Cognitive
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Laboratory

EID Design Rationale Project: Case Study Report

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- Understanding control strategy differences between people of various levels of expertise within the context of process control systems.
- Developing safer and more efficient interfaces for computer-based medical devices.
- Creating novel measure of human performance and adaptation that can be used in experimentation with interactive, real-time, dynamic systems.
- Investigating human-machine system coordination from a dynamical systems perspective.

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EID Design Rationale Project

Case Study Report

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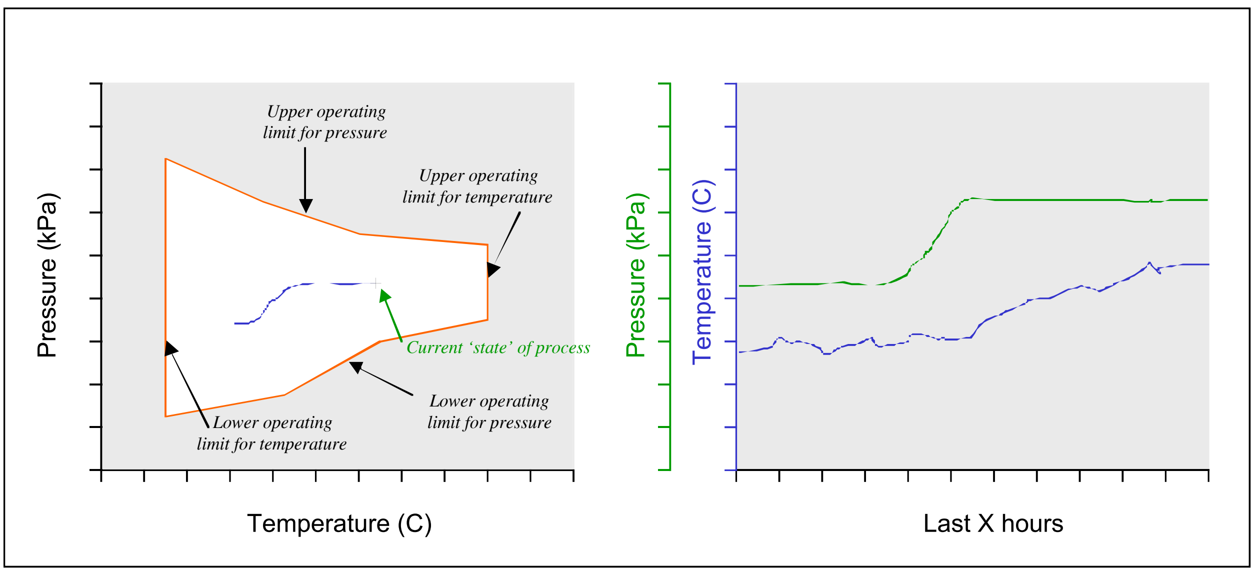
PREFACE

This report discusses the rationale behind the design of a functional interface for an acetylene hydrogenation reactor. The report covers key points in the process of transforming information requirements (generated by previously conducted analyses) into the visual representations depicted in the process displays. This work is the accompanying design step to the 'Unified Modeling Project' (UMP) conducted by Chris Miller (Honeywell Laboratories) and Kim Vicente (University of Toronto) (see References). The UMP generated an initial set of information requirements from both work domain analysis and hierarchical task analysis. Following the addition of a control task analysis, the information requirements were refined and consolidated. This set of requirements was then mapped onto a set of graphical displays. The report discusses each of these steps with the goal of making the process accessible to Consortium Member employees who might be charged with designing Operator Displays. A final chapter discusses the level of effort required to complete these steps and implement the displays as testable prototypes.

INTRODUCTION

The Abnormal Situation Management® Consortium has expressed interest in the development and implementation of visual displays[1] that depict the underlying 'functional' nature of a petrochemical process. A functional visual display communicates information about the state of a plant process as opposed to communicating point values requiring mental integration by the operator to assess that state. More specifically, functional visual displays indicate whether critical process parameters are within their acceptable operating boundaries; and typically, the indication is done graphically. A general, abstracted example of the difference between a functional display and a 'non-functional' display is presented in Figure 1.



(A) Simple example of a 'functional' display *(B) Common display format on the DCS*

Figure 1: Examples of various display approaches.

Functional displays integrate 'raw' data and present it as *information* in a form that helps an operator more easily and more accurately assess the current state of the process as well as predict the future state of that process. More elaborate functional displays might communicate:

- whether the mass balance for a process, unit, or plant is being maintained properly,
- whether the energy balance for a process, unit, or plant is being maintained properly,

[1] The terms 'visual display', 'user interface', 'display', and 'interface' will be used synonymously throughout this report.

- whether pressure vs. entropy relations for generating electricity with steam in a utility unit is being maintained properly, or
- whether process functions are being effectively executed, and so on.

In considering these claims and reviewing previous research, the Consortium has expressed several concerns about the design and implementation of functional displays. These include:

- Lack of familiarity with a design process for functional interfaces
- Uncertainty about what information should be communicated in a functional display
- Uncertainty of how to design the integrated graphics that typify functional displays
- Questions about how functional displays can be integrated with AEGIS graphics[2]
- Concern about the amount of time/effort involved in designing 'functional' displays

Unfortunately, very little information is available to address these concerns. Nova Chemicals and the University of Toronto set out to explore the above concerns by performing a ‘case study’ in functional interface design for a petrochemical process. This document captures the process followed to design functional visual displays for Nova’s E1 Acetylene Hydrogenation Reactor.

The document is divided into the following chapters. Chapter two discusses one approach to functional interface design, Ecological Interface Design (EID). We discuss the process of designing functional displays when following EID principles. Chapter three presents the process of compiling the necessary ‘knowledge’ (that is, results of specific analyses recommended by EID) that a designer must compile before she can start developing functional display concepts.

Chapter four then presents the details of the ‘case study’ of the Nova/U of T effort to develop and implement functional visual displays for Nova’s E1 Acetylene Hydrogenation Reactor. Chapter four illustrates design decisions with graphical illustrations and explains how certain process relationships were mapped onto the graphical forms that make up the displays. Chapter five shows how the results of different analyses make their way into the graphics. Finally, chapter six discusses the level of effort that went into the Nova/U of T display design effort.

FUNCTIONAL VISUAL DISPLAY DESIGN WITH EID

What is EID

Ecological Interface Design (EID) is a display design approach with a philosophy to support operators in handling changing and unanticipated situations[3]. EID addresses a design problem that is best described through an analogy. Consider a process environment with different constraints (e.g., safety and component capabilities), as shown in Figure 2. The operations objective is to move the process from a starting point to the goal state, and to keep it there. How can this be accomplished efficiently and effectively?

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[2] AEGIS graphics refers to the Consortium's design of displays to support the AEGIS prototype developed during the NIST-funded phase of the Consortium. "AEGIS graphics" encompasses not just how the graphics should look (e.g., the use of color), but display hierarchy (e.g., Level 1, 2, 3, and 4 displays – from overview to increasing levels of detail, respectively), navigation (e.g., the use of tabs to show the number of displays and the display hierarchy), and so on.

[3] A reader familiar with the EID approach may recognize that our treatment of the method is broader than that in the most frequently cited literature. The purpose of this report is to make the concepts of functional interface design accessible to industry. Theoretical developments are left for another document.

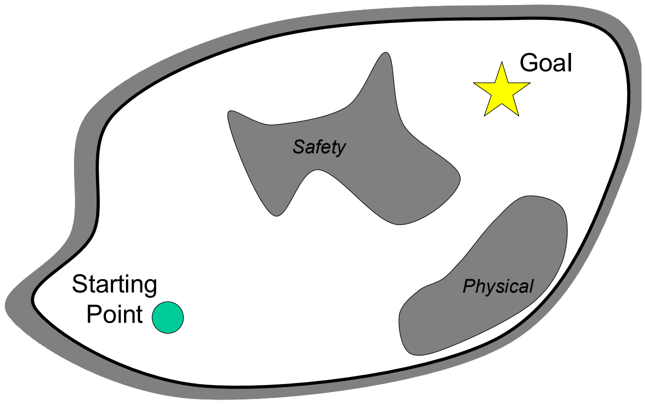

Figure 2: Generic problem of reaching process goal state.

Two contrasting strategies may be invoked that correspond with different display design philosophies. One strategy is to find the best path (defined by a predetermined set of actions) based on what is known about the process environment (Figure 3a). Once determined, this path can be encoded as a procedure and used efficiently to reach the process goal every time. This strategy can be effective when the process states are relatively static and predictable, and a predetermined starting point can be specified. An alternative strategy may be to show the constraints of the process environment, and leave it up to the operator to choose any feasible path to get to the goal (Figure 3b). This strategy can be effective when the constraints are dynamic, changing in predictable and unpredictable ways, and when the starting point is not predetermined or often variable.

The example characterizes the type of problem found in many industrial systems, including petrochemical processes. Operators are required to move, align, and maintain processes to meet the required demands. When the constraints are static and predictable, previously successful procedures may be invoked. However, more and more often, the constraints are dynamic, requiring continuous adaptation for success in managing their processes. Ideally, for operators to be effective for both anticipated and unanticipated situations, the support of both strategies needs to be considered when designing displays.

The focus of EID is to design displays by 'showing' operators the constraints and opportunities for action in a process environment. Skilled operators become more attuned to the process dynamics, and are able to efficiently decide on effective action alternatives, if available. This allows operators to cope with, and take advantage of, opportunities as expected or unexpected situations arise.

Premises of EID

EID has three basic premises. The primary premise is that the most difficult and potentially dangerous challenges facing the hydrocarbon industry are the unanticipated, abnormal events that threaten production and/or safety of a plant. EID suggests that, by communicating (i.e., displaying) the functional information in terms of operating constraints, process states, and so on, plant operators will have better information with which to handle these unanticipated, abnormal events. To determine what these operating constraints, process states, and so on are for a particular plant, EID uses a framework called the abstraction-decomposition space (ADS). For now, let's say that this 'space' describes the plant both in terms of (1) a part-whole decomposition (e.g., plant-unit-equipment relation) and (2) a means-ends dimension (e.g., a why-what- how relation).

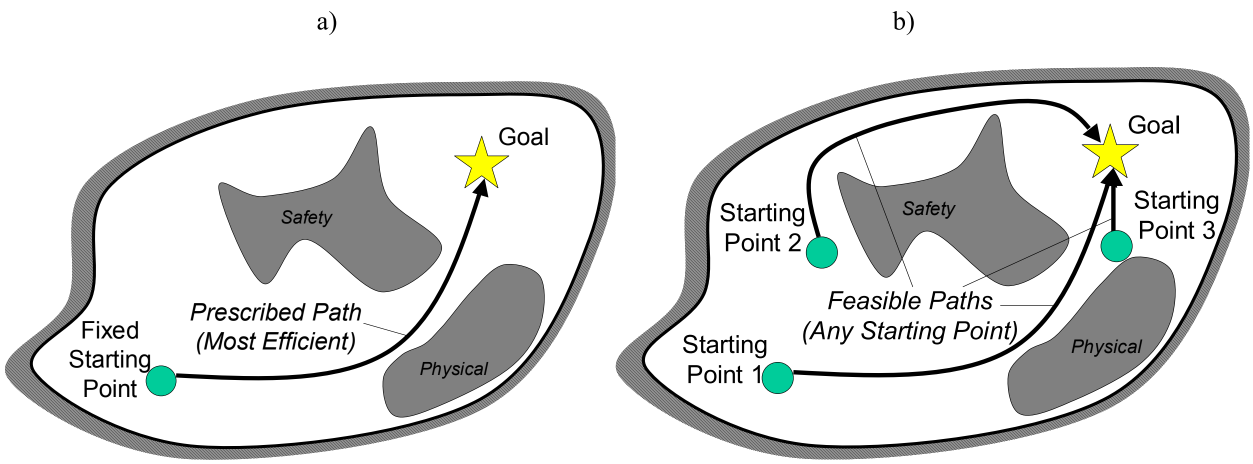

Figure 3: Alternative strategies for reaching the process goal – a) path approach using procedures and b) constraint approach using information feedback.

A second premise of EID is that people have different ways of carrying out their various tasks. Some activities are so routine that operators don't even have to think about it; they simply see an indication that the task should be done, and they do it automatically. In other cases, a task is carried out because a person knows the appropriate 'if-then' rule. For example, an operator might know that if the temperature in a reactor gets too high, they have to go to flare. The final way a person might carry out a task is through active problem-solving. In this case, the person consciously considers why an undesirable process state has occurred, and plans the appropriate sequence of actions to bring the process to a more desirable state. EID tries to present information in the right context and form so that an operator can use any or all of these ways of completing a task.

The third premise of EID is that an effective visual display can present information in such a way that people directly perceive process relations and states. That is, the information presentation is so effective that they don't have to think about those relations and states. Again, EID tries to present information graphically so that an operator can carry out a task with one or more of the ways described in the previous paragraph.

From this point on the terms "Ecological Interface Design" and "Functional Display Design" will be used interchangeably for simplicity's sake.

The Process of Functional Display Design

The problem of interface design for complex process control systems is summarized in Figure 4 in terms of two questions. There are three general parts to the representation: complex work domain, interface, and operator/user. The first question that needs to be answered is: How to describe the work domain complexity? To answer this question, a way of modeling the domain constraints and functionally is required. This will provide the information requirements (i.e., content and structure) of the user interface. The second question that needs to be answered is: How to communicate the information to the user? To answer this question, ways of presenting the information that allows operators to quickly develop a situational awareness of the process, within their limitations and capabilities, is required.

EID follows the process of answering the questions outlined above. There are three general steps to designing graphical user interfaces. The first is to conduct a work domain analysis, which specifies the functional relations that an operator should be aware of. These functional relations become information requirements for a user interface. The second step is to conduct task analyses, which specify the context-specific decision and execution requirements for assorted tasks that an operator is expected to do. These decision and execution requirements also

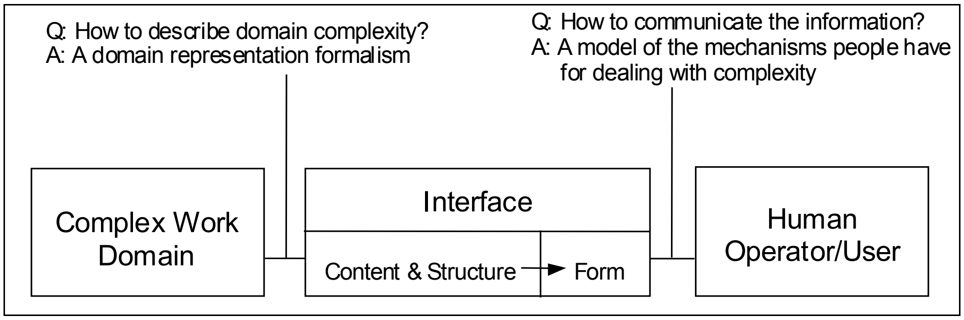

Figure 4: Interface design for complex systems (adapted from Vicente and Rasmussen, 1992).

become information requirements for a user interface. The third step is to integrate the information requirements from the first two steps into a meaningful graphical representation.

Each step will be presented with a high-level discussion in this section. Two technical reports by Miller and Vicente (1998, 1999) contain detailed examples of the first two steps for Nova's AHR unit, which was the target unit for the display design effort described in this document. This report covers the third step in detail.

Work domain analysis

The first step in doing functional display design is to determine the purposes, 'laws and constraints', and component resources that are governing the process. A 'work domain analysis' (WDA) identifies this information. WDA relies on a detailed knowledge of the plant and its interactions with the environment—and on the rules, equations, or models governing these interactions. The results of the analysis are analogous to modeling the constraints in the process environment shown in Figure 1 with the purpose of meeting target conditions with the component resources available.

Work domain analysis is represented by a two dimensional matrix. The first dimension of the matrix is the 'means-ends' dimension. This dimension describes the 'why-how' relations of a process (i.e., how various component resources link functionally to support process targets). The second dimension of the matrix is the 'part-whole' dimension, and this dimension describes the aggregation of the process *equipment* – from the parts that make up equipment to the aggregation of that equipment into a unit.

Figure 5 presents a 'skeleton' presentation of this matrix. A more detailed description of the means-ends dimension follows, as this is the less well-understood of the two dimensions. The means-ends dimension of the work domain analysis is a multilevel representation that describes different types of constraints of the unit. Each level represents a different 'language' for modeling the same underlying unit. The higher-levels represent the purposes, principles, and functions governing the process; the lower levels represent the component resources available to support the higher-levels. This will be illustrated more clearly below.

There are five levels of 'abstraction' in the means-ends dimension

1) Functional Purposes (PURPOSES): This level describes the system in terms of the purposes that it is meant to achieve (e.g., from the perspective of a catalytic reformer, these might include at least "produce reformate" and "protect against unit accidents").

2) Values & Priority Measures (PRINCIPLES): This level has typically described the unit in terms of the first principles that constrain and govern the unit. For example, in the process control domain, this would entail the laws of conservation in terms of mass, energy, and momentum.

3) Purpose-related Functions (PROCESS FUNCTIONS): This level has typically described the unit and equipment in terms of general functions that are independent of the physical instantiation that the function might take. Examples of such Purpose-related Functions would be separation functions, heating functions, feedback loops, cooling functions, reaction processes, and so on.

4) Object-related Processes (PHYSICAL FUNCTIONS): At this level of abstraction the unit, sub-units, and equipment are re-described in terms of physical and engineered characteristics. For example, "cooling function" for some liquid product can now be designated to occur in a shell-and-tube heat exchanger that has a coolant flowing, as opposed to a plate heat exchanger or a more extreme example of a vat with fans

blowing air over the surface of the liquid. This is usually the level where actions are performed on components to control the process.

5) Physical Objects (PHYSICAL FORM): This level is where the location, appearance, and exact physical characteristics of the components are described (in the cooling function example, the dimensions and location of the shell-and-tube exchanger would be indicated, along with the liquid coolant, its specific heat, and so on).

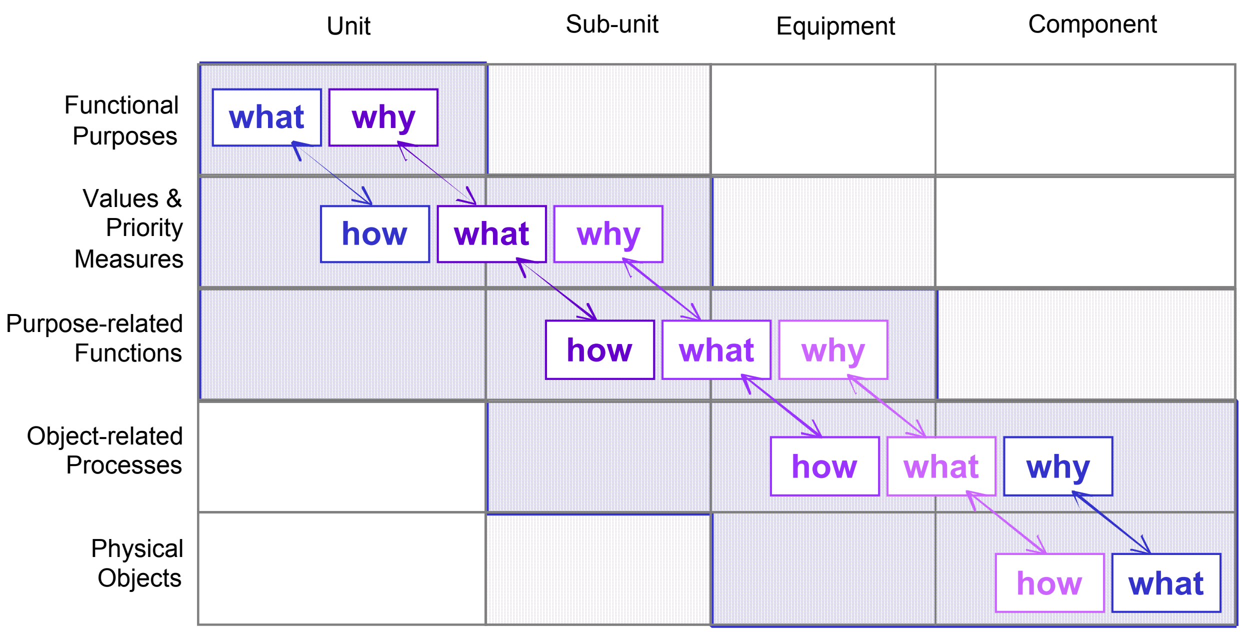

Figure 5: The work domain analysis matrix, with cells highlighted that potentially should consider for analyses .

