

Display Requirements for an Interactive Rail Scheduling Display

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Abstract: This work, a collaboration between Alstom Transport and the MIT Humans and Automation Laboratory (HAL), is focused on the development of an interactive in-cab scheduling interface for train operators. Currently, operators rely on a combination of paper schedules, paper speed charts, and rote memorization to meet the many demands of train operation. The separation of this information over multiple sources shifts driver attention away from the windscreen and may result in increased workload levels and safety compromises. A Hybrid Cognitive Task Analysis (hCTA), which derives the information requirements necessary to meet mission goals directly from operational tasks, was conducted to generate cognitive requirements for the desired scheduling display. The resulting seventeen requirements were used to guide the development of a new scheduling display, which is presented.

Keywords: Information requirements, cognitive task analysis, rail, schedule management, decision ladders

1 Introduction

The train operation environment has become increasingly complex. To operate a train from station of departure to station of arrival, an operator must gather information from multiple digital displays and paper supplements, while monitoring the external environment through the windscreen. A particularly difficult task for train operators is scheduling. Currently, operators rely on a combination of paper schedules, paper speed charts, and rote memorization to perform the scheduling task. The separation of this information (e.g., arrival times, speed restrictions, voltage changes) over multiple sources results in the shifting of driver attention away from the windscreen and may increase workload levels and compromise safety. The combination of the required information on a single display would ease workload levels and potentially result in safer train operations. In addition, designing a display that takes advantage of

information visualization using both textual and graphical elements would enhance driver adherence to posted schedules. This design could also include information on speed profiles to optimize trip efficiency [1].

This work, a collaboration between Alstom Transport and the MIT Humans and Automation Laboratory (HAL), is focused on the development of a minimum information interface for increased efficiency and safety during rail operations through the development of an interactive in-cab scheduling interface. Information about current high speed rail operations in France was collected through three train trips: two trips on RER (Réseau Express Régional) train routes and a single trip on a TGV (Train à Grande Vitesse) train traveling from gare de L'Est to Strasbourg. A visit to the Alstom Transport simulator located in Belfort also provided observation opportunities. These observations revealed that schedule management was indeed an existing problem for train operators.

The Hybrid Cognitive Task Analysis (hCTA) [2] method was used to generate the cognitive requirements for the entire train operation process. The requirements specific to train scheduling were then used to guide the development of a scheduling display. The next section will detail the hCTA process. The final prototype resulting from the generated requirements will then be presented.

2 Hybrid Cognitive Task Analysis

The goal of the hCTA process is to generate the functional and information requirements for an interface design within a complex system, starting from a high-level scenario task description [2]. The hCTA process attempts to define the workflow of a human operator within a complex environment, deriving a complete set of computer interface information requirements necessary to meet mission goals directly from operational tasks. The hCTA consists of the following components: 1) Scenario Task Overview, 2) Event Flow Diagrams, 3) Situation Awareness Requirements, 4) Decision Ladders (and jointly, display requirements), and finally, 5) Information and Functional Requirements. hCTAs have been utilized in a variety of domains, including in the design of displays for the control of unmanned underwater vehicles (UUVs) [3] and submarine surface collision avoidance [4].

An overview of the hCTA process for this interactive rail scheduling display effort is discussed in the following subsections, as well as the resulting output from each step for the train operation process. The full hCTA developed for this research can be found in Tappan, Pitman, et al. [5].

2.1 Scenario Task Overview

A scenario task overview formalizes the mission statement for a complex work environment into a set of distinct phases and tasks, similar to a hierarchical task analysis [6]. A phase represents an abstract grouping of similar tasks designed to meet some common goal, and for the purposes of this effort, phases can be temporally defined. Implicitly, each phase has a set of sub-goals that the operator is trying to

achieve while engaged in that phase of the scenario. Often, these sub-goals are represented as specific tasks for a phase. Phase tasks are not limited to just physical actions; they may also include temporal vigilance tasks (i.e., monitoring gauges) or problem solving (i.e., determining new speed to stay on schedule).

Ultimately, the scenario task overview provides a basis for the rest of the hCTA analysis by transforming a qualitative description of an operator’s job into a set of quantifiable tasks, which are then precisely defined using event flow diagrams.

For this project, four phases were identified relating to a train operator’s mission of driving a train along a route, with intermittent stops at stations: *Before Departure* (BD), *Leaving Station* (LS), *En Route* (ER), and *Arrival at Station* (AS). In the first phase (BD), the operator prepares the train cab for departure. In the second phase (LS), the operator guides the train out of the station and accelerates to the first posted speed limit. In the third phase (ER), the driver continuously monitors the displays and gauges within the train cab to ensure that all systems are within acceptable bounds and are functioning correctly. In the final phase (AS), the driver decelerates into the arrival location and brings the train to a complete stop. In all, 47 subtasks were identified within the four phases.

