs to do to drive a train safely and efficiently with automated functionality active. The CONEMP will serve as the baseline for the design of A3, an automation awareness HMI feature to be developed by the UCD-Rail team.

<u>AAR's Technical Advisory Group (TAG) on Automated Train Operations (ATO).</u> The Association of American Railroads (AAR) has noted that there "is no single industry-wide plan or schedule for automation. Automation of rail functions will continue to be incremental and progressive, with individual railroads developing and carefully implementing technologies that make sense for their operations and their customers (AAR, 2018)." The ATO TAG is developing an "automated rail taxonomy" including a concept of operations (CONOPS) for interoperable aspects of ATO systems for freight rail operations. This concept asserts (Fry & Nast, 2021) that in the locomotive "train automation functions are provided by the independent function and interaction of Positive Train Control (PTC), Energy Management Systems (EMS), and ATO Support Systems (ATOSS)," requiring, to ensure system safety, human operator cross monitoring of the interactions among automation systems and subsystems. Our A3 HMI concept is an **interoperability solution** that can be used to generate the system of systems, the function automation, and the HMI requirements to support the ATO TAG CONOPS for adding new automated functionality into existing and future rail systems. It should be noted that UCD-Rail and its A3 concept are focused on human operational tasks in the locomotive cab with the goal of reducing operator workload and improving operator performance to increase train safety and efficiency. Nothing in our approach presumes or precludes the application of our results to other aspects of rail operations.

<u>Classification Strategies</u>. A3 will need systematic methods for reducing rail systems uncertainty to support human operator signal detection, classification, and fault mitigation. In determining the most effective strategy for signal classification, A3 will need to consider the operational factors present in that mission. A3 should employ a strategy that reflects the environmental conditions, the type and amount of known systems information, and the amount of time constraints imposed by the potential failure. Three classification heuristics (See Figure G-8) are proposed to assist in the detection and classification of fault signals. The first, a function identification strategy, will be most effective in a high-density signal environment. In this strategy, the heuristic will identify signal characteristics first from only parameters known to be related to automation functions. If the signal is not classified, then other categories of function control could be searched (See Figure G-7). The selection of parameters to be searched will ultimately depend upon A3's understanding of the relationship between automation functions and rail systems parameters. Static-to-dynamic is another classification strategy. It will be most effective when there is high similarity among signals, but time is not a factor. In this strategy, the heuristic will classify a signal from system parameters starting with the most static parameters and progress toward the most dynamic parameters until classification is reached.

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[7] A more in-depth discussion of cognitive monitoring can be found in the CTA.

The third strategy is a process of elimination based on the number of available parameters. It will be most effective under low signal density, low signal similarity conditions, and when time is not a factor. In this strategy the heuristic is employing an elimination strategy that is based upon comparing signal characteristics to specific critical system parameters expected during a segment of the trip. In this case, the heuristic rejects all signals that are not from the current part of the trip (i.e., mission critical parameters). In this strategy system parameters are not analyzed in a systematic manner. Rather, only mission critical parameters that differentiate are searched.

There are advantages and disadvantages to each of these strategies. The analysis of function strategy may be able to quickly classify a signal, but its accuracy is limited by the validity of the selected parameters. The analysis conducted using a static-dynamic approach will yield the most information and may provide the highest confidence factor for operational decisions, but it will also be the most time consuming if many signals are detected. The process of elimination approach can efficiently manage a large quantity of dissimilar information, but it could potentially lead to serious consequences if the classification decision is based on limited critical cues. Strategy effectiveness should be validated using realistic trip scenarios that contain diverse and messy system data.

In summary, the locomotive engineer needs HMI assistance to manage surges in workload from unexpected automation behaviors, trying to make sense of large amounts of rail systems data. The assistant proposed here will be able to help manage and display automation status notifications under high signal densities situations, integrating information from a variety of train and external sources, to create situation awareness to support overall mission objectives. A3 will support getting the right information or affordance to get to the next step in the process to detect and classify faults occurring under automated control, a process that may include alerting and remediation. This can be traced to the rail system not accurately knowing what the human operator is thinking or what the human operator wants at that moment. The big challenge for Phase II is designing a rail role and task-based HMI to support better decisions without overwhelming the human operator with too many notifications or losing the capability to simply activate system functions. The following rail HMI design issues will be addressed in UCD-Rail Phase II:

- How much alerting is needed (depending on the workload)
- When it is needed, how is it provided and geospatially displayed
- How status notifications algorithms can be used to keep the locomotive engineer informed so that the execution cycle is continuous

Abbreviations and Acronyms

ACRONYM	DEFINITION
A3	Automation Awareness Assistant
AAR	Association of American Railroads
ATC	Automatic Train Control
C2	Command and Control
CONEMP	Concept of Employment
FRA	Federal Railroad Administration
HMI	Human-Machine Interface
MODAF	Ministry of Defense Architecture Framework
OPS	Normal Operations
PTC	Positive Train Control
SA	Situation awareness
UCD	User-Centered Design
UCD-Rail	User-Centered Design for Railroad Automation
UI	User interface