Each level of this means-ends dimension represents a complete model of the unit in the specific language of that level. While what is contained in each level of this abstraction is important, another key aspect of this means-ends dimension is the logical relation between each level of abstraction. This logical relation is defined by asking "why-what-how" questions. Specifically, for a given level of abstraction, the answer to "what" is found at this given level. To answer "why" an element (the what) is at a current level, one looks to the level of abstraction one level above, where one can find the more general purpose or function that element is serving. To answer "how" an element (the what) is achieved, one looks to the level of abstraction below, where one can find how the element is operationalized. For example, if we return to the previous paragraph's example, we could ask "what" of the Object-related Processes level and find "shell-and-tube heat exchanger." We can ask why there is the need for this exchanger. The answer is given at the Purpose-related Functions level where we find a requirement for a cooling function. Moreover, we can also ask how this shell-and-tube exchanger is engineered. This answer is given at the Physical Objects level, where its location within the unit is indicated, the lengths and diameters of the tubes are specified, the volume of the shell is specified, and so on.

By modeling the process constraints in this fashion, information requirements emerge that can help operators handle abnormal or unanticipated situations. Because an event was not anticipated by system designers, the available procedures, experience, and automated aids may not be directly applicable. The one thing that does remain unchanged, however, is the functional structure of the plant and the principles that govern its interactions with the environment (defined in a WDA). It is within these constraints that the operator must improvise a solution. Displays that include these information requirements will better support operators in adapting to the situation.

Task analysis

The second step in functional display design is to conduct a task analysis (TA). Task analysis is complementary to the WDA and defines efficient modes of interaction with the environment in predictable situations. TA defines the actions that an actor (i.e., operator or automation) can or should take to achieve a process goal state. The focus of

TA is the action, not the work domain (as with WDA). Knowledge about tasks captured in this analysis typically includes either hierarchical, means-ends relationships (how subtasks may be composed to accomplish higher level tasks) or sequential relationships (how tasks must be performed temporally in order to be successful), or both. Sources of information for TAs are typically user interviews, through observation, and training or procedural manuals may also be used.
Information requirements are deduced for the tasks and can serve as the basis for prioritizing, clustering, filtering, or sequencing information presentation elements in an interface design. Task-linked information requirements serve as a particularly powerful basis for constructing "context" sensitive (actually, user intent, goal or procedure) interfaces because they dynamically present information on the basis of the current process situation and user information needs.

- Hierarchical Task Analysis

One common TA technique is Hierarchical Task Analysis (HTA). HTA produces a hierarchy of operations and plans, which include statements of actions that need to be performed under specific conditions. Initially, the goal to be achieved is determined. This goal is then reformulated into a set of sub-operations or plans governing when they are carried out. Further subdivisions are generated as required. The output is a table or hierarchical diagram (see Figure 5).

HTA, as with all task analysis techniques, focuses on "…what an operator… is required to do, in terms of actions and/or cognitive processes to achieve a system goal" (Kirwan and Ainsworth, 1992). Knowledge about tasks captured in an HTA typically includes both (1) hierarchical action relationships (how subtasks may be composed to accomplish higher level tasks) and (2) sequential relationships (how tasks must be performed temporally). Sources of information for an HTA are typically user interviews, though observation, experimentation and training or procedural manuals may also be used (Diaper, 1989). Where these sources are absent or break down (e.g., unanticipated situations), the HTA will be impossible, or worse, misleading. When these sources exist reliably, however, failure to incorporate them will result in inefficiencies or errors in training and operations. Information needs (both input and output) are typically deduced for the tasks and these, combined with the task relationship information described above, can serve as the basis for prioritizing, clustering, filtering, or sequencing information presentation in an interface design.

The hierarchical relationships captured in this format are means-ends relationships, but it is important to note, that they are 'action' means-ends links (i.e., what actions need to be performed in order to achieve ends at a higher level). By contrast, an ADS represents 'structural' means-ends relationships (i.e., what structural degrees of freedom of the system are available in order to achieve higher level functions). This distinction, while subtle, is at the core of the comparison of the two approaches.

- Control Task Analysis

A second task-based analysis was required in the present case study because the HTA by Miller and Vicente (1999) did not address the behavior of the automated controllers used in the process. This is because the primary knowledge source of the HTA was the procedures and these procedures assume that the behavior of the controller is a) known to the operator, and b) reliable. The WDA had not captured the activity of these controllers either because control is placed in the task domain by WDA[4]. The effect of this combination of analyses was that the role of the automation had not been analyzed. This was clearly a problem as these controllers are an important part of the operations activity.

To fill in this gap, a Control Task Analysis (CTA) was conducted to supplement the HTA. Similar to HTA, CTA aims to "identify the requirements associated with known classes of events in a particular application domain" Vicente, 1999, p. 182. In this particular application, the events are the control actions required to direct the process in a productive way. It is important to note that the analysis does not differentiate between automated and manual execution of these actions. The information requirements are identical whether the operator is serving as the actor, or merely an observer.

[4] The separation of work domain and automation is an ongoing debate on the academic side of EID and should not concern the Consortium Member reader. The work presented here shows one way in which the automation can be brought into the scope of the design problem. There are other effective ways of doing this.

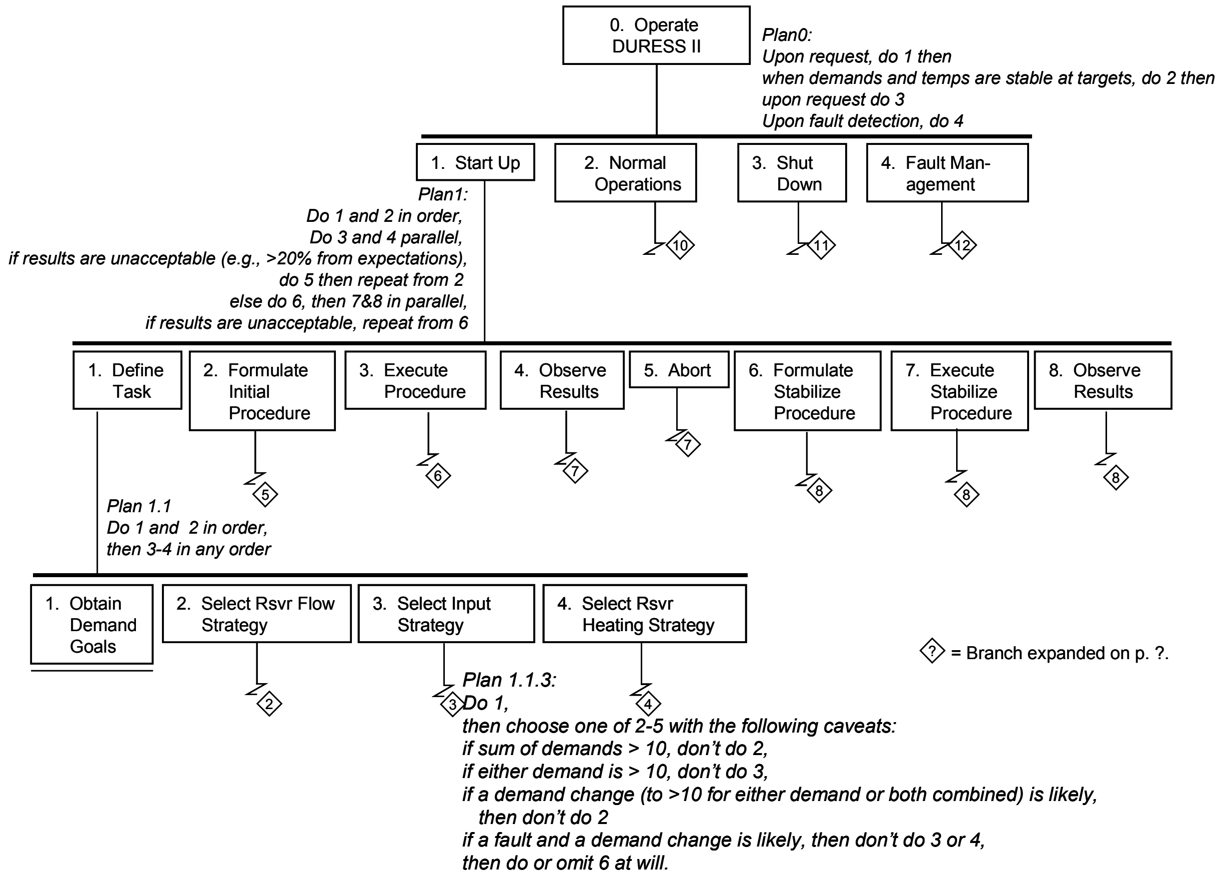

Figure 6: An example of the top level of the HTA for the AHR.

To complete the CTA, a non-linear information processing framework called the Decision Ladder (DL) is used (see Figure 7). The DL is a sequence of information processing steps (the boxes) and intermediate states of knowledge (the circles). The framework is non-linear, because the component boxes and circles do not have to be completed in a specific sequence. Rather, the framework allows an actor (a generic term that incorporates the operator or the automation) to take advantage of shortcuts in association between the steps. For example, neither an operator nor a machine needs to reason about the meaning of an error signal; it is merely a signal that implies an immediate corrective action.

Figure 8 Figure 8 shows a DL for the ratio controller that regulates flow of the hydrogen/carbon-monoxide stream based on the flowrate of the C2 stream and a setpoint to the controller. The task begins with the setting of the setpoint Target State. This value is then sent to the Observe process, which specifies the data to be gathered to complete the task. The data form a Set of Observations. The Identify process seeks to turn the point data into a task-relevant process state that can be associated with an action. In this controller, once the process state has been identified, the controller can proceed directly to a pre-defined Procedure. In this case, the procedure is simple to calculate a valve output to move the process to its desired state (i.e., the setpoint Target State). The next step in the task is to return to the Activation process, signaling the control system to complete another cycle.

Several important points are revealed by this example. First, the control task in question does not use all of the steps in the Decision Ladder template. Specifically, the task does not require higher-level uncertainty resolution or action planning. There are two reasons for this. First, this simple controller cannot handle uncertainty that is outside of its design parameters. Second, the planning activity is embedded in the design of the controller. The designers have dictated, in advance, what task is performed by the controller. Second, the task in this case is repetitive. This is a common characteristic of automated tasks and it is clearly reflected in the DL. The ladder is equally adept at representing linear tasks.

DL's for each of the controllers active in the AHR are included in Appendix A.

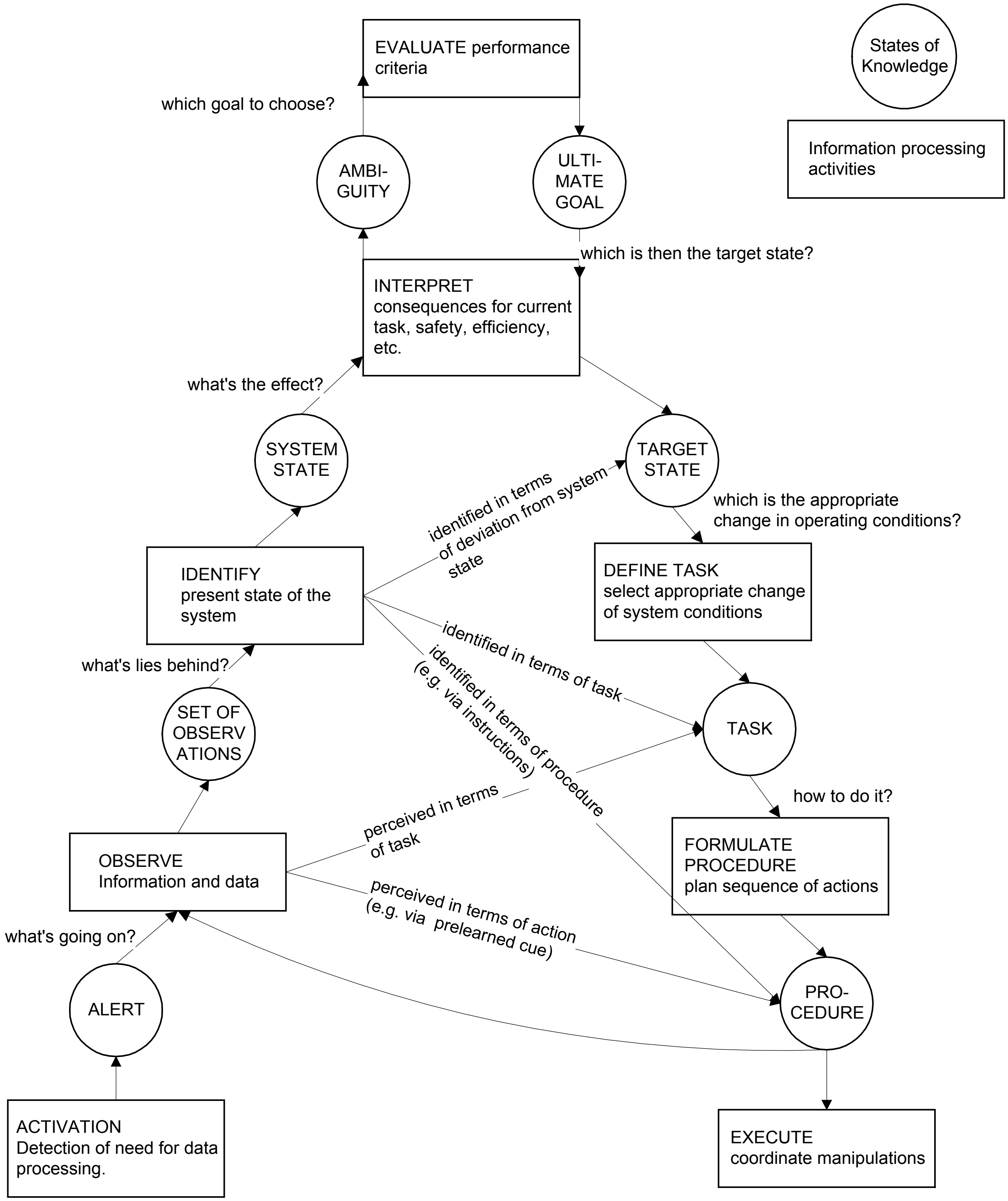

Figure 7: Decision Ladder template for Control Task Analysis.

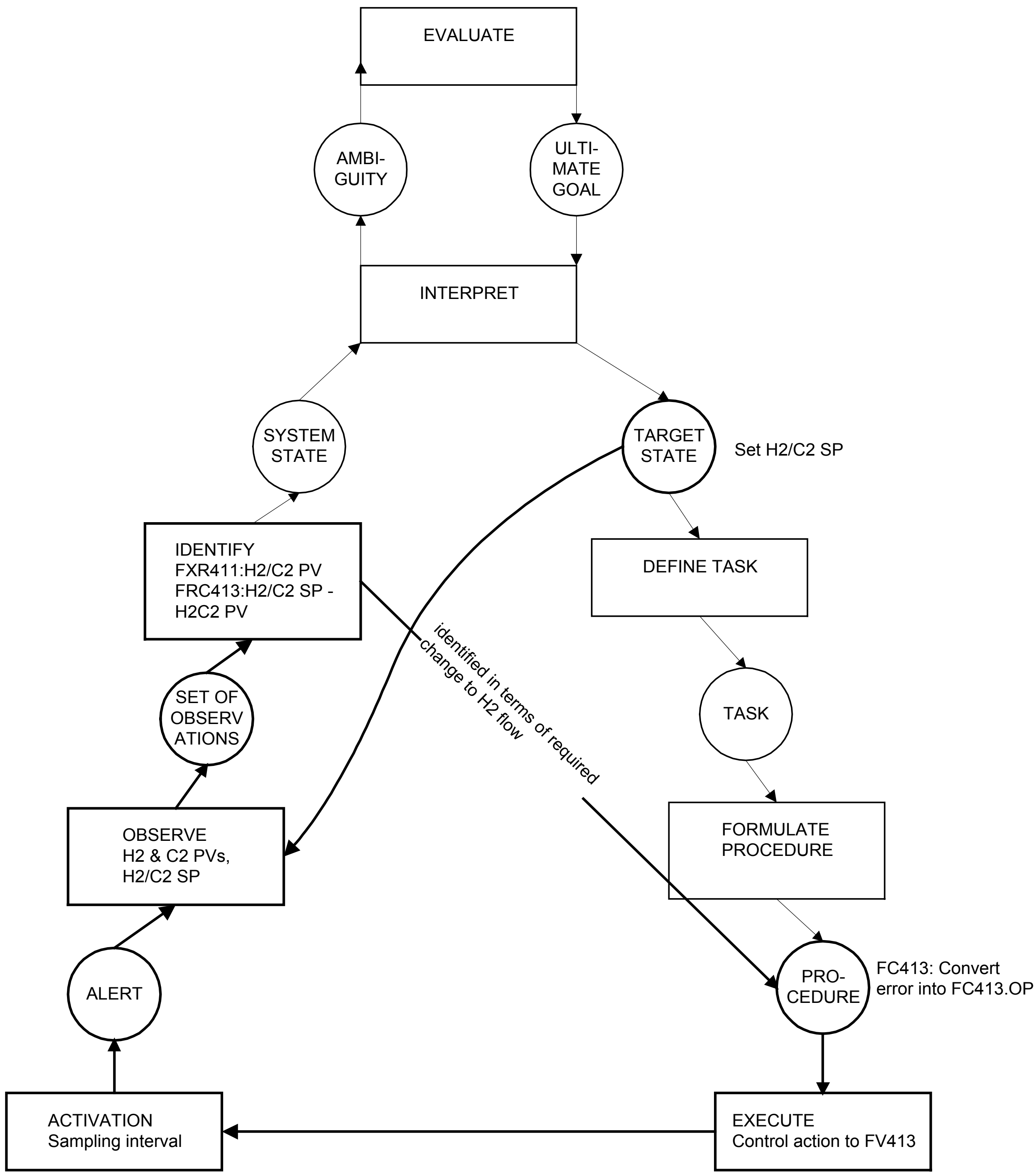

Figure 8: Decision Ladder for the H2/C2 flow ratio control.

The complementary roles of WDA and TA in generating information requirements.

Both WDA and TA serve complementary roles in EID that can help support operators in coping with abnormal and unanticipated situations (i.e., WDA) and provide more efficient ways of managing the process in more predictable situations (i.e., TA). Thus, both approaches are important in providing the information requirements for display design for process environments. A comparative summary of benefits and limitations of each approach is shown below.

Work Domain Analysis:

- Does a better job of providing 'deep knowledge' about the full set of constraints and capabilities for system behavior that are inherent in the work domain.
- More readily and directly identifies information requirements for monitoring, controlling and diagnosing the system—by contrast, the task analysis tends to reduce the granularity of tasks to an increasing level of detail, making it progressively easier for the analyst to infer information requirements without actually identifying them.
- Is more independent of the specific context in which the system is used (e.g., its interface, organizational goals, social structure, etc.)

Task Analysis:

- Provides 'compiled' procedural knowledge which, while being easier to learn and follow for anticipated cases, hides the deeper rationale for why procedures work and risks unexpected behavior in unexpected situations.
- Is more 'human-centered' in that it focuses more on what the operator must or can do and how s/he naturally thinks about the domain, dividing the set of operational behaviors into discrete chunks (i.e., tasks).
- More readily identifies when, how and with what priority information will be needed to perform expected tasks—and thus is more applicable to prioritizing, sequencing and dynamically configuring information presentations.
- Is less independent of context, but therefore requires a more comprehensive consideration of the full set of factors which influence operator behavior.

By conducting both analyses, a more comprehensive list of information requirements is generated. Of course, there is also a substantial amount of overlap between the analyses as well. In the next section, the process of integrating the information requirements is discussed.

INTEGRATING INFORMATION REQUIREMENTS

In two previous reports, Miller and Vicente (1998, 1999) presented the results of work domain- and task-analyses for the reactor section of the Nova E1 AHR process. Each of these reports included extensive lists of information requirements derived from the analysis. The process of modifying, extending, and integrating those requirements is described in this chapter. This process culminates in a comprehensive list of information requirements for the subsequent interface design step.

Filtering by 'System' Boundary and Simulator Fidelity

The HTA performed by Miller and Vicente (1999) used the existing written procedures as the sole knowledge source. One of the limitations of this approach is that the procedures are not written with the same concept of system boundary[5] that was employed in the ADS. The boundaries used for the ADS were confined to a sub-unit (the AHR) whereas the procedures can address equipment throughout the unit. Therefore, most of the procedures cut across the ADS system boundaries substantially. It should be noted that this difficulty arose because the UMP sought to isolate a manageable section of the entire E1 process. One of the tradeoffs of the attempt to moderate the complexity of the project was this discrepancy between system boundaries.

The result of the system boundary discrepancy was that the HTA identified information requirements that were outside the scope of the ADS. Therefore, the information requirements from the HTA were filtered for those requirements that were outside of the system boundaries prescribed by the ADS. The filtered items can be divided into two categories. First, equipment and functions addressed in the procedures that were either upstream or downstream of the reactor section. Second, equipment and functions addressed in the procedures that were within

[5] The use of the term "system boundary" is the same as in solving thermodynamics problems. In such cases, it is critical to establish, prior to the analysis, the bounds of the analysis. The analyst aims to set a system boundary so that interactions are concentrated within the boundary and minimized across the boundary.

the reactor section, but not included in the ADS. For example, some lines used in reactor swings and regeneration were not included in the ADS, but are mentioned in the HTA.