2.2 Event Flow Diagram

An event flow diagram represents the temporal constraints (i.e., when and in what order) of events and tasks that occur within a specific phase of a mission. There are three basic types of symbols in an event flow diagram: 1) Processes, which require interaction between the operator and system (e.g., activate control *x*), 2) Decisions, which require the operator to make rule-based (simple) or knowledge-based (complex) judgments, and 3) Loops, which are processes that occur iteratively until a pre-determined event occurs (e.g., monitor surroundings for *x*). Three additional symbols often used in event flow diagrams are Phases (representing other flow diagrams accessible from the current diagram), Assumptions (information or requirements assumed to have been met before phase execution), and the transition arrows linking all diagram elements. The event flow symbols are shown in Figure 1.

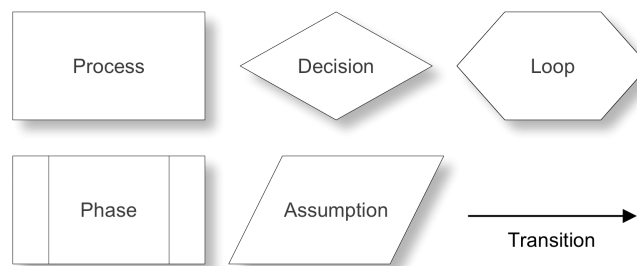


Fig. 1. Event flow diagram legend.

It is important to note that within the flow diagrams (and independent of which loop the operator is in), it is always possible for the operator to follow a preemption path where the operator halts their current task and instead attends to another event that has become more urgent.

A single event flow diagram was created for each of the four phases. Alphanumeric labels were given to the blocks so that they could be cross-referenced throughout the rest of the hCTA process (P for processes, D for decisions, L for loops). In all, 92 processes, 13 decisions, and 31 loops were identified over the four operational phases.

The work of train operators is predominantly comprised of the continuous monitoring of their environment, both within the train cab and through the windscreen, with multiple monitoring tasks occurring simultaneously. This monitoring task can be depicted using basic event flow symbols by combining a *loop* symbol, representing the item being monitored, and a *process* symbol, representing the method of monitoring. Upon detection of a signal, the *loop* would be exited, leading to a set of *decisions* and/or *processes* before returning to the original *loop*. While the monitoring task can be represented using these basic symbols, it is difficult to depict multiple concurrent monitoring tasks due to the temporal connections that dictate movement through flow diagrams. In order to overcome this limitation, a new graphical symbol was created for the train event flow diagrams, termed the *monitoring block* and represented visually by a dotted outline. This outline is placed around each monitoring task, grouping the symbols within, and is labeled with the monitoring task that is represented by the symbols. These blocks are not directly connected to the rest of the event flow diagram, conveying their continuous nature throughout the duration of each phase. In the train environment, monitoring blocks occurred within all phases, and included monitoring the radio, weather, and speed.

A portion of an event flow diagram, depicting the continuous monitoring by the train operator for threats on or beside the track, is shown in Figure 2. The dotted outline surrounding the flow diagram symbols indicates that this is a *monitoring block*, with the title *threat detection* conveying its purpose. The block begins with the loop, *L15: Monitor surroundings for pedestrians, tunnel*. If the exit condition for the loop is not met, the operator continues to gather environmental cues through the windscreen (P40). If an object is detected, the loop is exited and the operator must decide whether the object is on or beside the track (D4). If the operator decides that the object is on the track, tasks P41 and P42 must be completed. If instead the object is deemed to be beside the track, task P43 must be completed. The operator then resumes the original loop task until a new threat is detected.

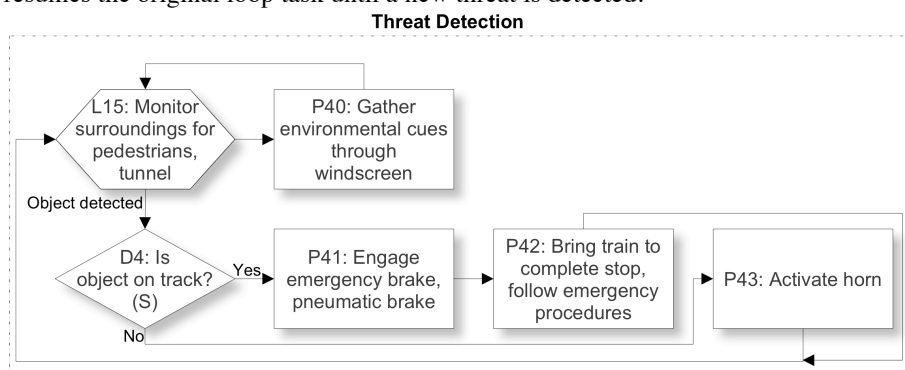


Fig. 2. Portion of an event flow diagram.