A second filtering process was required when attention was shifted from the actual process to the simulator model. This shift in focus was required because an empirical evaluation of the displays is to take place in the simulator. Therefore, equipment not included in the simulator model of the reactor section was removed from the ADS and not included in the display design process. Using the notation created by Miller and Vicente (1998), the equipment removed was:

CV1, VH2, and line to H2/CO inlet stream

VM2, CV4, and line to flare

VM3, CV5, and line to flare

CV2 CV3 VH4 VH5 VM7 VM9 VW1 VM12

SDV413B, SDV413C

SU411

VM11 and line to flare

Fuel gas flow

ST1052 and line

It should be noted that, although this is a substantial amount of equipment, many of them combined with remaining equipment to form functions that are retained in the simulated process.

Integration: The IR Matrix

Once the lists of information requirements had been modified based on the system boundary and simulator fidelity criteria, they were integrated. An information requirements (IR) matrix was formed listing the requirements from each of the three analyses (ADS, HTA, CTA). Then, each requirement was cross-checked against the requirements drawn from the other two analyses. Duplicate IR's were removed. Frequently, requirements from one analysis had to be assimilated or parsed in order to rectify them with requirements from another (see below). The IR Matrix is given is Appendix B.

For each resultant IR, the analysis or analyses that identified it were cited in the matrix. Thus, the matrix contains a column for each analysis and checkmarks in the appropriate cell when the analysis identified the IR (see Table 1 for an example). In general, the analysts employed liberal decision criteria in affirming that an analysis had identified a requirement.

Identify state, and range of possible states, for Physical Function-Component functions	**ADS**	**HTA**	**CTA**
E410 shell side INLET temperature	✔		
E410 shell side OUTLET temperature	✔		
E410 tube side INLET temperature	✔		
E410 tube side OUTLET temperature	✔		
E411 shell side INLET temperature	✔	✔	
E411 shell side OUTLET temperature	✔	✔	✔
E411 tube side INLET temperature	✔	✔	
E411 tube side OUTLET temperature	✔	✔	

Table 1: Example of how grouping allows for specific information requirements.

Differences in level of specificity

One of the early problems encountered was that the IR's differed substantially in their respective specificity. The requirements generated by the ADS and the CTA were very precise while those from the HTA ranged from precise to vague. The ADS requirements were precise because they appeared in groups based on level of abstraction and aggregation (see Table 1). Each group created a local context for those IRs. Thus, each IR drew on the context created by its group, allowing for more specific requirements within that context. The CTA requirements were also related by group; this time the individual controllers created the shared context. The specificity of these IR's also benefited from the precise nature of feedback control algorithms. In contrast, the HTA requirements were identified based on their order of appearance in the procedure sequence. Removed from the procedure, these requirements lost their context and were often vaguely stated. Moreover, Jamieson and Miller (2000) showed that Nova has a culture that allows the operator a great deal of operational freedom when following their defined procedures. Thus, many of the details cited by the ADS as IR's are 'assumed' in the procedures that were referenced by the HTA.

Analysis overlap

Figure 9 gives a Venn diagram showing the proportion of IRs accounted for by each analysis and the overlap between the various analyses. There is a large overlap in the information requirements generated by each analysis. However, there is also substantial uniqueness in each of them.

There are several difficulties with this count. One of them is level of specificity problem discussed above. The count treats all requirements as having the same value. This can be misleading. For example, the ADS is credited for identifying the IR corresponding to the location and appearance of a particular in-line valve. This rather trivial IR is counted as one. In comparison, the IR corresponding to the procedure steps is contained as a single IR. This critical requirement is clearly more important than the location and appearance of an in-line value. Perhaps another analyst would have chosen to identify each procedure step as a single IR, thereby inflating the number of IRs cited by the HTA that were not captured by the ADS.

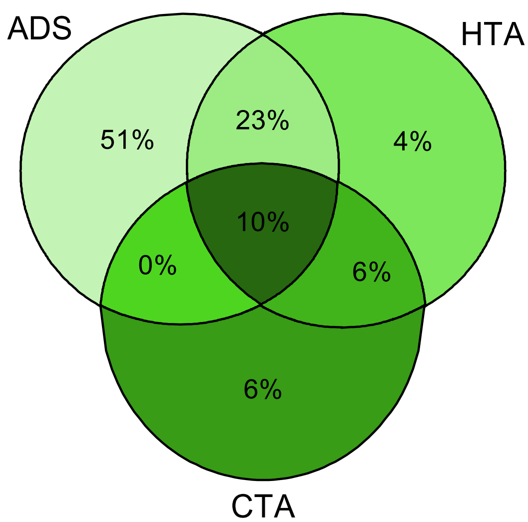

Figure 9: Proportion of information requirements captured by each analysis (circles not to scale).

Given these problems, how is the IR matrix to be meaningfully interpreted? The answer is that it gives qualitative insight into the value of each analysis. The large overlap confirms that work domain- and task-based analyses are both largely effective methods for building a knowledge base for interface design. However, each analysis clearly identifies requirements not cited by the others. Thus, the analyses are mutually re-enforcing

Observations for Future Applications

In retrospect, the process of integrating the information requirements benefited from having the foundation established by the ADS. The two-dimensional hierarchical structure of this analysis provided a framework within which the requirements gleaned from the task analyses could be inserted. Had the analysts known this in advance, the HTA-derived requirements could have been initially stated in relation to the ADS structure. In contrast, the two analyses were conducted quite separately using different knowledge sources. The prior knowledge obtained from the ADS analysis, while certainly valuable in making sense of the procedures, was not fully exploited in performing the task analysis.

This situation may be reversed for an analyst who is highly familiar with the operation of the plant. S/he may find it beneficial to start with a task-based analysis and use that as a foundation to integrate ADS results. There are, however, arguments against this. Because the WDA identifies functionality that exists independent of operational task, it should be broader and more inclusive than any task-based analysis. Thus, from an analytical perspective, it may always hold an edge over the TA analysis as a foundation-forming analysis.

Summary

The process of integrating the information requirements was, in at least one way, much easier than expected. This is because the IR was useful concept in both analyses. The ADS, HTA, and CTA were all fairly adept at leading to clearly defined data elements that need to appear in an effective interface. Notwithstanding the level of specificity challenge noted above, the IRs from each analysis were fairly compatible with each of the others. We had anticipated that it would be more difficult to assimilate the results of the analyses.

In the following two chapters, we turn to the problem of graphics design. In Chapter 4, the process of developing functional graphics is discussed both generically and in terms of a case study example. Chapter 5 shows how the IR's from the various analyses map onto the graphics.

DESIGN PROCESS

The details of the design process for functional interfaces will be unfamiliar to many Consortium Members. However, at a high level, the process is very similar to a generic iterative engineering design approach. In this section, we document the design history of one display in the new graphics suite. The following section provides a detailed account of the source of the information requirements for three characteristic graphics. A separate technical report provides a detailed design specification for the complete set of graphics (Jamieson and Ho, 2001)[6].

Interface Overview

Figure 10 presents the novel functional interface that has been developed for the AHR. The interface is presented on two monitors as described in the Design Specification (Jamieson and Ho, 2001). Each monitor is divided up into several display windows, five for the top monitor and three for the bottom. In this and the following chapter, several of the displays in the top monitor are described in detail. The display discussed in this chapter is highlighted for reference in Figure 10.

Iterative Design Approach

The designers[7] employed an iterative approach in developing the functional interface. To start, initial design concepts were developed based on the contents of the IR matrix. Two experienced operators and two process engineers reviewed these initial concepts. Their feedback directed the revision of the initial concepts. Once the revisions were complete, a rapid prototyping tool was used to create dynamic prototypes of the major process displays. These prototypes, dynamically driven using recorded process data, served as the medium for a detailed operator review of the designs. Twenty-two professional operators critiqued the prototype displays and offered

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[6] There is a terminological inconsistency between this document and the Design Specification. In the specification, the individual "displays" are referred to as "views". We have used the more familiar term "display" to make the following descriptions more understandable to the Consortium Member reader.

[7] It is worth noting that the two primary designers were not familiar with the process at the outset of the design effort. One had several years of experience with human factors in process control and both were familiar with the analysis and design methods. It is estimated that 2/3 of the effort that went in to the design of the graphics was expended in learning the details of the process. This had a substantial impact on the course of the design activity. In parallel with the design process, a learning process was taking place. Many of the errors committed and difficulties encountered stemmed from the designers' inexperience with the process. The ideal situation for building functional displays for petrochemical processing would place process unit experts and domain-savvy designers who know display design issues together on a design team.

suggestions for improvement. These suggestions were factored in to a final, pre-implementation specification. During the implementation process, modifications were made to correct errors and reduce the cost and complexity of the implementation task.

Rationale

In this section, the iterative development of one of the visual displays is described in detail. We discuss the evolution of the visual form from conception, through various stages of revision and operator feedback, to implementation. The target display for this discussion is the Hydrogen Balance Display.

Scope of the display

The first decision to be made in transforming a list of information requirements into an interface is how the full set of requirements will be parsed into displays. In most contemporary interface design, displays are primarily parsed according to stages of process flow. Other displays are parsed according to operator task, such as alarm summary pages. EID places greater emphasis on parsing the graphics according to functional relations. Often, these three approaches to parsing complement each other. This is true in the current case study.

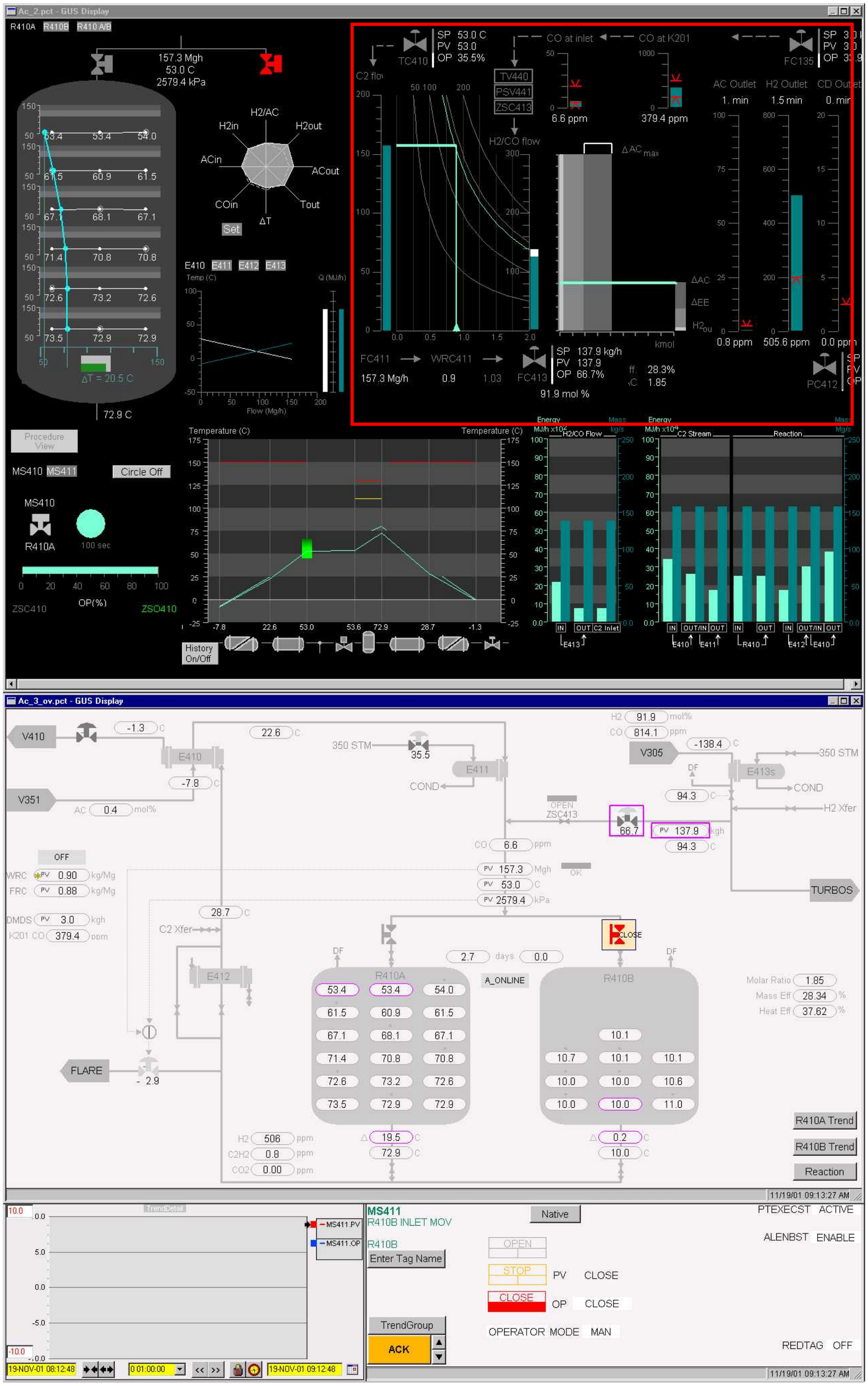

Figure 10: The novel functional interface for the AHR with a H2 Balance Display noted.

For example, we observed, in both the work domain- and task-based analyses, a cluster of closely coupled functions in and around the reactors. These included functions related to the incoming process flows, the reaction of those flows, and the effluent flow. Many of these functions were spatially local to one another; the equipment that afforded them could be found in close proximity in the plant. However, there were also some functions that were served by equipment that was geographically distant from the reactors themselves. In this case, the close functional coupling lead us to form a display that integrated these functions graphically.

Having identified a set of functions that we wanted to combine into a display, we then examined those functions and tried to identify a consistent relationship between them. In the case of the reactor, that consistent relation was the critical role of hydrogen. Hydrogen serves as the facilitating and throttling agent in the chemical reaction. Providing hydrogen to the reaction is a necessary function, and understanding its disposition in the reaction is the key to maintaining effective control. Therefore, hydrogen became the central focus of the display.

Version 1

The first draft of the display focused on the stages of hydrogen functionality (see Figure 11). Hydrogen flow into the reactor must be regulated and it must be accounted for in the reaction. A flow or weight ratio controller (WRC) establishes a setpoint for hydrogen flow based on the C2 flow. Thus, we showed C2 flow (gold column at left) and developed a graphic (blue scale) to show how the setting of the controller would result in a setpoint for the hydrogen flow (black and blue column). The scale was intended to move up and down with the C2 flow column. The setting of the WRC is shown on the scale with a green arrow that points out the setpoint on the hydrogen flow column. We discuss below how this graphic was later modified.

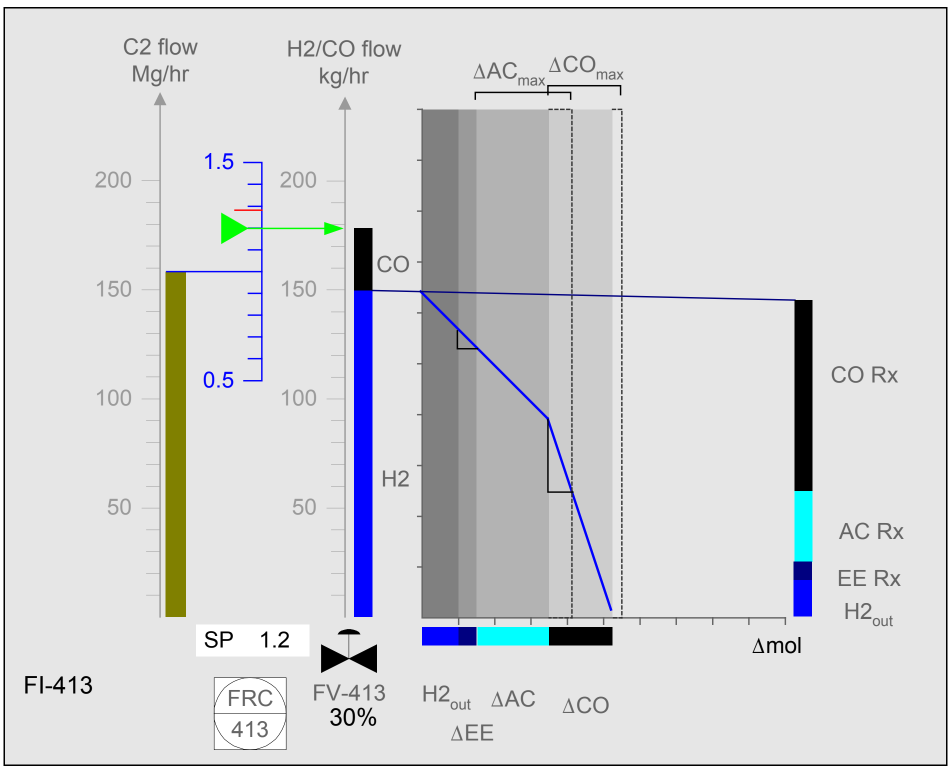

Figure 11: Hydrogen Balance Display, version 1.

With a representation of the amount of hydrogen entering the reactor provided, we next drafted a graphic to show how the hydrogen was being used in the reactor. A mol-mol scale shows hydrogen coming in to the reactor on the vertical scale and hydrogen "sinks" (i.e., outlet hydrogen, acetylene conversion, ethylene conversion, and CO conversion) on the horizontal scale. Gray blocks represent the sinks with the block thickness corresponding to the measured (H2, AC) or calculated (EE) number of moles of hydrogen given up to each sink. A blue, sloped line is drawn from the hydrogen inlet point across the blocks. It descends at a slope of –1 for the first three reactions because they each use up one hydrogen mole for each mole converted. When the consumption line reaches the CO sink block, it descends at a slope of –3 because 3 moles of hydrogen are required for each mole of CO. Here again, we will see changes to this graphic in later versions.

Prior to the next revision, the designers showed this graphical concept to two engineers and two experienced operators. Their comments were very positive. The engineers said that the design showed graphically what they knew was happening in the reactor from a process control standpoint. The operators commented that it gave them greater insight into a process that they knew from experience was central to effective operation of the reactor.

There were, as we noted above, several problems with version 1. First, the WRC graphic would prove to be flawed. This flaw would escape detection both by the designers and several reviewers. Second, the CO reaction that had been represented in the graphic does not take place as called out in the ADS. An error in the analysis had worked its way into the graphic. This was to have a substantial impact on the graphic, as is revealed in version 2.

Version 2

In version 2 (Figure 12), the CO reaction components no longer appear in the balance graphic. It was removed because we learned that the CO reaction was actually very rare, and that the analyzers for measuring the outlet concentration were located downstream of the system boundary. Consequently, the consumption slope is now monotonic. Note also the addition of a gray horizontal reference line to the balance graphic. This graphical element enhances the appearances of small slopes in the balance line.

Three analyzer columns have been added on the right side of the graphic. They were added here because the display was evolving into a comprehensive treatment of the reactor performance, as opposed to just a treatment of the hydrogen balance. These scales complete the inlet, reaction, and outlet process flow through the reactor, showing that the functional and process oriented parsing can be met simultaneously.

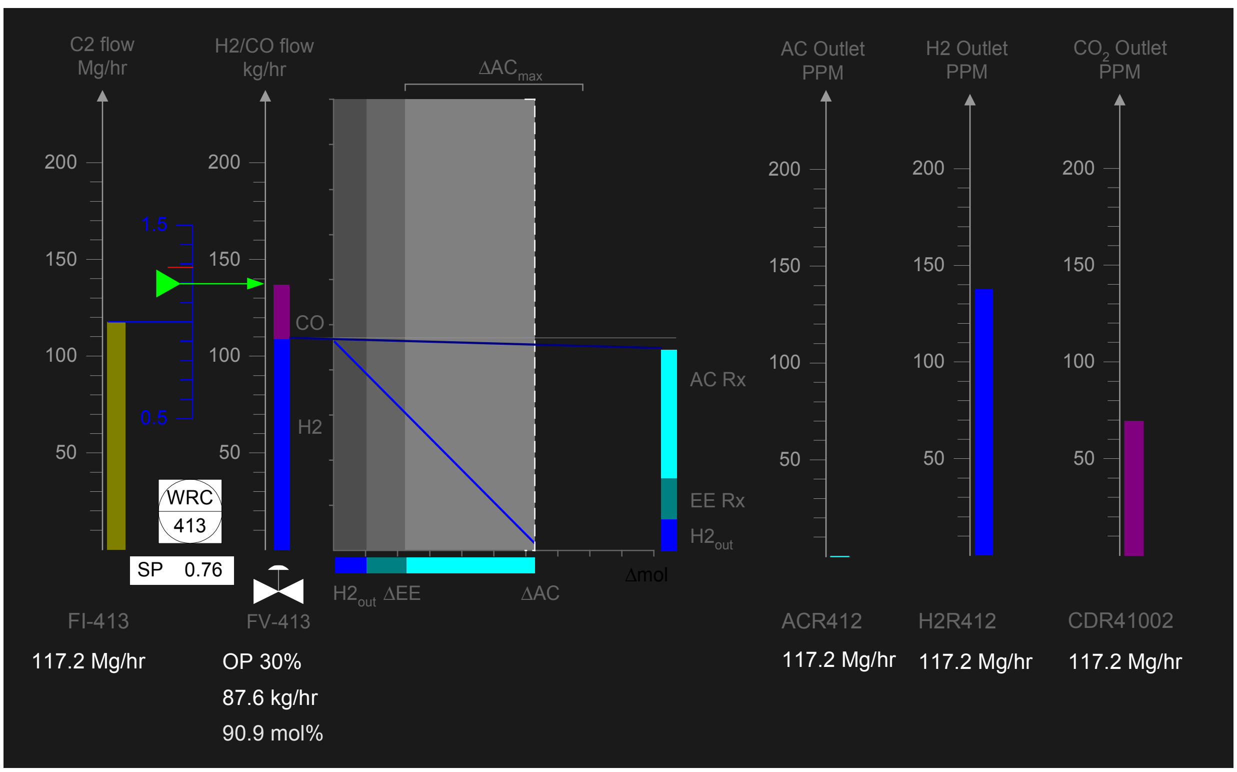

Figure 12: Hydrogen Balance Display, version 2.

Version 3

In version 3, the designers introduced a new graphic for the representation of the WRC. The new design was necessary because the original concept did not work properly. It was showing an additive relationship when a multiplicative relationship was required. The replacement graphic shows the multiplicative behavior of the WRC accurately. Note, however, that it has required a substantially larger graphic than that used in versions 1 and 2. The graphic shows the setpoint for the WRC along the bottom axis in the form of a green triangle. The vertical axis represents the C2 flow. A series of constant value curves is drawn in this surface, such that the product of the values of the horizontal and vertical axes meet on that curve. The current value of that product should be the setpoint for the H2/CO flow. This is represented by the green curve, which intersects the H2/CO scale at the intended setpoint. The graphic thereby allows the user to assess how effectively the control task of regulating H2/CO is being met.

Note also in version 3 that the consumption slope has been removed. This line was only marginally useful given that all of the reactions taking place in the reactor have the same stochastic relationship. In other words, a depiction of a functional relationship was removed form the display because that relationship turned out to be a simple one.

An addition to the analyzer columns graphics prompts an important distinction about process and operating limits. Each of the three columns in Version 3 includes red limit arrows. In the case of the acetylene column (AC Outlet), this limit is a process limit. The outlet acetylene concentration must be kept below the 5 ppm threshold in order to meet the functional purpose of the AHR. If this constraint is not met, downstream equipment cannot function effectively. In contrast, the hydrogen and carbon dioxide (error in Figure 13) columns have operations limits. These limits, while certainly related to the process functionality, are introduced by an examination of the task of controlling the reactor. They are benchmarks for effective control, as opposed to limits on functionality.

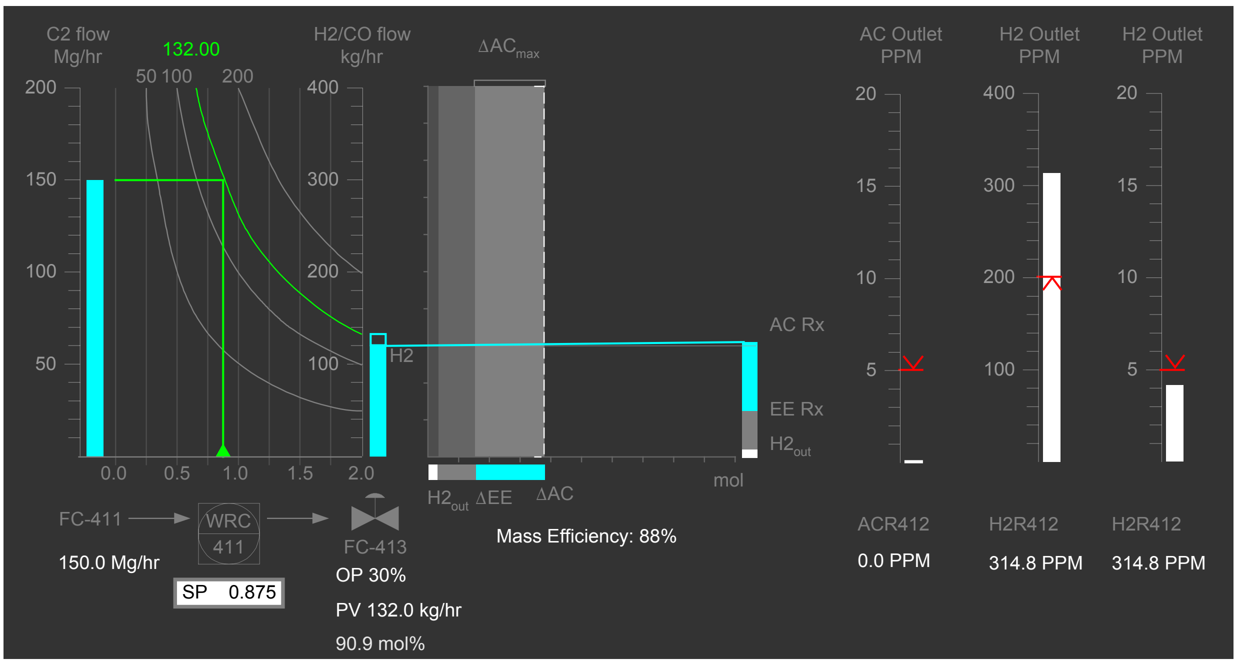

Figure 13: Hydrogen Balance Display, version 3.

Version 4

Version 4 (Figure 14) of the display shows a substantial addition of information to the display. There are four new control valves and two inlet analyzer representations. This information was added to the display based on the comments of the operators who critiqued the prototype display. They wanted to have a single graphic that they could use to monitor all of the functions related to the reactor performance. It is important to note that the CTA identified all of the information requirements from the control valves and that the WDA and HTA both had identified the requirements for the inlet analyzer information. If this information hadn't been placed on this display, it would have appeared elsewhere in the interface, although possibly in another form. That these elements weren't added to the display until the fourth version reflects the continually evolving nature of the displays. Thus, the functional scope of the display was expanded to include the CO flow into the reactor, reactor inlet temperature, and flare flow control.

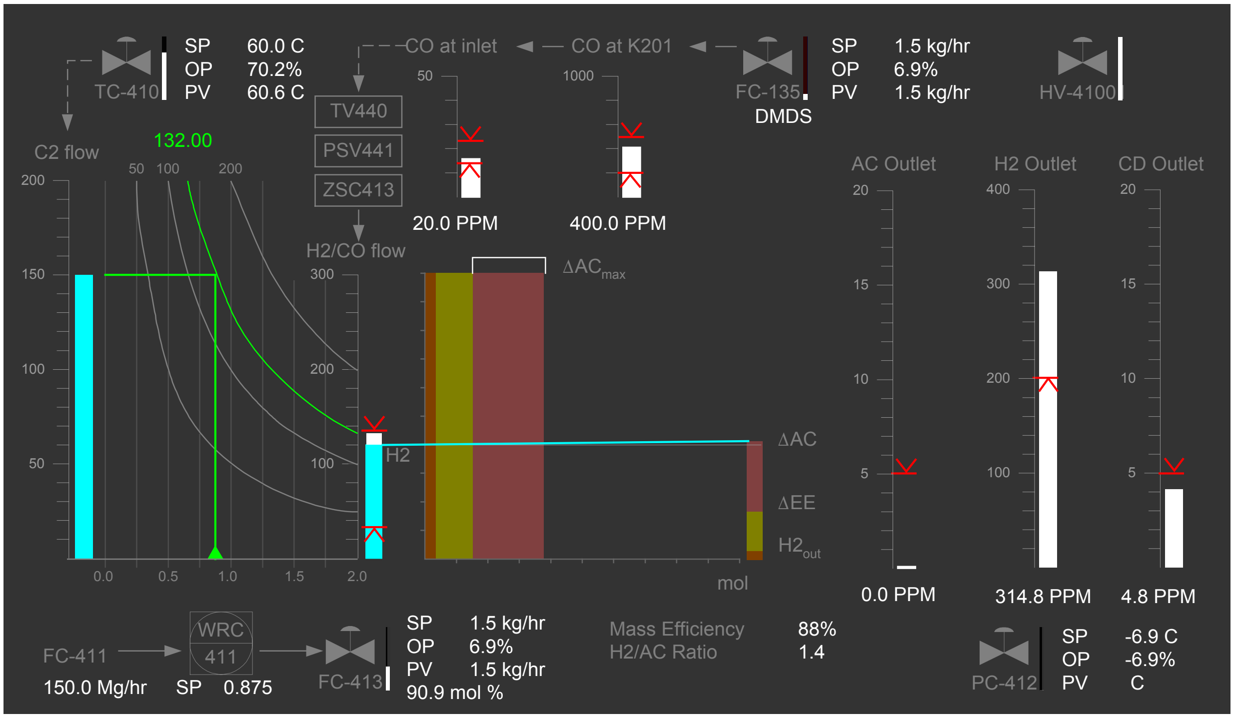

Figure 14: Hydrogen Balance Display, version 4.

Summary

There are several takeaway messages from the above design history. First, the iterative approach allowed us to make several improvements to the design and to catch several errors. The improvements came from two sources; designer innovation and comments from domain experts. However, it should also be noted that in some cases, the iterative approach failed to catch design errors (e.g., the WRC error, which was caught by a third party observer). Perhaps this failure can be attributed to the engineers and operators being unfamiliar with the design approach and not practiced in evaluating such graphics. Design review by non-designers is a critical step in the development of functional graphics. Additional emphasis on training non-designer collaborators to evaluate functional displays may prove beneficial.

Second, the functional scope of this display expanded as the design evolved. User comments encouraged us to group additional information with this graphic. Other displays went through the opposite course in their evolution, where information was removed from one graphic and placed in another graphic as the displays evolved. The WDA and TA results do provide some direction for parsing displays. However, target users can restore some of the operational context that is lost by the analyses. Their input once again becomes critically important.

The purpose of this chapter has been to show both how the Hydrogen Balance Display evolved and how it encapsulates information from all three analyses. A detailed description of the final form of the display appears in the next section. There, an examination of this and two other displays from the novel functional interface reveals different ways in which the information requirements can be parsed.

MAPPING INFORMATION REQUIREMENTS TO DISPLAYS

In the previous section, we discussed the evolution of the Hydrogen Balance Display. There the focus was on how the display acquired its graphical form through the iterative design process. In this section, we discuss the sources of the information requirements that instruct the designer on what needs to be included in the interface. Three displays are discussed in detail, starting with the Hydrogen Balance Display from the previous section, which draws information requirements from both the work-domain- and task-based analyses. The Reactor Temperature Profile Display draws primarily from the ADS, while the Procedure Display draws almost exclusively on the HTA. We discuss how these displays work, show the mapping of the information requirements included in each one, and discuss the relative contributions of the various analyses.

For this chapter, we return to the IR Matrix in Appendix B. Each display in the new interface has a column in that Matrix. For each information requirement, a check appears in the column(s) for the display(s) in which it appears in the display. The columns for the three displays discussed in this chapter are highlighted.

Hydrogen Balance Display

Purpose

The Hydrogen Balance Display (Figure 15) provides information about the types and rates of reactions taking place in the reactor. It also provides information about the input and output streams. The display can be described in terms of four separate graphics: the Ratio Controller, Hydrogen Balance, Analyzers, and Control Valves.

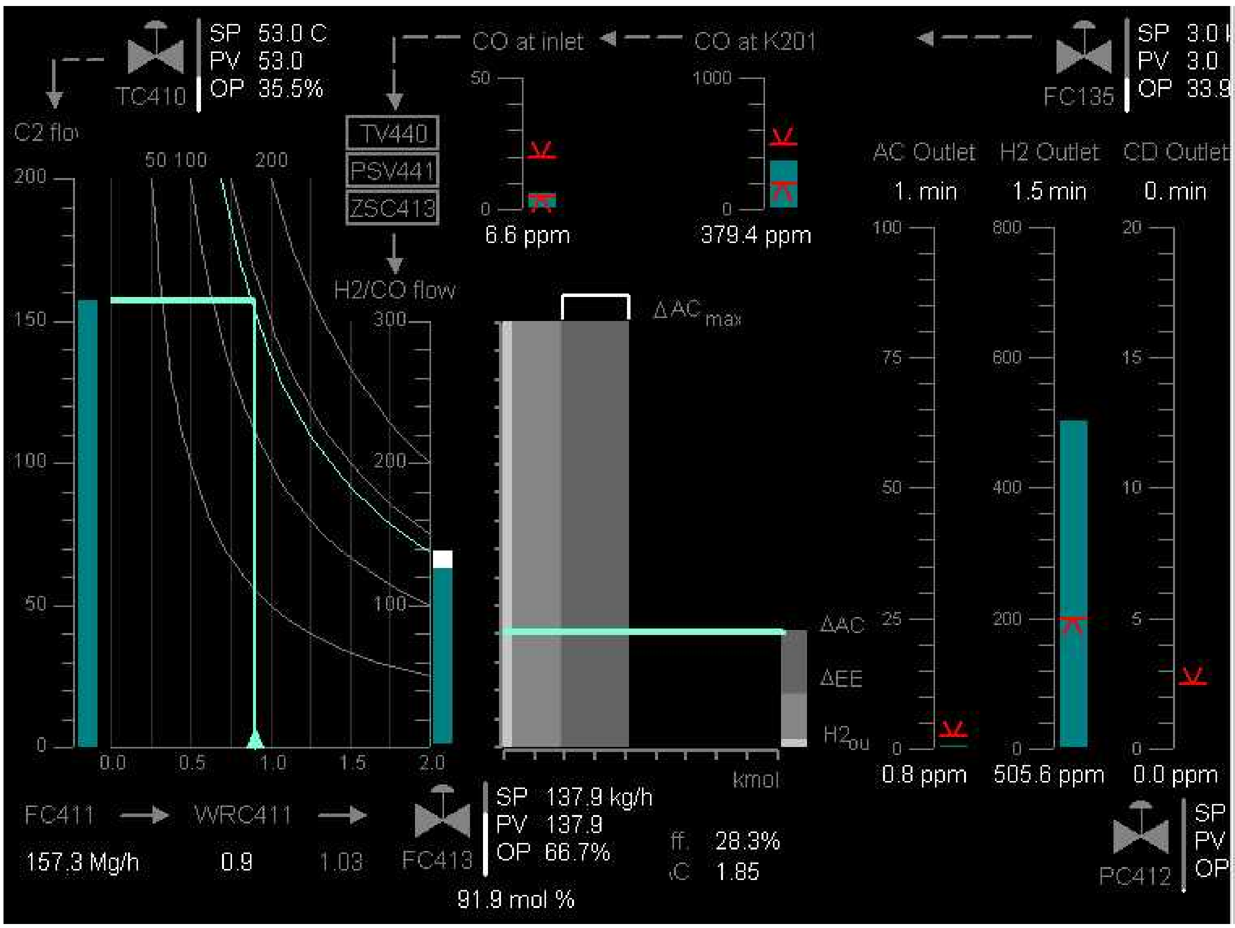

Figure 15. Hydrogen Balance Display.

Ratio Controller.

The Ratio Controller Graphic allows the operator to monitor the control of the H2/CO stream (see Figure 16). Two flow-rate graphics are used to display the flow-rate of the C2 stream (left side of Figure 16) and the H2/CO stream (right side of Figure 16). Each graphic has a gray fixed scale, ranging from 0 to 200 in Mg/hr for the C2 flow (FC411) and 0 to 300 in kg/hr for the H2/CO flow (FC413). Above each of the scales, the flow is denoted in gray. A minimum limit for the FC411.PV is set at 40 Mg/hr. The limit is indicated by red limit arrow formed by a chevron above a horizontal line segment, both of width 2. This graphic is used several times in the Display.

For the C2 flow, a cyan bar indicates the flow rate. A divided cyan and white bar is used to describe the flow rate of the H2/CO stream. The total height of this bar is given by FC413.PV. The cyan portion of the bar represents the amount of H2, the white portion represents the amount of CO and impurities. The proportion of the column drawn in cyan is given by H2M304.PV. It is assumed that H2M304.PV will take a value between 0 and 100. For values greater than 100, the graphic behaves as if H2M304.PV=100. For values less than 0, the graphic behaves as if H2M304.PV=0.

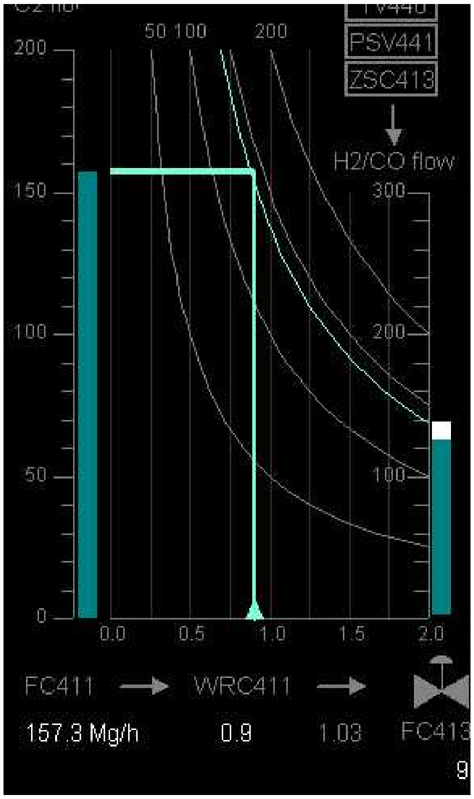

Figure 16. Hydrogen Balance Display: Ratio controller.

The behavior of the ratio controller is represented by a graphic that lies between the two flow rate bars (Figure 16). The baseline of the graphic reflects the value of the weight ratio controller (WRC) setpoint. It is drawn in gray and has a range of 0.0 to 2.0. Vertical gray lines extend from the baseline at 0.25 increments, extending to a point equal to the maximum values of the C2 flow scale. Four gray constant value lines are drawn on the plot at values of 50, 100, 150, and 200. At every point along each of the lines, the product of the value along the baseline and the value along the C2 flow scale is a constant. The lines are static. A fifth constant value line is drawn in sea green. The value of this line is determined by the current value of FC413.PV. A small triangle rests on the baseline at the present value of the setpoint of the weight ratio controller. A sea green line of width 2 extends vertically from the triangle, up to the present constant value line. A second line is drawn horizontally from the top of the C2 flowrate column across to the current constant value line. The two lines should meet near the current constant value line defined by Fc413.PV.

Below the Ratio Controller graphic is a combination of text indications and connecting arrows (see bottom of Figure 16). These include static text for the C2 flow and weight ratio controller in gray font. Actual values for the C2 flowrate and WRC setpoint, are printed in white font. A weight correction factor appears in gray text.

Information for the graphics described above came primarily from the WDA, although the C2 and H2/CO flowrates were simultaneously identified by the HTA. In contrast, the WRC graphic was derived from requirements specified exclusively by the CTA. This is one of the most salient contributions of the CTA in the interface.

Hydrogen Balance

The middle portion of the display shows the Hydrogen Balance Graphic (see Figure 17). The graphic displays the amount of H2 entering the reactor (H2F410.PV), what reactions occur inside the reactor (ACD411.PV, EAD411.PV), and the H2 accounted for after the reactor (H2F411.PV). As a whole, the graphic depicts the mass efficiency calculation (EFM410.PV). The actual value for the mass efficiency tag is given in white 11-point Arial font at the bottom of the graphic. The graphic is based on a kmol-kmol scale with a range of 0-150 kmol/h on the vertical axis. No scale values are shown on this axis. However, the axis itself forms a focus region for H2F410.PV, with the tooltip showing both tagname and current value. This current value forms a point on this axis. Although this point is not shown graphically, it serves in the construction of a later graphic.

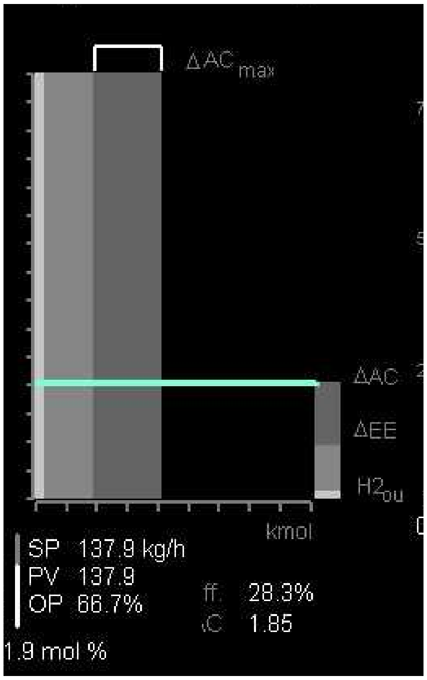

Figure 17. Hydrogen Balance Display: Hydrogen balance.