2.3 Decision Ladders

Decision ladders are tools that aid in capturing the states of knowledge and information-processing activities necessary to reach a decision [7]. In the hCTA process, decision ladders are created for each complex decision identified in the event flow diagram process to better understand the information required to adequately support the human decision-maker when faced with such a decision. Complex decisions are those that include many dynamic variables and occur in uncertain environments. These are in contrast to simple decisions (also identified in the event flow diagram), which are typical binary decisions (i.e., yes vs. no), and can be easily made from information readily available in the environment.

Decision ladders depict the decision-making process, beginning with the observation of an anomalous state, the identification of that state, the interpretation and evaluation of the ultimate goal in addressing the decision, and finally, the determination and execution of the correct response. In a decision ladder, this process is categorized using three levels of human behavior: 1) Skill-Based Behavior, or unconscious control, 2) Rule-Based Behavior, where decision-making is based on stored rules learned from previous experience, and 3) Knowledge-Based Behavior, where decision-making is based on environmental cues and individual goals [8].

Once a primary decision ladder is completed, two iterations are produced: 1) a ladder incorporating display requirements, and 2) a ladder incorporating potential levels of automation [9]. The display requirements and automation levels are listed in annotations beside the related information-processing activity. These annotations detail data that needs to be displayed in order for the human decision-maker to progress to the next stage, or the role that automation should play in the human's information processing.

The resulting three decision ladders, along with the generated situation awareness requirements (SARs), guide the next step of the hCTA, the development of information and functional requirements. These requirements are then used to begin the interface design process.

The single decision ladder developed for the rail domain was for the complex decision *is train ahead or behind schedule?*, which originated from the continuously monitored *Speed* loop in the *En Route* flow diagram. This decision ladder depicts the train operator continuously monitoring the current and estimated arrival times. When a schedule anomaly is detected, the operator determines the extent to which the train is behind or ahead of schedule, concludes whether some action will resolve the anomaly, and if so, takes the required action to return the train to on-time travel. The display requirements (Figure 3) and potential automation levels to assist the operator through this decision-making process were included in two iterations of the original decision ladder.

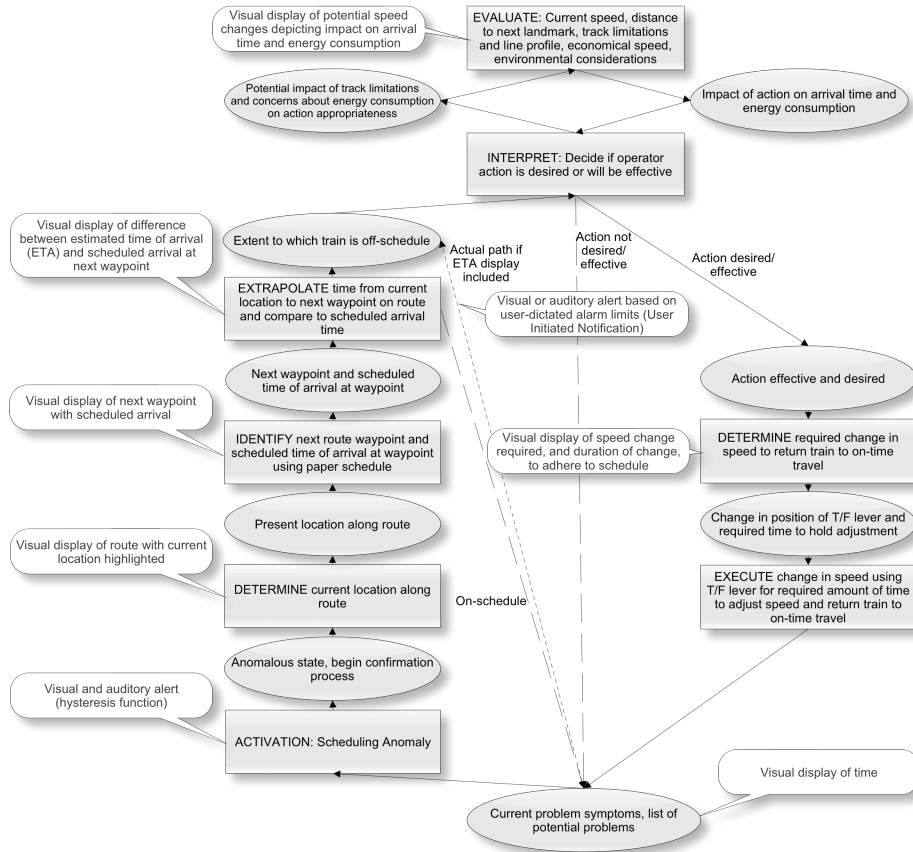


Fig. 3. Decision ladder with display requirements.