There are three anticipated dispositions for the hydrogen, two of which are reactions:

1. Ethylene Conversion (ΔEE): C2H4 + H2 -> C2H6 + heat
2. Acetylene Conversion (ΔAC): C2H2 + H2 -> C2H4 + heat
3. Some hydrogen may pass through the reactor without reacting ($H2_{out}$)

A baseline scale below the rectangles denotes the amount of H2 accounted for in kmol/h. The increments on this scale are the same as those on the vertical axis. The width of three gray rectangles represents the rates of H2out, ΔEE, and ΔAC. The height of the rectangles is fixed at the height of the H2/CO scale. Each rectangle also serves as a focus region, with the tooltip showing both tagname and current value. To the right of the scale, a stacked bar graph reflects the width of each of the three disposition rectangles, using the same colors. This vertical bar represents the total H2 consumption and can be compared to the H2 input on the left side of the reactor graphic. A cyan line of width 2 is drawn from the point on the vertical kmol scale corresponding to H2F410 to the top of the stacked H2 output bar. If all of the H2 is accounted for, the line will be horizontal. If the line is sloped negatively, the graphic indicates that some of the incoming H2 is not being accounted for and there may be a problem. If the line is sloped positively, the graphic indicates that more outgoing H2 is being measured than there is measured incoming H2. A gray horizontal reference line is drawn from the point corresponding to H2F410.PV to help operators detect deviations in the balance line[8].

The Hydrogen Balance graphic also includes an indication of the maximum amount of acetylene conversion possible (i.e., the total number of acetylene moles entering the reactor). This is shown by a white bracket located just above the ΔAC rectangle. The left edge of the bracket lines up with the left edge of the rectangle and its width is equal to the number of moles of inlet acetylene. Any discrepancy between the end of the bracket and the rectangle indicates that some acetylene is not reacting.

The entire balance graphic is derived from IR's called out by the ADS at the Generalized Function – Component level of analysis. Neither of the other analyses captured these requirements. That the ADS captured these

[8] Not visible in the figure because the hydrogen count is balanced.

requirements reflects the power of examining a system for its functional structure as opposed to solely reviewing its method of operation.

Note that the balance graphic employs derived values (i.e., molar flow rate comparisons) that were not previously available to the operator, but are all afforded by the existing sensors. The process of work domain analysis revealed several relationships that were critical to effective operation of the reactor and the graphic exposed those relationships. Additional analyzers up- and down-stream of the reactor would allow accounting for other reactions. However, we tried to work exclusively with available analyzers in these displays.

Analyzers

Analyzer readings for acetylene (AC), hydrogen (H2), and carbon monoxide (CO) in the outlet stream are located on the far right of the H2 Balance Display (see Figure 18). White bars indicate the value of the concentration of each in PPM. The scales are fixed from 0 to 100 for acetylene, 0-800 for H2, and 0-20 for carbon dioxide. A limit graphic (described above) on each scale indicates a limit for the concentration. For AC and CO, these are maximum limits of 2.5ppm, for H2 a minimum limit is prescribed at 200ppm. Digital values for the instrument readings are provided below the scales. Above each of these three scales is a digital update timer for the measuring instrument. The digital value is presented in white font in the form #.# minutes and counts down to the next update for the analyzer.

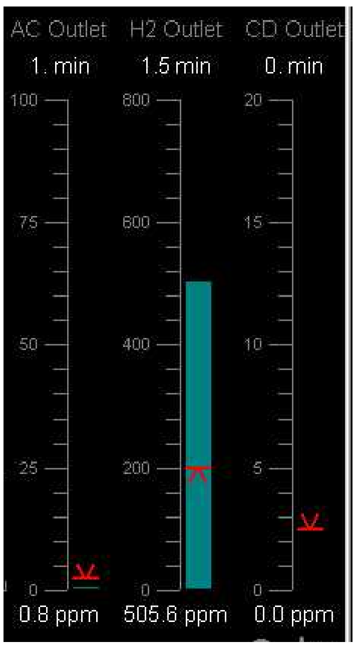

Figure 18. Hydrogen Balance Display: Analyzers (outlet)

Additional Analyzer graphics appear above the Hydrogen Balance graphic to represent the incoming CO concentration and H2/CO flow lock-out (see Figure 19). The two CO concentration graphics use the same color and style as those described above (less the analyzer update timer). However, their vertical height is reduced. The CO at inlet scale ranges from 0-50 with minimum and maximum limits at 5ppm and 20ppm, respectively. The CO at K201 scales ranges from 0-1000 with a maximum limit at 500ppm and a minimum limit at 200ppm. Dashed gray lines connect the text indications together and to the H2/CO flow rate scale.

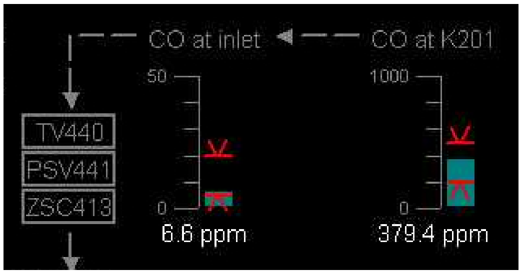

Figure 19. Hydrogen Balance Display: Analyzers (inlet)

All five analyzers reflect information requirements from the both the ADS and HTA. The limits on the acetylene flow are drawn from the ADS, while the limits on the hydrogen, carbon monoxide, and carbon dioxide flows are task-relevant. The analyzer update times are based on IR's captured by the HTA.

Three gray outline rectangles lie on the flow path line leading to the H2/CO flow rate column (see Figure 19, left). Each represents one possible location for blocking or venting H2/CO flow. The box colors for TV440 and ZSC413 can change depending on process values. The TV440 box changes to yellow when 0<TV440.PV<=25.0C; the box turns red when TV440.PV<=0. The ZSC413 box turns red when ZSC413.PV=ON. The box color for PSV441 cannot change color because the relief valve that it represents is not instrumented.

Control Valves

Four standard control valve representations appear above the three graphics discussed above (see Figure 20). These are for the reactor temperature inlet control (TC-410), the DMDS control (FC-135), H2/CO flow control (FC-413), and reactor inlet pressure control (PC-412). The standard control valve representations consist of a valve icon and a simple graphic for the valve position. This consists of a gray column to represent the range of possible positions (0-100% open) and a white column whose length is proportional to the valve OP position. Text values for the SP, OP, and PV tags are shown in white 11-point Arial font.

Figure 20. Hydrogen Balance Display: Standard control valve representation.

The control valves reflect a combination of ADS and CTA IR's. The valve itself, its position, and the flow rate are IR's at the Physical Form, Physical Function, and Generalized Function levels, respectively, for this Component. The three controller values are called for by the CTA.

Information content

The Hydrogen Balance Display blends together the information requirements of the system-based and task-based analyses. It is a prime example of how the analyses can complement each other and lead to the integration of task and function. The specific IRs communicated by the display can be found in Appendix B.

Reactor Temperature Profile Display

Purpose

The Reactor Temperature Profile Display (Figure 21) provides the operator with the vertical and horizontal temperature distributions of the reactor bed. It also includes the common feed input temperature, flow, and pressure, and the outlet temperature reading. The display allows the operators to monitor the status of the reactors and determine if temperatures are within desired operating conditions. The design also assists operators in understanding the state of the reactions, planning future actions, responding to potential problems, and troubleshooting.

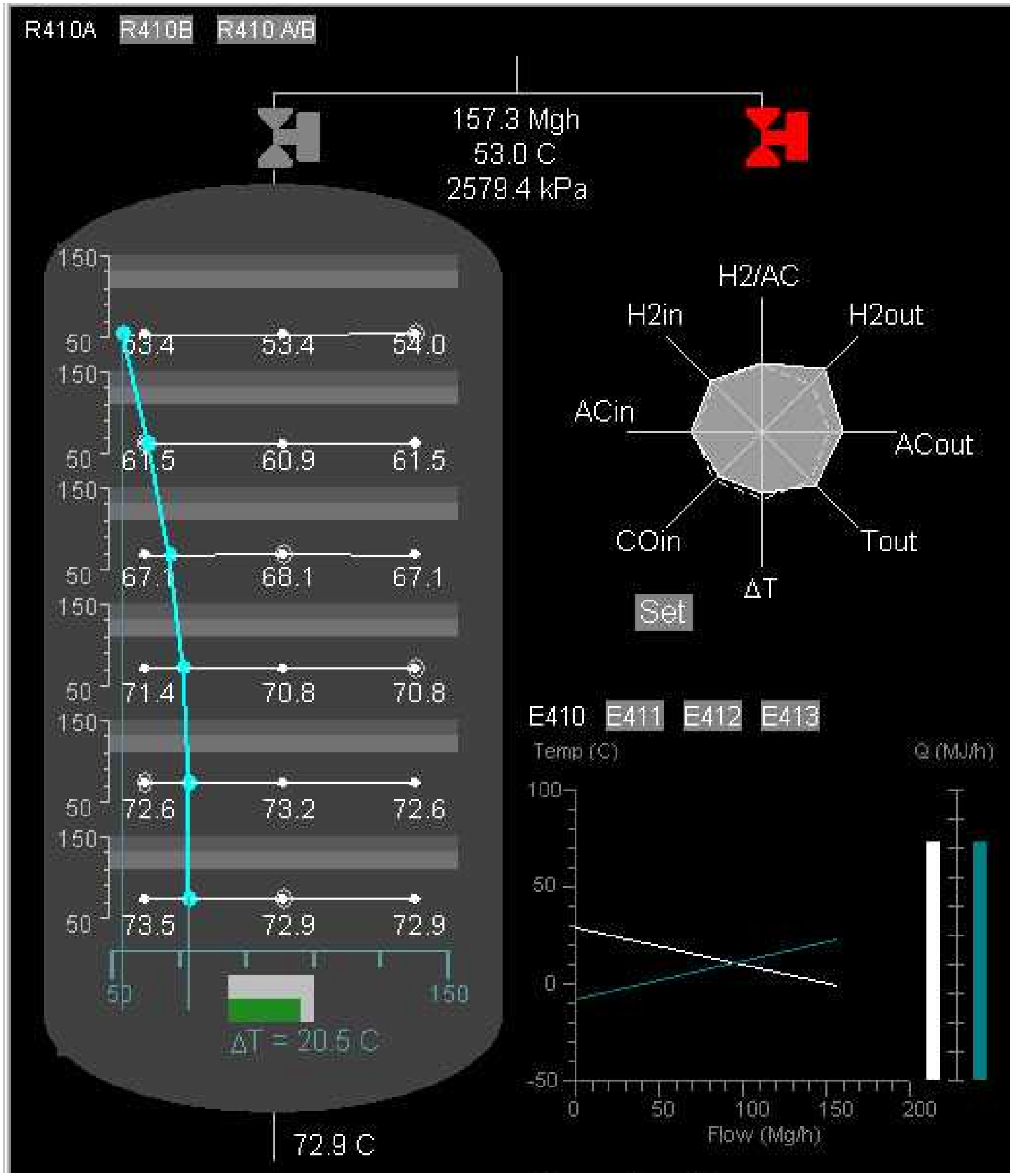

Figure 21. Reactor Temperature Profile Display (A&B tab).

Tab selection

The design consists primarily of a gray schematic-like display of the reactors with supporting equipment icons and digital values. A detailed temperature display graphic is integrated into the schematics of each of the two reactors. There are three tab-based displays; the temperature profile of reactor R410A with associated polar star and Heat Exchanger panel (see Figure 22, left), R410B with associated polar star and Heat Exchanger panel (see Figure 22, right), or both R410A and R410B simultaneously with no polar stars or Heat Exchanger panel (Figure 21). The operators can switch between the display options by clicking on the tabs. The default operating condition is for presentation of data pertaining to the on-line reactor [tag ACX410.S1]. Thus, the display will appear as the left-hand side of Figure 22 if R410A is on-line [ACX410.S1 value=1] or as the right-hand side of Figure 22 if R410B is on-line [ACX410.S1=2].

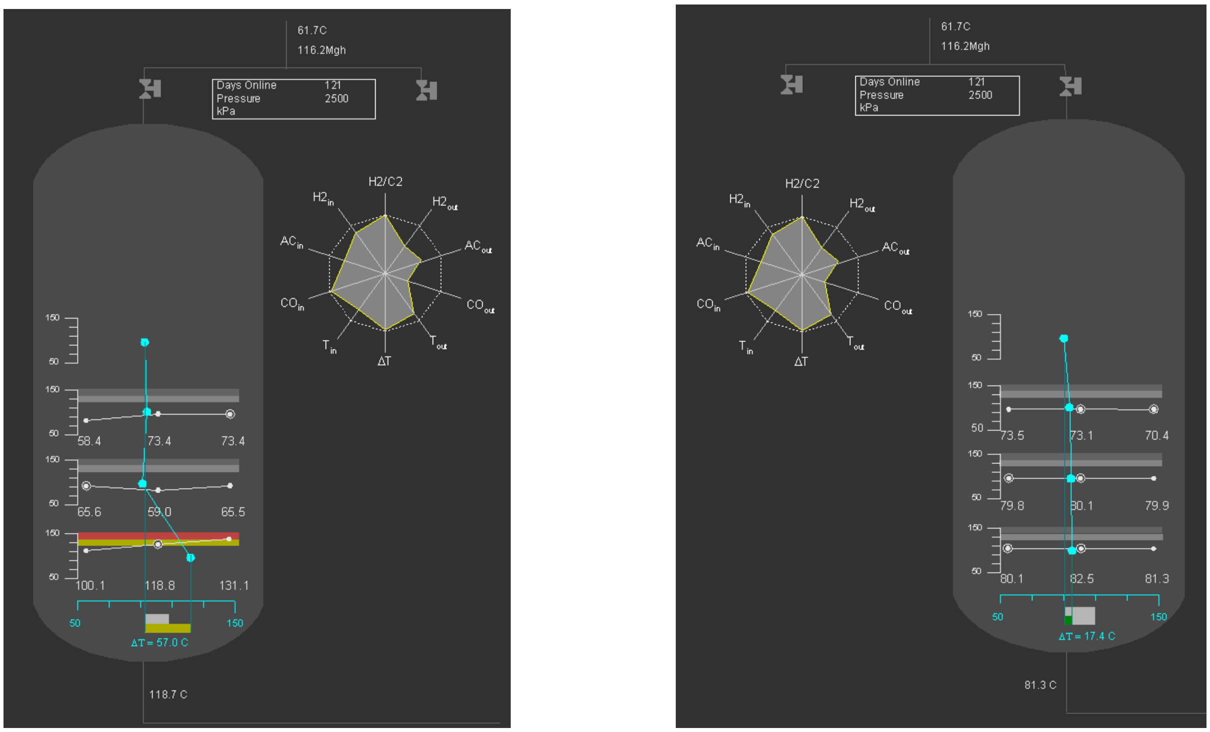

Figure 22. Reactor Temperature Profile Display: R410A with associated polar star (left); R410B with associated polar star (right).

Reactor temperature display graphic.

The reactor temperature display graphic provides a visual indication of the temperature profiles in the reactors (see Figure 23). It is composed of the horizontal and vertical temperature profile graphical elements (described below). Each reactor has 3 rows of temperature sensors, each row having 3 sensors corresponding to a temperature tag.

Horizontal temperature profile graphical element.

Each row of three temperature tags is displayed against a temperature scale (see Figure 23). Both scale lines and text are gray. Values for scale limits for each row are drawn from the INI file with a default range of 50 C to 150 C. Three individual temperature readings are displayed as white dots placed at their appropriate relative position on the vertical scale. These dots act as focus regions with tagnames only appearing in the tooltip. One (R410A) or two (R410B) dot(s) in each row has a white circle around it to indicate that the associated tag is connected to the PLC410 Reactor Temperature Trip Function. The temperature readings for a given row are linked together with straight white lines of width 2. The digital value of each temperature indication is displayed in white below the dots. The digital values are positioned below the scale and are fixed (i.e., the position of the digital values will not change). The white dots should be the predominating visual element in the display, followed by the connecting lines.

The two gray bands located near the top of the scale are indicators of alarm and trip temperatures (see Figure 23). The lighter gray band begins at 110.0 C and ends at 129.9 C and indicates the alarm/warning temperature range. The darker gray band begins at 130.0 C and continues to the top of the scale (in this case, 150.0 C). These bands provide an indication of how close the temperatures are to a possible alarm or trip.

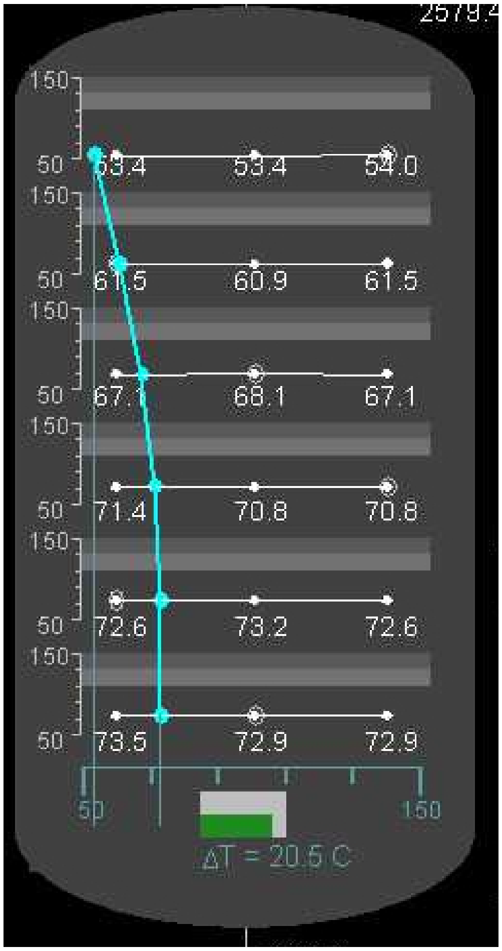

Figure 23. Reactor Temperature Profile Display: Temperature display graphic.

Name: Temperature Encroaches on Alarm or Trip Region	
Description:	The indicator bands remain gray until any one of the temperature parameters in the respective row enters the warning (110.0 –129.9 C) or trip (130.0 C or greater) regions. If any of the three temperature readings in a given row is inside the warning band, the band in that row will turn [goldenrod] (see Figure 24). If a temperature reading is inside the trip band, the band will turn [red]. The band(s) will remain [red] or [goldenrod] until the temperature reading(s) fall below 130 C and 110 C, respectively. They then return to their normal color.
Actors:	The event is caused by a regular update in the temperature tag parameter where the value of the parameter falls in the ranges specified.
Preconditions:	The alarm band is [gray45]; the trip band is [gray35].
Postconditions:	The alarm band is [goldenrod]; the trip band is [gray35] or [red].
Primary Path:	The alarm band will change to [goldenrod] before the trip band changes to [red]. The trip band cannot be red unless the alarm band is [goldenrod].
Alternate Paths:	Both bands could simultaneously change from [gray45/35] to [goldenrod] or [red], respectively. Similarly, they can change from [goldenrod] or [red] to [gray45/35].
Exceptions:	

Table 2: Use Case: Temperature Induced Alarm or Trip in Reactor Temperature Profile Display.

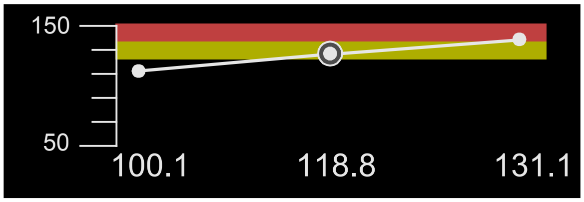

Figure 24. Reactor temperature profile Display: Alarm/warning temperature bands.

Name: Temperature tag parameter exceeds 150 C	
Description:	The value of any one of the temperature sensors in the reactor can exceed the upper scale limit of 150.0 C. Between 150.0 and 160.0 C, the temperature dot continues to rise. At or above 160.0 C, the dot stays at the position associated with 160.0 C and the lines connecting that dot to either of the other two dots are not drawn.
Actors:	The events are caused by a temperature tag parameter exceeding 150.0 C.
Assumptions:	Highest temperature required is 300.0 C, above which plant will be evacuated.
Preconditions:	Temperature <=150.0 C. Temperature indicator moves with changes in tag value.
Postconditions:	150.0<T<160.0: Indicator continues to move as it would within scale range. T>=160.0 C: Temperature indicator remains fixed at 160.0 C; connecting lines not drawn.
Primary Path:	
Alternate Paths:	
Exceptions:	

Table 3: Use Case: Temperature tag off scale (high) in Reactor Temperature Profile Display.

Name: Temperature tag parameter falls below 50 C	
Description:	The value of any one of the temperature sensors in the reactor can fall below the lower scale limit of 50.0 C. Between 40.0 and 50.0 C, the temperature dot continues to fall. At or below 40.0 C, the dot stays at the position associated with 40.0 C and the lines connecting that dot to either of the other two dots are not drawn.
Actors:	The event is caused by a temperature tag parameter falling below 50.0 C.
Assumptions:	Lowest temperature required is 35 C, below 35 C the reaction will not occur.
Preconditions:	Temperature >=50.0 C. Temperature indicator moves with changes in tag value.
Postconditions:	40.0<T<50.0: Indicator continues to move as it would within scale range. T<=40.0 C: Temperature indicator remains fixed at 40.0 C; connecting lines not drawn.
Primary Path:	
Alternate Paths:	
Exceptions:	

Table 4: Use Case: Temperature tag off scale (low) in Reactor Temperature Profile Display.

Vertical temperature profile graphical element.

The Reactor Temperature Display graphic also contains a vertical temperature profile (Figure 23). The Vertical Temperature Profile graphic displays the average (mean) temperature tag for each row, but on a separate scale placed at the bottom of the graphic. The Vertical Temperature Profile Display element is superimposed on top of the Horizontal Temperature Profile Display element. The mean temperature for each row is depicted by a cyan dot placed in each horizontal row. The cyan dot acts as a focus region with the text, “Mean=” followed by the tag value. The dots are connected by straight cyan lines of width 2 to help the operator visualize the temperature profile across the height of the reactor.

The ΔT across the reactor height is indicated at the bottom of the display (see Figure 25). This value is the difference between the average temperature of the bottom row and the average temperature of the top row. CadetBlue lines are drawn from the average temperature indicator of the top row and the average temperature indicator of the bottom row to indicate the ΔT value on the scale.

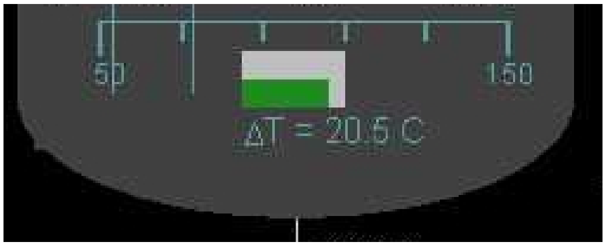

Figure 25. Reactor Temperature Profile Display: ΔT Graphic.

It is desirable that ΔT should not exceed 25°C. A [gray 75] box placed below the scale is used to indicate the maximum-desired ΔT. The left edge of the box begins at the CadetBlue line extended from the average temperature indicator of the top row and extends to the right for 25°C. A forest green bar is drawn between the two dark blue lines to indicate the ΔT.

ΔT exceeds 25 C	
Description:	The ΔT across a reactor can exceed 25 C. When this occurs, the bar between the blue lines changes to [goldenrod] (see Figure 26).
Actors:	The event is caused by the value of the ΔT tag exceeding 25.0 C.
Assumptions:	
Preconditions:	The ΔT bar is [forest green]
Postconditions:	The ΔT bar is [goldenrod]
Primary Path:	
Alternate Path:	
Exceptions Path(s):	

Table 5: Use Case: ΔT exceeds threshold in Reactor Temperature Profile Display.

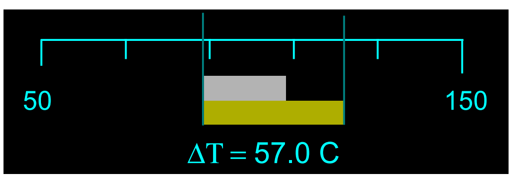

Figure 26. Reactor Temperature Profile Display: ΔT Graphic with ΔT falling outside the desired range.

Supplementary Data and Graphics.

In addition to the graphical elements discussed above, gray flow path lines are included above and below the reactor as shown in Figure 24. Five digital tag values are presented in the proximity of these lines. The common reactor inflow rate (FC411.PV), temperature (TC410.PV), and pressure (PV412.PV) indications are positioned at the top of the display. Below each reactor is a temperature indicator, TI417 for Reactor A, and TI418 for Reactor B. All five of these digital values functions as a focus region with a tooltip showing the associated tag name.

MOV Valve Icons.

An MOV valve icon appears above each reactor schematic. Each acts as a focus region with only tag name appearing in the tooltip. The current status of the valve is taken from the tags MS410.PV (for R410A) and MS411.PV (for R410B). These PVs have three states and an important BADPV condition. The states are 0-STOP, 1-OPEN, and 2-CLOSED. The 0 state is effectively non-functional and would only appear in the case of a sensor failure. A BADPV state will occur when the MOV does not meet the conditions that define the states 0, 1, and 2. This will occur whenever the valve is between its fully open and fully closed position. Three MOV icons are defined to convey the four possible states of the PV parameter. The color mapping is: 0-[yellow], 1-[gray], 2-[red], BADPV- [yellow].

Information content

The specific IRs communicated by the display can be found in Appendix B. The IR's that specify the content for the Reactor Temperature Profile Display are all specified by the ADS. Some are redundantly called out by the HTA, but it was functional requirements that prompted this display. Rather than merely communicating the temperature values, the graphic answers critical questions about the state of the process. Is the reaction distributed evenly across the reactor? Where is the reaction taking place? Are the temperatures within desired limits? While answers to these questions can be deduced from the raw indicator values, the graphic completes the processing for the operator.

We would expect that the information contained in this display would be useful in all operating conditions, normal or abnormal, proceduralized or novel. This is because the IR's reflect the functional constraints of the reactor (in terms of temperature); constraints that must be met at all times. This characteristic is only partially met by the Hydrogen Balance Display discussed above, and not at all met by the Procedure Display discussed next.

Procedure Display

Purpose

The Procedure Display (Figure 27) supports the operator in executing the reactor swing and reactor temperature runaway procedures. The procedure steps are included in the display in a color-coded tree structure. Each step is associated with a static image of the reactor equipment state.

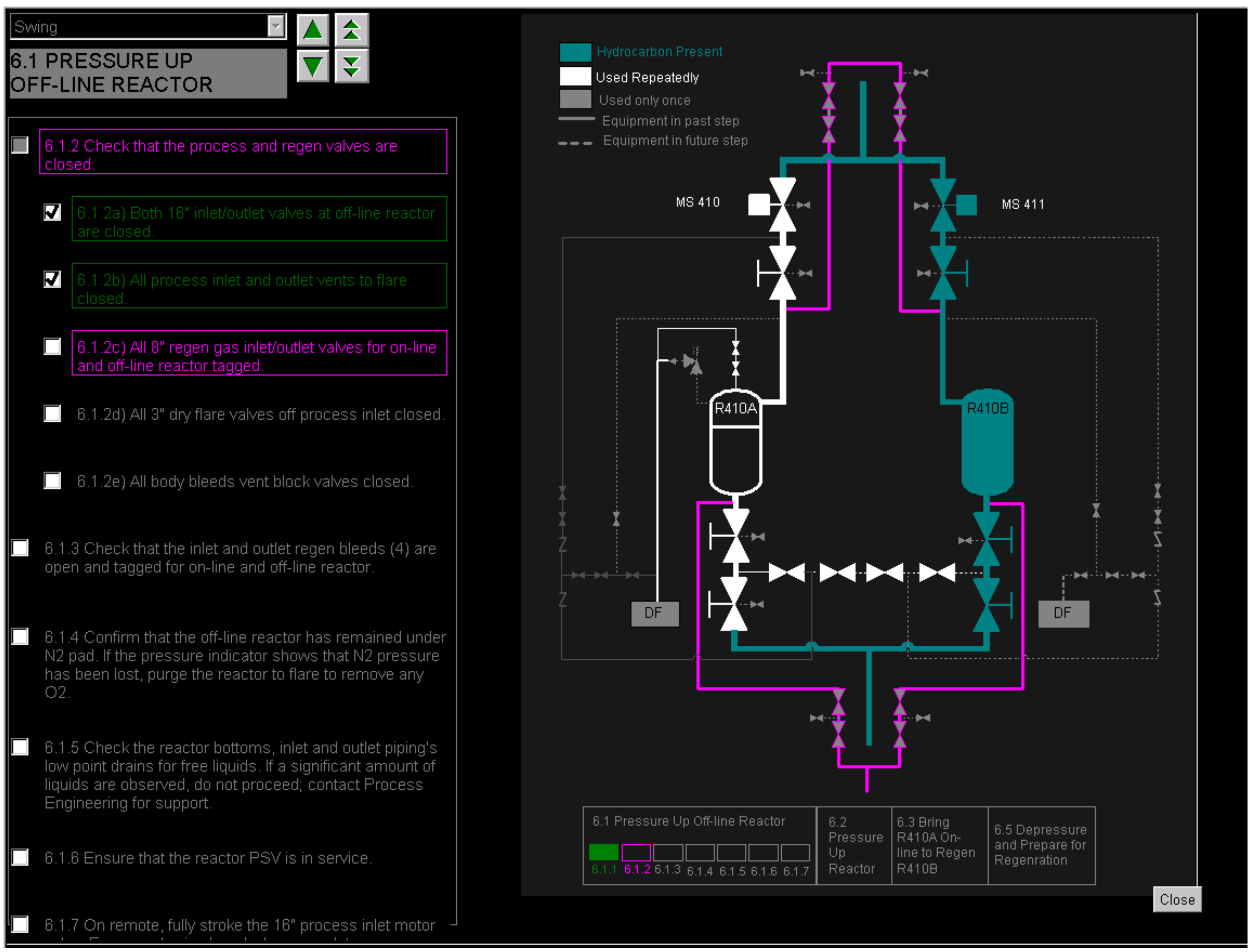

Figure 27. Procedure Display

Steps Window.

The display is divided into two areas, the Steps window on the left and the Images window on the right (see Figure 28). The Steps window presents the steps of the procedure printed as a tree structure in gray 11-point Arial font. The steps are hierarchically organized in the tree structure to reflect their organization in the procedure. Each step is numbered and its text content and associated images (see below) are provided in a text file. The step text is color-coded based on the progress of the operator through the procedure. The color mappings are as follows:

Active Step	[magenta]
Acknowledged Step	[chartreuse]
Previous Steps	[dark green]
Future Steps (all)	[gray]

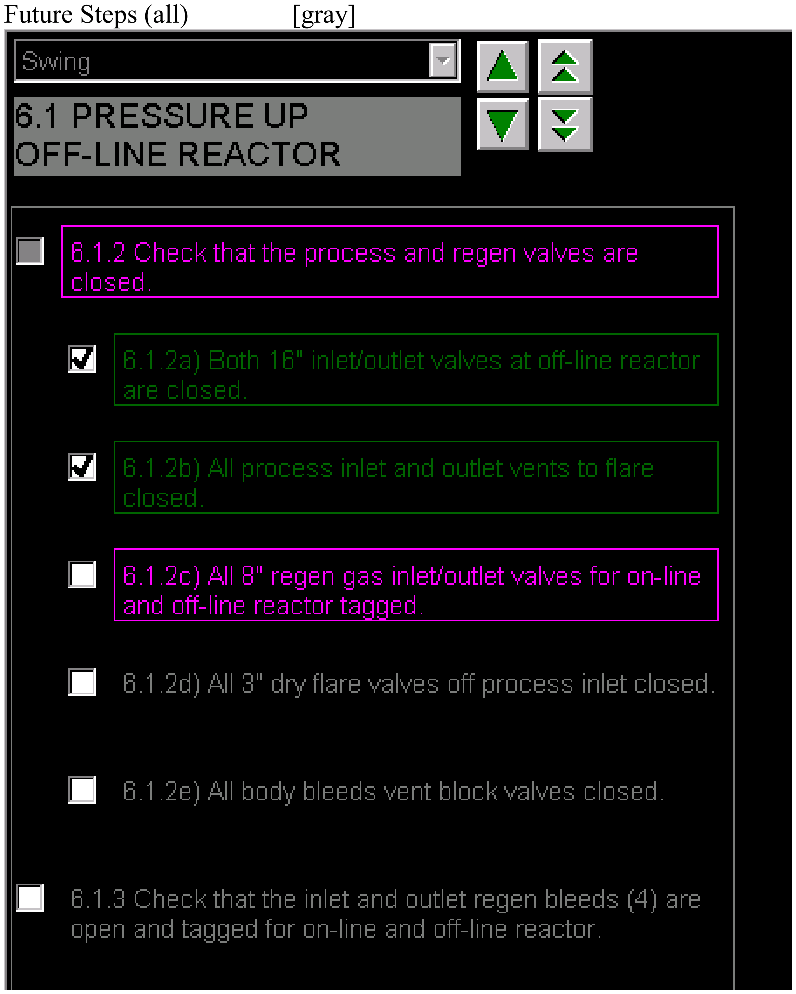

Figure 28: Procedure Display: Steps Window.

There is a check box to the left of each step. Interaction with this check box determines the color of the step text . The ‘active’ step is the step that the operator is currently working on, but has not been confirmed to be complete. When a step is confirmed to be complete, clicking in the check box changes the status of that step to ‘acknowledged’. Following a 2-second delay, the next step in the sequence is placed in ‘active’ status. Once the succeeding step is made ‘active’, the formerly ‘acknowledged’ step transitions to ‘previous’ step status. A ‘future’ step is one that has not yet been reached in the procedure. A use case for checking off steps and stepping between them is provided in Table 6).

Name: Step progression
Description: A method is required to transition between the four step statuses. When a user checks off that an 'active' procedure step is complete, the image changes for a period of seconds to show the 'acknowledged' image. After the several seconds have elapsed, the step moves to 'previous' state, while the successive step simultaneously changes to its 'active' image. The pattern is repeated for all steps of the procedure.
Actors: Active1->Acknowledge1: User initiated
Acknowledge1->Previous1; Future2->Active2: Automatic (time delay)
Assumptions: Only the active step can be checked off.
Preconditions: The 'active' image for the initiating step is shown in the Image Window; the 'future' image for the successive step is shown.
Postconditions: The 'previous' image for the initiating step is shown in the Image Window; the 'active' image for the succeeding step is shown.
Primary Path: 'Active' image for initiating step, 'acknowledged' image for initiating step (time delay), 'active' image for succeeding step, 'previous' image for initiating step
Exceptions: If the succeeding step is part of the next high level step, then the text at the top of the scrolling region will update as well.

Table 6: Use Case: Procedure Display step progression.

At the top of the scrolling window, the high level (e.g., 6.X) step is shown in black text printed in 14-point bold Arial font on a gray background. This text is not part of the scrolling window and no images are associated with it. It is determined by the active step (6.XX or 6.XXx). The text updates to the next high-level step when the first sub-step of that level is activated.

A box surrounds the text of the 'active' and 'previous' steps. The color of the box matches the color of the step text. No box is drawn around 'future' steps. See Figure 28 for an example.

Several steps act as 'parent' steps with several 'children'. Parent steps have grayed out check boxes that a user cannot check off. An alternative set of step states are defined for parent steps. These are:

Active Parent (1)	[magenta]
Acknowledged Parent (1)	[chartreuse]
Previous Steps (all)	[dark green]
Future Steps (all)	[gray]

A parent step becomes an 'active parent' in the same manner that a regular step does (i.e., when the previous step has been completed). However, the first child step under the parent also becomes 'active' at the same time. The parent remains in the 'active parent' state while any of its children is 'active'. The standard step progression semantics follow for the child steps until the last child step is completed. When the final child step is checked off, it transitions to 'acknowledged' and the parent transitions to 'acknowledged parent' for 2 seconds. Then both steps transition to 'previous'. Once the parent step is 'previous', a check mark is placed in its check box. Throughout the child steps, the child steps determine the images. No images are associated with the parent step itself.

Check boxes for parent steps are grayed out. A check mark will automatically be placed in the check box of the parent step once the last sub-step of the parent step has been checked off. This should require no direct interaction by the operator.

Images Window.

The images window shows a series of static bitmap images that are mapped to each step of the procedure. The files are identified by name in the formatted procedure text file (see above). Two images are identified for each non-parent level 1 and 2 step. One image maps to the 'active' step and one maps to the 'acknowledged' step. No interaction with the bitmap images is required. However, the characteristics of the images are described here for the record.

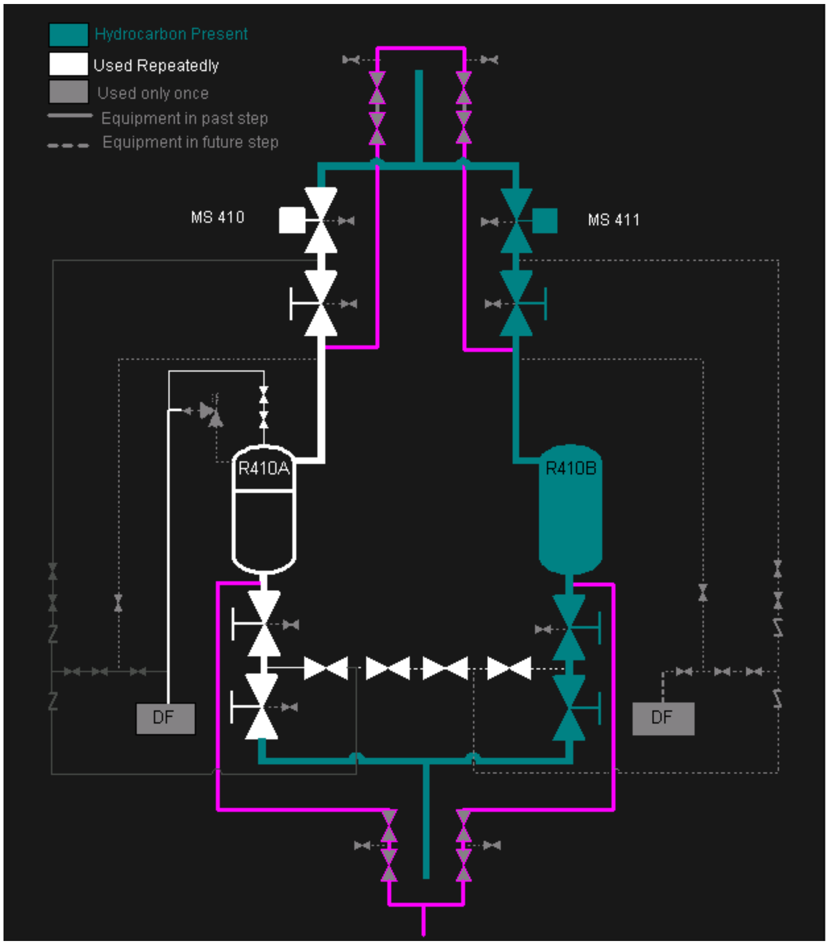

Figure 29: Procedure Display: Images Window.

For each step, the 'active' image highlights the pieces of equipment that are associated with that step. To do so, the relevant lines and outlines are colored magenta while the step is active (see Figure 29). The 'acknowledge' image highlights the same pieces of equipment in chartreuse for several seconds before the next active image is shown. Other codes employed in the jpegs will be described later.

A legend is also included in the upper left hand corner of the Images window. It helps the operator to map the color graphic codes in the images to their meaning.

The steps overview (shown in detail in Figure 30) provides the operators with a brief idea of how far they have gone with respect to the entire swing process. It is located at the bottom of the Images Window. A small rectangle represents each substep. The rectangles are color-coded to match the status of the procedure steps to which they refer.

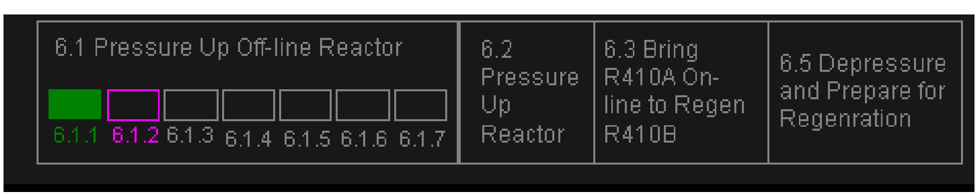

Figure 30: Procedure Display: Step Overview.

Access and Procedure Selection

The Procedure Display is launched from a "Procedure Display" button in the lower-left corner of the Reactor Temperature Profile Display. Once launched, the display appears in the lower monitor. The Steps and Images windows are initially empty. Above the Steps window, a combo box pull-down menu can be accessed to select from the available procedures. “Select Procedure” should be written on the combo box. Once a procedure is selected, the Steps and Images windows are populated with the appropriate text and jpeg. An alternative procedure can be selected from the pull-down menu before the first step of the procedure is checked off. Once any step of the populated procedure has been ‘acknowledged’, the pull-down menu is disabled.

The control is closed by left-clicking on a “Close” button in the MOV window.