2.4 Situation Awareness Requirements

After completing the event flow diagrams and in conjunction with developing the decision ladders, Situation Awareness Requirements (SARs) are generated. Decision ladders represent a specific known decision process. However, for the majority of supervisory control tasks, operators are essentially monitoring the system to detect some anomaly or need for intervention, which may not be clearly mapped to a decision. SARs are generated for these tasks.

Situation awareness is commonly split into three levels, Perception (Level 1), Comprehension (Level 2), and Projection (Level 3) [10]. During Level 1, the human operator perceives any available information from the environment, (e.g., visual, auditory, or tactile data). During Level 2, the human operator integrates the acquired data to form and guide his or her current mental model of the environment. Finally, during Level 3, the human operator forecasts future situation events based on his or her current mental model, allowing for timely and accurate decision making.

SARs were generated for each of the four mission phases. Each requirement is directly linked to at least one process, loop, or decision from the event flow diagrams with this link included beside the requirement in the table. For example, for the operator to determine and select a voltage level (P10 in the *Before Departure* event flow diagram), he or she would need a list of available voltages and the required voltage level. Information about upcoming voltage changes would also be useful in order to prepare for future changes. Therefore, a resulting Level 1 (Perception) SA requirement in the *Before Departure* phase was *available voltage levels*. The related Level 2 (Comprehension) SA requirement was *required voltage level for current location*. Finally, the associated Level 3 (Projection) SA requirement was *voltage changes during route traversal*. A total of 45 situation awareness requirements were identified.

2.5 Information Requirements

The resulting SARs, in combination with the already-produced display requirements from the decision ladder, are used to populate the final list of information requirements. These requirements are sorted into functional groupings based on the functions they support. Within the Information Requirements (IR) table, the source of the requirement is listed, allowing for the requirement to be traced to previous portions of the hCTA and therefore justifying the need for the requirement. The ability to trace requirements is critical because if one requirement is not included in the final display design (typically for cost or implementation concerns), the impact of such a decision can be assessed across the entire system.

As a result of the hCTA, 58 information requirements were defined and then grouped into three display functional groupings. The first display grouping, Situation Awareness Display (SAD), would transmit general status updates about overall system and sub-system operation. The IRs important for the detection and resolution of system errors were grouped into the second category, Error Identification and Recovery Display (EIRD). Finally, the IRs important for train scheduling were grouped into the third category, Planning and Scheduling Display (P&SD).

2.6 Display Prototype

Seventeen requirements applied to the P&SD (Table 1), which is the first display prototyped under this joint effort. Due to the traceability of the hCTA process, the information requirements can be linked to the situation awareness requirements (SAR) or display requirements (DL-DR), which can be associated with event flow diagrams and, in turn, the original scenario task overview. Therefore, our resulting list of requirements represents the complete set of data needed by a train operator to safely and efficiently manage scheduling for a passenger train from the departure station to the arrival station. With the hCTA process completed, the focus shifted to design of the P&SD.

Table 1. Information Requirements for P&SD.

IR#	Description	Grouping
1	Current speed	SAD/P&SD
2	Goal speed	SAD/P&SD
3	Speed differential	SAD/P&SD
4	Current Traction/Friction lever position	SAD/P&SD
5	Current time	P&SD
6	Impact of event (system error, weather, etc.) on schedule	P&SD
7	Suggested speed profile	P&SD
8	Departure time	P&SD
9	Time to departure	P&SD
10	Potential impact of rail grade on speed	P&SD
11	Upcoming speed change indication	SAD/P&SD
12	Scheduling anomaly alert	P&SD
13	Train route with current location	SAD/P&SD
14	Next waypoint with scheduled arrival time	SAD/P&SD
15	Difference between predicted arrival and scheduled arrival at next waypoint	SAD/P&SD
16	New recommended speed profile with impact on schedule	P&SD
17	New recommended goal speed	P&SD

A well-designed interface, with the appropriate use of visualizations and display elements, can support decision-making [11] and minimize the cognitive complexity of a task [12]. Many design principles and usability heuristics were referenced to guide the development of the P&SD interface to ensure that the display could adequately support the train operator. The design principles used to guide the design included the *Principle of Information Need*, the *Principle of the Moving Part*, and the *Principle of Proximity-Compatibility* [13]. Usability heuristics, while not formal design principles, were also used to guide interface development. Many experienced design experts have devised lists of “best practices”, including Nielsen [14], Tognazzini [15], and Schneiderman [16], and the heuristics of *Consistency*, *Recognition Over Recall*, and *Simplicity* were also applied to the design.

The resulting display included six main functional groups (Figure 4): 1) Title Bar summarizing high-level trip details, 2) Trip Planning Bar providing schedule updates and new proposed speed profiles, 3) Route Overview Bar providing an overview of the train route from departure location to arrival location, 4) Speed Profiles Bar visually depicting important speed profiles, including maximum acceptable speed, minimum acceptable speed, and suggested speed, 5) Terrain Profile Bar depicting terrain changes through the route, and 6) an Information Dashboard summarizing important data related to the trip, including scheduled time of arrival at the next waypoint, current speed, and current track grade.

With a display prototype complete, the next step is to evaluate the prototype through usability and performance assessments, including testing in a high-fidelity simulation environment. Long-term goals are to determine a technology transition path towards system integration.

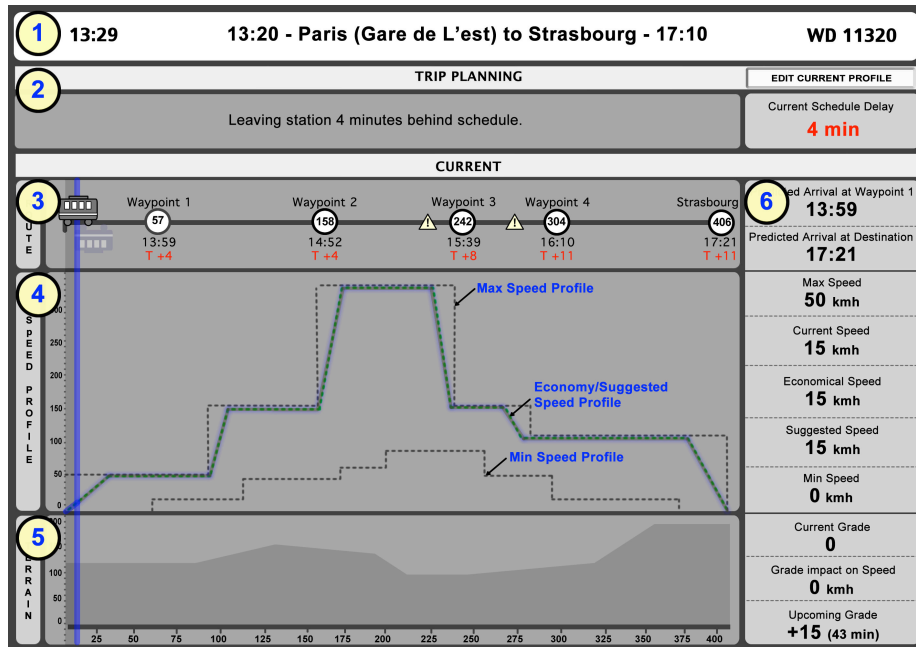


Fig. 4. Annotated Planning and Scheduling Display.

3 Conclusion

This paper described the analysis of a complex work environment, train operation, with the ultimate goal of deriving requirements for a train schedule management interface. A Hybrid Cognitive Task Analysis (hCTA) was used to generate the information requirements for the engineer of a passenger train through departure to arrival. The hCTA included constructing a scenario task overview and converting it into event flow diagrams for each identified operational phase. Complex decisions were then analyzed using ladders, which allowed for the derivation of related display requirements. Finally situation awareness requirements were derived for the remaining operational tasks. In order to accurately depict the continuous monitoring tasks that frequently occur during train operation within the event flow diagrams, a new symbol was created, termed the *monitoring block*. The addition of this symbol extended the temporal bounds of traditional event flow diagrams, allowing for the depiction of simultaneous continuous-monitoring blocks.

The result of the hCTA included seventeen information requirements that were directly related to the scheduling task. These requirements were then used to guide the development of a Planning and Scheduling Display (P&SD) to be used within train cabs to assist operators with schedule management. With a display prototype complete, the next step is to assess the usability and performance aspect of the display.

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