Information content

The specific IRs communicated by the display can be found in Appendix B. The procedure content and step sequence are uniquely captured in the HTA IR’s. Specific equipment states are also specified by the HTA. Normally, we would expect the ADS to capture such requirements. However, this is an example of the system boundary problem discussed above. The content of the Images window is largely based on equipment location, information normally provided by the ADS. However, the image files specifically relate to the procedure step and the anticipated state of that equipment based on the sequence of procedures.

The requirements gathered in this display were grouped together for the specific purpose of supporting procedure execution. This task relies heavily on pre-determined sequences of activities focussed on specific process components. The display supports this task by not only relating those steps, but also drawing the connection to the components in an easily perceived way. Moreover, the broader challenge of executing a procedure is supported by providing an overview of the progress through the procedure steps.

More than any other display in the functional interface, the Procedure Display reveals its prototype status. As Consortium members are aware from previous work, the design of procedure support tools can be extremely laborious. The aim here was to meet the minimum information requirements with a usable and useful tool. Many obvious opportunities for improving upon the display were passed up on account of program limitations.

Summary

The three displays discussed in this section emphasize that there are several ways of connecting information requirements to displays. Displays content can consist of requirements from any single analysis or combination of analyses.

DISCUSSION

Time and Cost

One of the key concerns that the Consortium has raised about functional interface design approaches is the cost of the approach. A key aims of the Design Rationale study, therefore, was to form a case study estimate of these costs. This estimate is provided in this chapter.

Projection

Based on his previous interface design experience in the petrochemical domain, the lead interface designer projected that 6 person-months (~1000 hours) of labor were required to complete the design. This estimate was made assuming that the designers would quickly develop an adequate level of domain familiarization to start. Twelve calendar months were initially allotted for both the domain familiarization and design activities.

Time expenditures

In total, the final design product required approximately 150% of the projected level of effort. That effort was extended over a period of 18 months. The process of domain familiarization for the two designers was 6 months in duration, requiring approximately 500 hours. The design process itself took place over a period of 12 months, requiring approximately 1000 person hours of labor. Thus, while the design effort itself came in fairly close to the initial prediction in terms of hours, the difficulties with domain familiarization lead to overruns in terms of total hours and elapsed calendar time.

The efforts of the two designers were augmented by those of a prototype developer, who contributed approximately 500 hours over 4 months. The prototype was used as a basis for soliciting feedback from operators.

The implementation process was completed in 1200 hours, over a period of 9 months, by a highly experienced graphical interface developer. His efforts were supplemented by an undergraduate research associate who invested approximately 250 hours in the evaluation of implementation versions.

The above accounting should not be viewed as a series of strict sequential activities. Domain familiarization, while largely completed in the first six months of the project, continued informally throughout the design and implementation. Moreover the design itself evolved though the implementation experience. In sum, the design process was massively iterative.

Cost-critical program findings

Two factors challenged the entire process and impacted program cost; domain familiarity and human resource availability. First, the domain proved more difficult to master than anticipated. One of the two display designers was unfamiliar with the petrochemical domain, although he was an experienced interface designer and was familiar with the functional interface design process. The other had several years of display design experience in the domain and had designed a prototype functional display for an FCCU previously. The effort required to bring the novice display designer up to speed in the domain was under-appreciated. Moreover, the level of effort required to bring both designers to a sufficient level of familiarity with the target process was also underestimated. In sum, a substantial amount of time (in both absolute hours and calendar months) was spent teaching the designers about the process for which the functional displays were to be designed.

The impact of the domain-familiarity factor was two-fold. First, it inhibited the start of the design process. Second, it slowed down the design process itself as frequent interruptions to the design activity were required to confirm ideas or clear up uncertainties about the AHR process.

A second challenge to the project was the lack of qualified people available to work on it continuously. Following the completion of the analytical phase by Miller and Vicente (1998, 1999), the project was to be continued under the tactical direction of a postdoctoral candidate with the assistance of a second graduate student[9]. At no time was this level of manpower reached. Throughout the post-analysis integration, design, and implementation phases, a doctoral candidate handled the project management and technical development. For 6 months, a part-time Masters student assisted in the design iterations. Two undergraduate students worked on the prototype and integration testing during their summer break from classes. This was the full manpower contingent for the project.

The impact of the resource availability problem was simply that, even after the domain-familiarity problem was left behind, the project did not progress at the pace that it could have.

Taken together, these findings suggest an important consideration for an organization considering this design approach. The cost of the design effort will be minimized if a coherent team with complimentary skills can be assembled and maintained throughout the project. This should include, at minimum, one person with a strong engineering knowledge of the process, one person with a background in the operations of the unit, and one person familiar with the modeling techniques and functional interface design approach. To the extent that these people can have shared expertise in each other's areas of specialty, the development cost may be reduced.

Cost- and cycle-time- reduction recommendations

The records left by the ADS and HTA modeling frameworks were not very effective as independent learning tools. The display designers found it difficult to develop a command of the process by reviewing these records. It was necessary for the display designers to return to both the source material and to domain experts to reconstruct the knowledge that had been acquired by the analysts, and in effect, have to "re-do" portions of the analyses. This finding was unexpected because the ADS has been noted as being particularly useful in helping the analyst to develop a deep understanding of the process. It had been anticipated that designers familiar with the ADS would be able to extract that knowledge from the record and construct their own understanding of the process. However, neither analysis served as an effective training medium.

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[9] The project planned originally called for the displays to be implemented by a software consultant. This manpower requirement was met as planned.

It is worth noting that, in all previous applications of EID with which the authors are familiar, the designers have been the analysts. This was not the case with this design effort. The takeaway message from this experience for organizations considering functional interface design is clear. To the extent possible, the same team should be tasked with both the information requirements gathering and design stages. This approach would drastically reduce the time invested in learning the meaning of the content of the analysis results and reduce the design hours indicated above.

There is a further advantage to be gained in having domain experts act as the analysts and designers. Such individuals will clearly benefit from their prior expertise with the target process. Of course, this approach would require that the analysts be familiar with the ADS and TA techniques. There is, however, a potential disadvantage to this approach. Persons who are too familiar with current process operations may fail to exploit the strengths of the analyses. These analysis methods are extremely meticulous. Persons highly familiar with operations for the target domain would almost certainly be drawn into contrasting the process of the analyses with current practice. This could easily lead to focussing on the process as it is practiced, as opposed to a high level examination of the process in terms of how the unit was designed and what the functions and operations afford in terms of process behavior.

Finally, two observations about the supplementary assistance that contributed to the design effort. First, the interim prototype was an effective tool for facilitating the design reviews by the operators. However, a cheaper, lower-fidelity prototype would probably have been almost as effective. For example, paper prototypes can be very effective for facilitating design reviews and they are much faster and cheaper to produce. While it was useful to demonstrate the design concepts with actual process data, it probably wasn't required for the operators to give useful feedback. Second, the use of a summer undergraduate student as an implementation reviewer was a very inexpensive and effective resource. Her role was twofold; a) review the design spec for any description that was underspecified, and b) compare the control versions against the spec, looking for discrepancies. Having a person that was not involved with the design or implementation to crosscheck the design specification to the implemented display was very beneficial to the project. Because this person did not need to be a domain expert, the cost of this resource was very low and is highly recommended for future implementation efforts.

Integrating AEGIS Graphics into Functional Interfaces

The Consortium has invested substantial time and funds in the development of a graphics practices and guidelines that represent improvements over current industry practice. The question of how the AEGIS graphics can be integrated with functional interface graphics is therefore an important one. In fact, there appears to be a natural compatibility between the two approaches – they are not competing techniques.

From the perspective of the ADS and HTA analyses, the AEGIS graphics are very effective at communicating the lower-level functions and activities. These are the information requirements with which operators are already familiar, but receive from the AEGIS displays in a format that is more useful and usable than afforded by typical native displays. However, the AEGIS graphics as designed do not present the higher-level functional and task-oriented relationships captured by the analyses.

The functional displays were therefore conceived as a supplement to the AEGIS graphics, perhaps serving as Level 1 or Level 2 displays (in the AEGIS terminology). They are designed to support functional monitoring, problem solving, and upset management. Lower level monitoring and control actions are supported by the AEGIS graphics. This strategy does allow for some overlap in information content between the displays that reduces the need for superfluous display navigation when shifting between monitoring, problem solving, and control.

Summary

The development of functional interfaces for the AHR has proven to be both challenging and labor intensive. However, it has been shown that these advanced interface design methodologies can be applied to the process industries. Moreover, the experience gathered in performing this case study points to several opportunities for reducing the time and cost of the design process. Additional opportunities for the development of new technologies to assist the process are also readily apparent. It remains to be demonstrated that the performance advantages seen with these sorts of displays in laboratory setting will manifest in representative simulator studies.

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APPENDIX A: CONTROL TASK ANALYSES

The Decision Ladders for each of the controllers (with the exception of the example given in Figure 8) are shown in this section.

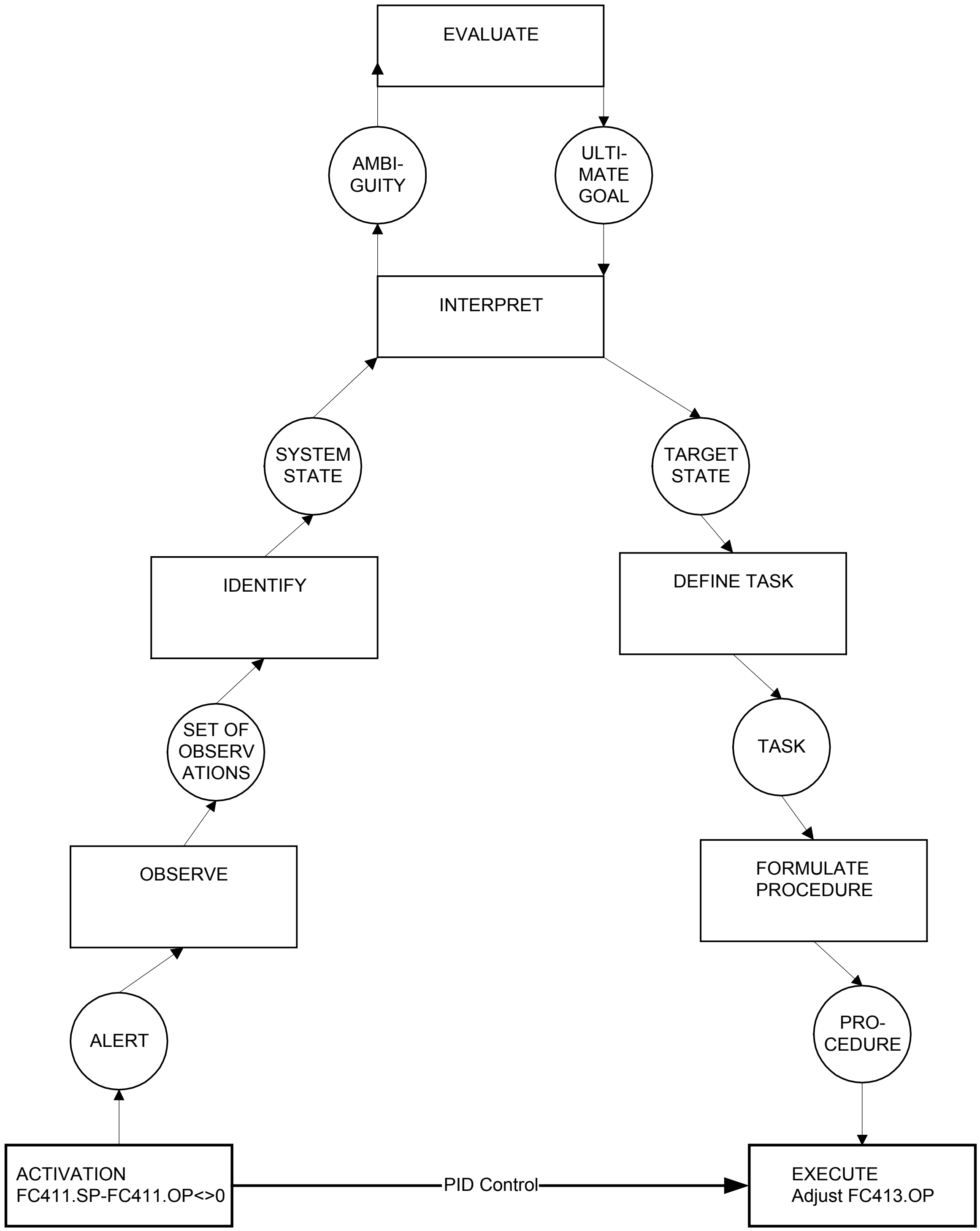

Figure 31: Decision Ladder for Reactor Inlet Temperature Control

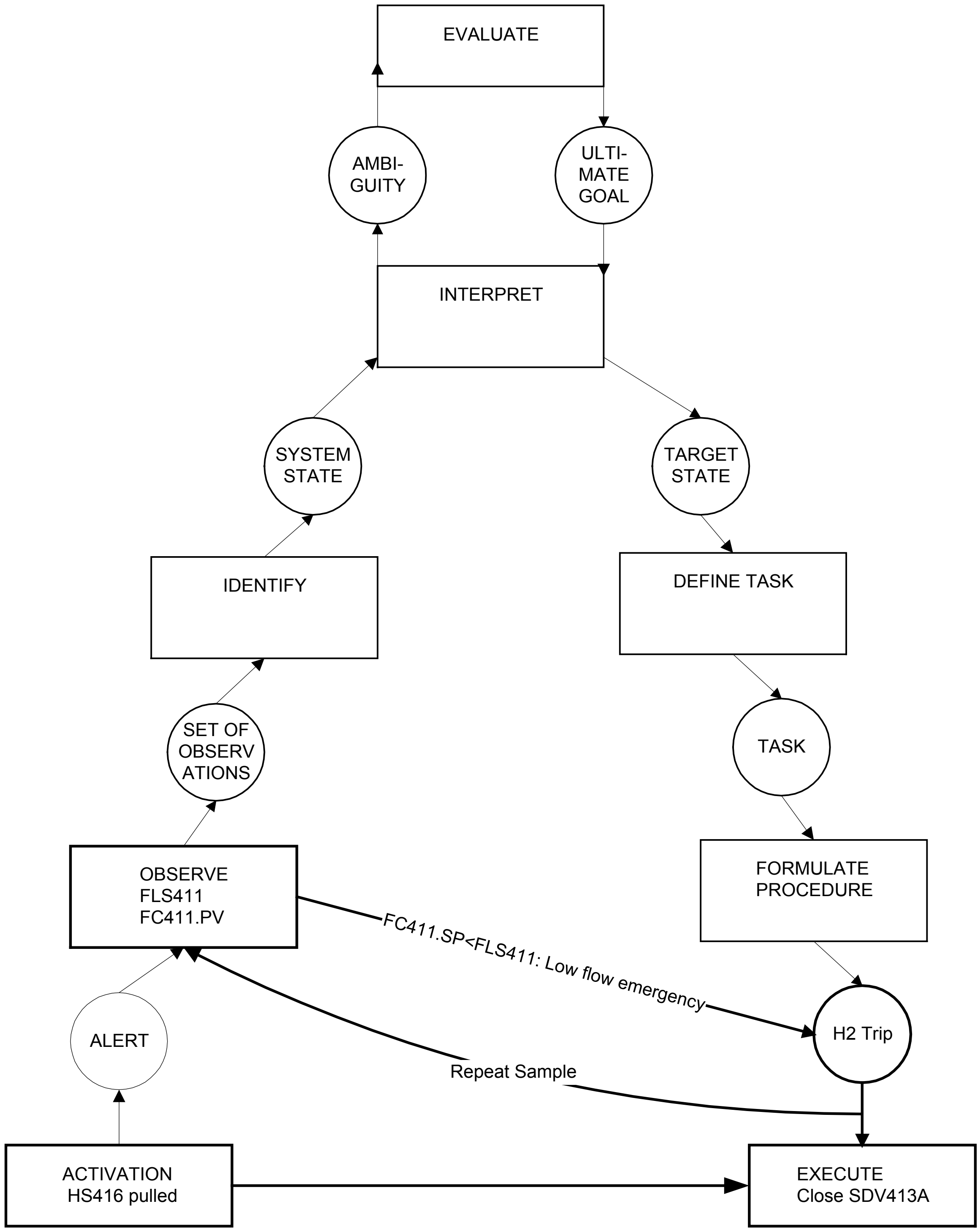

Figure 32: Decision Ladder for Hydrogen Flow Trip Control.

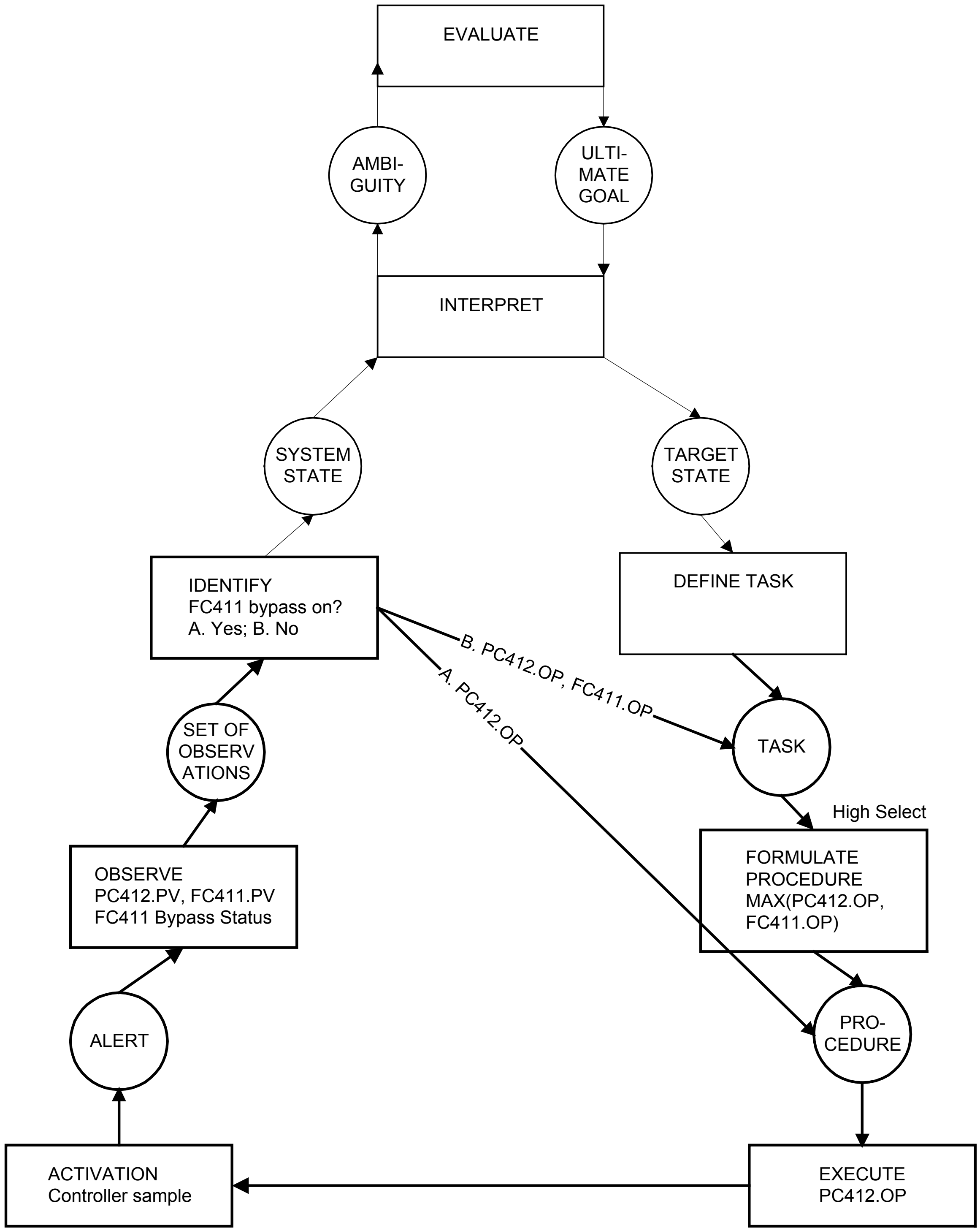

Figure 33: Decision Ladder for Process to Flare Control.

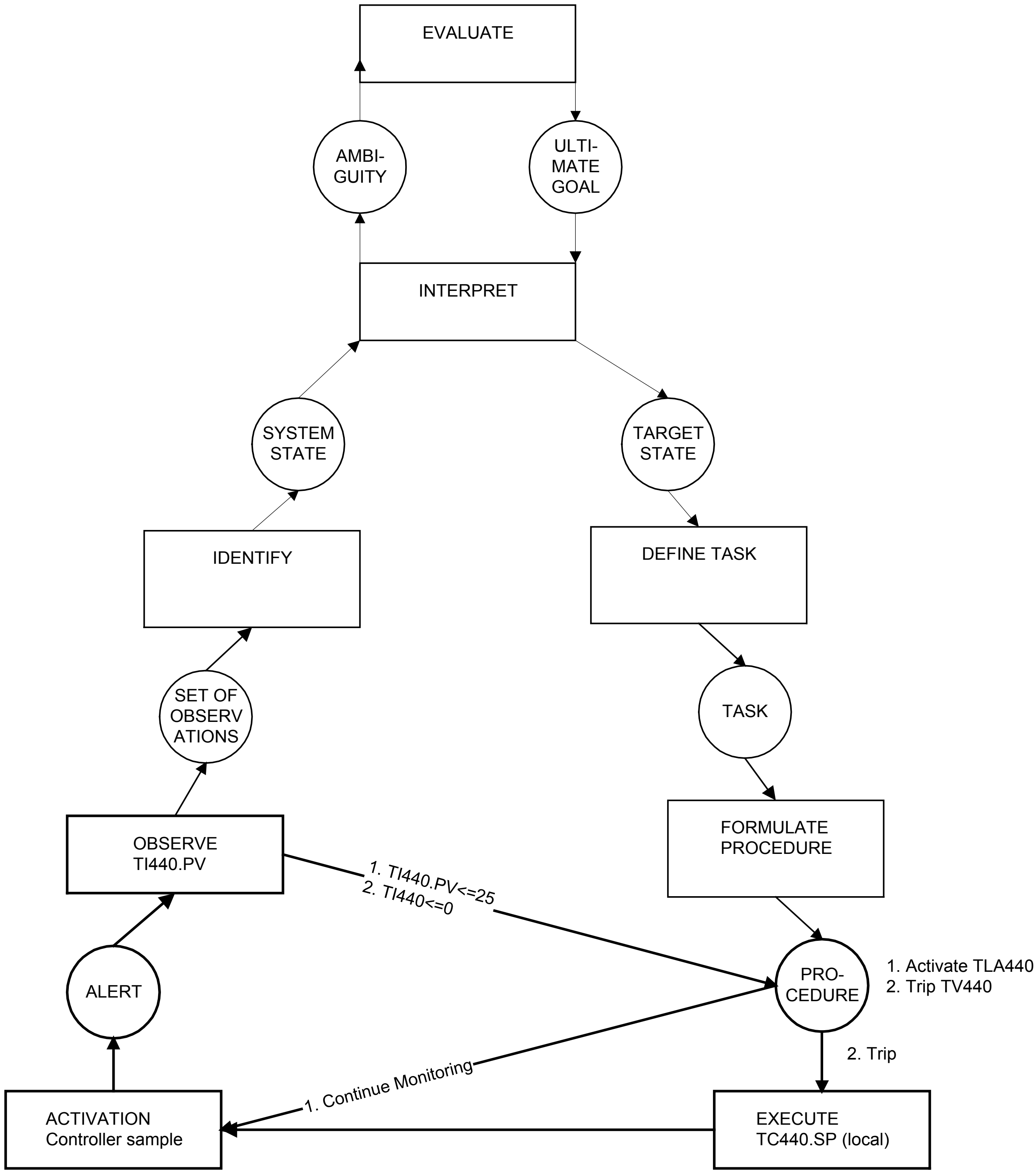

Figure 34: Decision Ladder for Hydrogen Feed Temperature Control.

APPENDIX B: INFORMATION REQUIREMENTS (IR) MATRIX

The information requirements matrix primarily conveys three types of information. First, the IR itself is cryptically described. Second the analysis (or analyses) that identified the IR is(are) indicated. For each IR (left most column), the column for ADS, HTA or CTA may be checked off. A check mark indicates that the analysis identified the requirement. Third, the display(s) that communicate the IR is (are) indicated. The ten components displays each head up a column. A check mark indicates that the IR is contained in that display.

The IR's follow the order of analyses. First, those identified by the ADS are listed. They are organized by cell of the ADS, starting in the lower right and moving up and then left (see Figure 5). Next, the CTA-based IR are organized by controller (see Appendix A). Finally, the remaining unique HTA-related requirements are organized by relatedness.

The purple columns indicate the specific displays discussed in this document. It is left to the reader to complete the mapping of the IR to the graphic, and this is relatively straightforward for the majority of the IRs. .

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
Provide identity, appearance, and location for Physical Form-Component functions													
E410	✔	✔		✔				✔	✔				
E411	✔	✔		✔				✔	✔				
E412	✔	✔		✔				✔	✔				
E413	✔	✔		✔				✔	✔				
R410 A	✔	✔	✔	✔			✔	✔	✔			✔	✔
R410 B	✔	✔	✔	✔			✔	✔	✔			✔	✔
FV135	✔	✔	✔	✔						✔			
PV441	✔	✔		✔						✔			
TV440	✔	✔	✔	✔						✔			
FV413	✔	✔	✔	✔						✔			
TV410	✔	✔	✔	✔						✔			
SDV413 A	✔	✔	✔	✔						✔			
PV410 A	✔	✔		✔								✔	
PV410 B	✔	✔		✔								✔	
PV412	✔	✔	✔	✔						✔		✔	
HV41001	✔	✔	✔	✔					✔				
MV410	✔	✔	✔	✔			✔		✔			✔	✔
MV411	✔	✔	✔	✔			✔		✔			✔	✔
VS1 (rf35503)	✔	✔		✔									
VH3 (e2h2vlv)	✔	✔		✔									
VM1 (rf35504)	✔	✔		✔									
VM4	✔	✔		✔								✔	
VM5	✔	✔		✔								✔	
VM6 (rf35501)	✔	✔		✔								✔	
VM8 (rf35502)	✔	✔		✔								✔	

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
VM10 (rf35402)	✔	✔		✔									
VM13 (rf35404)	✔			✔									
VM14 (rf35403)	✔			✔									
VW2 (rf35401)	✔	✔		✔									
Identify state, and range of possible states, for Physical Function-Component functions													
E410 shell side INLET temperature	✔			✔	✔	✔			✔		✔		
E410 shell side OUTLET temperature	✔			✔	✔	✔			✔		✔		
E410 tube side INLET temperature	✔			✔	✔	✔			✔		✔		
E410 tube side OUTLET temperature	✔			✔	✔	✔			✔		✔		
E411 shell side INLET temperature	✔	✔		✔	✔	✔			✔		✔		
E411 shell side OUTLET temperature	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔		
E411 tube side INLET temperature	✔	✔			✔	✔					✔		
E411 tube side OUTLET temperature	✔	✔			✔	✔					✔		
E412 shell side INLET temperatures	✔				✔	✔					✔		
E412 shell side OUTLET temperature	✔				✔	✔					✔		
E412 tube side INLET temperature	✔			✔	✔	✔	✔		✔		✔		
E412 tube side OUTLET temperature	✔			✔	✔	✔			✔		✔		
E413s shell side INLET temperature	✔				✔	✔					✔		
E413 shell side OUTLET temperature	✔				✔	✔					✔		
E413 tube side INLET temperature	✔				✔	✔					✔		
E413 tube side OUTLET temperature	✔	✔		✔	✔	✔					✔		
R410 A temperature profile	✔	✔	✔	✔	✔	✔	✔		✔				
R410 A days in service	✔	✔		✔		✔							
R410 B temperature profile	✔	✔	✔	✔	✔	✔	✔		✔				
R410 B days in service	✔	✔		✔	✔	✔							
FV135 setting	✔	✔	✔	✔	✔	✔				✔			
PV441 state	✔	✔	✔							✔			

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
TV440 setting	✔	✔	✔							✔			
FV413 setting	✔	✔	✔	✔	✔	✔				✔			
TV410 setting	✔	✔	✔	✔	✔	✔				✔	✔		
SDV413A state	✔	✔	✔	✔	✔	✔				✔			
PV410 A state	✔	✔											
PV410 B state	✔	✔											
PV412 setting	✔	✔	✔	✔	✔	✔				✔			
HV41001 setting	✔	✔	✔	✔	✔	✔							
MV410 setting	✔	✔	✔	✔	✔	✔	✔						✔
MV411 setting	✔	✔	✔	✔	✔	✔	✔						✔
VS1 setting	✔	✔											
VH3 setting	✔	✔											
VM1 setting	✔	✔											
VM4 setting	✔	✔											
VM5 setting	✔	✔											
VM6 setting	✔	✔											
VM8 setting	✔	✔											
VM10 setting	✔												
VM13 setting	✔												
VM14 setting	✔												
VW2 setting	✔												
Identify topological connections between Physical Function-Component functions													
DMDS is added to the raw feed stream (at FV135) before upstream of the furnaces	✔									✔			
The C2 feed stream and the H2/CO stream are split after the pyrolysis furnaces, but before reaching the remaining AHR components. The streams enter the AHR separately	✔	✔		✔						✔			

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
separately													
Two different sources of H2/CO stream are available to the AHR—the stream from the pyrolysis furnaces and the E2 stream	✔	✔		✔									
The E1 H2/CO stream enters E413 directly, with no limiting valve available	✔			✔									
The E2 H2/CO stream can be routed into the H2/CO stream for the AHR after (that is, bypassing) E413 by appropriate settings on VH3.	✔			✔									
The H2/CO stream can be diverted to flare immediately after E413 by means of PV441.	✔	✔		✔									
FV413 is located before the SDV valves and before the point where H2/CO and C2 feed mix.	✔			✔									
SDV A is positioned to interrupt the flow of H2/CO to the C2 stream.	✔			✔									
The C2 feed stream enters the tube side of E410 directly, with no limiting valve available.	✔			✔									
From E410, the C2 stream is connected to shell side of E411, with no limiting valve available.	✔			✔									
After E411, the C2 stream intersects the H2/CO.	✔			✔									
Utility steam supplies both E411 and E413, but the pathway splits before entering either heat exchanger.	✔			✔									
VS1 is positioned before E413 and can affect the flow of steam to it.	✔			✔									
TV410 is located before E411and can affect the flow of steam into it.	✔			✔									
Steam and condensate flow out of E411.	✔			✔									

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
Mixed H2/CO and C2 feed can be connected to flows downstream (thereby bypassing) the reactors by means of appropriate settings on VM1 and MV410 or MV411.	✔	✔		✔								✔	
The two reactors (R410 A and B) are located side by side, but there is no direct connection between them.	✔			✔			✔					✔	
MV410 and VM4 are located on a pipeline entering R410A, while VM6 is located on a pipeline leaving that reactor. R410 B has a similar configuration using MV411, VM5 before and VM8 and after.	✔	✔		✔								✔	
Pressure relief valves PV410A (R410A) and PV410B (R410B) provide a path to flare	✔	✔		✔								✔	
Reactor outflow lines connect after VM6 and VM8.	✔			✔								✔	
A connection exists from after the connection of the effluent flows to PV-412, which regulates flare flow	✔			✔								✔	
Connections exist after the reactor to the tube side of E412 (VM10 lies on this connection), or to the pipelines after E412 (VM13 lies on this connection), or to the flare (PV412 lies on this connection).	✔			✔									
The tube side of E412 is connected to a pipeline leading to the shell side of E410.	✔			✔									
Cooling water enters the shell side of E412 via a pipeline and leaves via a pipeline which contains VW2.	✔	✔		✔									
The connection from E412 to E410 intersects a connection bringing reacted feed to or from E2. VM14 lies on this connection.	✔	✔		✔									

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
The connection from E412 enters and exits the shell side of E410 where it leaves the AHR. HV41001 lies on the exiting connection.	✔			✔									
Identify values, and range of possible values for the Generalized Function-Component functions													
The flow of DMDS into the pyrolysis furnaces	✔	✔	✔		✔	✔				✔			
The flow of H2/CO entering the AHR [H2 Flow 1]	✔	✔		✔	✔	✔		✔		✔			
The flow of steam into E413 [Steam flow 1]	✔	✔			✔	✔					✔		
The flow of heat into the H2/CO stream in E413	✔							✔			✔		
The flow H2/CO to flare [Flare flow 1 at PSV441]	✔	✔											
The flow of heat and H2/CO to or from E2 [E2 H2 flow]	✔	✔											
The flow of heat and H2/CO to the Turbo Expanders	✔												
The flow of heat and H2/CO through SDV413a valve	✔	✔	✔							✔			
The flow of cracked gas entering the AHR at E410	✔	✔		✔	✔	✔		✔		✔			
The flow of heat from the reacted feed stream into the C2 feed stream at E410 [Heat xfer 1]	✔	✔						✔			✔		
The flow of steam into E411 [Steam flow 2]	✔	✔	✔								✔		
The flow of heat into the C2 feed stream at E411 [Heat Xfer 2]	✔	✔						✔			✔		
The flow of heat and mixed feed through the reactor bypass [feed bypass]	✔	✔											
The flow of CO into the reactor [Heat and CO flow 3]	✔	✔			✔	✔				✔			
The flow of H2 into the reactor [Heat and H2 flow 3]	✔	✔			✔	✔				✔			

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
The flow of C2H2 into the reactor [Heat and C2H2 flow 2]	✔	✔			✔	✔				✔			
The flow of C2H4 into the reactor [Heat and C2H4 flow 2]	✔	✔			✔	✔							
The flow of C2H6 into the reactor [Heat and C2H6 flow 2]	✔	✔			✔	✔							
Flow of heat into the reactor	✔				✔	✔		✔					
Pressure in the reactor	✔	✔	✔	✔									
The rate of C2H2 conversion	✔				✔	✔				✔			
The rate of C2H4 conversion	✔									✔			
The rate (or presence) of C2H4 decomposition	✔									✔			
The flow of CO out of the reactor	✔	✔											
The flow of H2 out of the reactor.	✔	✔			✔	✔				✔			
The flow of C2H2 out of the reactor	✔	✔			✔	✔				✔			
The flow of C2H4 out of the reactor	✔	✔								✔			
The flow of C2H6 out of the reactor	✔	✔			✔	✔				✔			
Flow of heat out of the reactor	✔							✔					
The flow of reacted feed around E412 and toward E410	✔												
The flow of reacted feed to flare (via PV-412) [Flare Flow 3]	✔	✔	✔		✔	✔				✔			
The flow of reacted feed into E412	✔			✔	✔	✔					✔		
The flow of reacted feed out of E412 toward E410	✔			✔	✔	✔					✔		
The flow of cooling water into and out of E412	✔	✔			✔	✔					✔		
The flow of heat from the reacted feed in E412	✔	✔			✔	✔					✔		
The flow of reacted, cooled feed to or from E2	✔												

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
The flow of reacted, re-cooled feed (after E410) to the rest of the plant [Reacted cooled feed outflow 2]	✔	✔	✔		✔	✔				✔	✔		
Identify connections between Physical and Generalized Function-Component functions													
The effect of valve setting on flow through the valve for all valves.	✔	✔	✔	✔	✔	✔				✔			
The effect of the state of PV441 on flow of H2/CO through TV440.	✔			✔						✔			
The effect of the setting of TV440 on flow of H2/CO through CV6 and downstream, and on flow through VH3.	✔	✔	✔	✔						✔			
There is no physical function connection to H2/CO flow to E319	✔			✔									
The effect of the setting of SDV413a on the flow of H2 to the C2 stream.	✔		✔	✔						✔			
The fact that the flow (and temperature) of the steam into E411 alone affects the flow of heat into the C2 feed stream in that heat exchanger.	✔			✔					✔		✔		
The effect of the setting of VM1 on flow of mixed feed through MV410 and MV411.	✔	✔		✔									
The effect of the state of pressure relief to flare valves (PV410A and PV410B), secondary reactor input valves (VM4 and VM5) and reactor outlet valves (VM6, VM8) have on flow through the primary reactor input valves: MV410 and MV411.	✔			✔									
The effect of the setting of the reactor flare valves (PV410A and PV410B) on flow through VM4 and VM5 into the reactors.	✔			✔									
The effect of the settings of the reactor outlet valves (VM6 and VM8) have on flow through the reactors.	✔	✔		✔									

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
The effect of the setting of PV412 on flow of reacted feed through VM10 and VM13.	✔			✔									
The effect of the setting of VM13 on flow of reacted feed through VM10.	✔			✔									
The effect of the setting of VM10 on flow through VM13 and through E412.	✔			✔									
The effect of the setting of VW2 on flow of cooling water through E412.	✔	✔		✔									
The effect of the setting of VM14 on flow of cooled, reacted feed through VM13 and into E410.	✔			✔									
The effect of the setting of HV41001 on flow of reacted, cooled feed through E410 and, therefore, on the heat transfer from the reacted feed to the unreacted C2 feed stream.	✔			✔									
Identify topological connections between Generalized Function-Component functions													
The effect of the rate of DMDS flow on CO concentration	✔	✔								✔			
Diverting H2/CO flow to or from E2 means affecting the heat input to either Heat Transfer 3 or downstream to feed mixing.	✔	✔											
Diverting H2/CO flow to flare means affecting the heat and H2 and CO flows downstream.	✔												
Diverting H2/CO flow to the Turbo Expanders means affecting the heat and H2 and CO flows downstream.	✔												
H2/CO Flow lockout means affecting the heat and H2 and CO flows downstream.	✔									✔			
The rate of heat transferred in Heat Transfer 1 can affect the rate transferred in Heat Transfer 2 (and vice versa).	✔												

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
The effect of routing mixed feed to the Reactor Bypass on the heat, component materials and pressure in the reactors (it will reduce or eliminate them).	✔												
The effect of routing mixed feed to the flare on the heat, component materials and pressure in the reactors (it will reduce or eliminate them).	✔	✔											
The effect of acetylene conversion on acetylene flow out of the reactor. Same for CO and CO conversion.	✔									✔			
The effect of C2H4 decomposition on the CH4 flow (it is one of two ways to produce it), C2 production (it is the only way to produce it) and heat flow out of the reactor (it is extremely exothermic).	✔												
The effect of the availability of H2 on C2H2 conversion and C2H4 conversion—it is required for both and limits them if not available.	✔									✔			
CO presence affects the availability of H2, and therefore affects the incidence or rate of C2H2 and C2H4 conversion.	✔									✔			
Ethane does not participate in any reaction, thus any increase in ethane across the reactor must be the result of ethylene conversion, and any loss of ethane across the reactor is indicative of a leak or unexpected reaction.	✔									✔			
The effect of all reactions on heat flow out of the reactor: all are exothermic and happen more rapidly (or at lower pressures) with increased heat. This is especially true of ethylene decomposition. Thus, there is the potential for self perpetuating reactions if heat is not removed from the reactor.	✔									✔			

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
The effect of flare flow after the reactor (at Flare flow 3) on reactor pressure, heat and reactant availability. It also reduces the availability of heat and reacted feed downstream.	✔												
The effect of bypassing E412 on the heat flow to E2 or to Heat Transfer 1.	✔												
The effect of heat and feed flow to Heat Transfer 1 on the rate of heat transfer to the incoming C2 Feed.	✔	✔											
Identify Physical Function-Component:Subsystem part-whole relationships													
H2/CO Heat and Supply Input Unit: FV135, VH3, E413, VS, TV440, CV6, FV413, SDV413 A, PV441	✔												
C2 Heat and Supply Input Unit: VM1, MV410, MV411, VM4, VM5, E410, E411, TV410	✔												
Reaction Unit: R410A, R410B, PV410A, PV410B, VM6, VM8	✔												
Effluent Cooling Unit: E412, E410, VM10, VW2, VM14, VM13, HV41001, PV412	✔												
Identify Generalized Function-Component: Subsystem part-whole relationships													
H2/CO Heat and Supply: DMDS Flow, Raw Feed Flow, CO Flow 1, E2 H2 Flow, E2 CO Flow, Steam Flow 1, Heat Transfer 3, Heat and H2 Flow 1, Heat and CO Flow 1, TE Flow, Heat and H2 Flow 2, Heat and CO Flow 2, Flow Lockout, Flare Flow 1	✔												
C2 Heat and Supply: C2H2 Flow 1, C2H4 Flow 1, C2H6 Flow 1, Heat Transfer 1, Steam Flow 2, Heat Transfer 2, Feed Bypass, Heat and C2H2 Flow 2, Heat and C2H4 Flow 2, Heat and C2H6 Flow 2, Heat and H2 Flow 3, Heat and CO Flow 3, Flare Flow 2	✔												

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
Reaction: Reactor Pressure, C2H2 Conversion, C2H4 Conversion, C2H4 Decomposition, Heat and C2H2 Flow 3, Heat and C2H4 Flow 3, Heat and C2H6 Flow 3, Heat and CH4 Flow 1, Heat and H2 Flow 4, Heat and CO Flow 4, Heat and C2 Flow 1, Heat and C2H2 Flow 4, Heat and C2H4 Flow 4, Heat and C2H6 Flow 4, Heat and CH4 Flow 2, Heat and H2 Flow 5, Heat and CO Flow 5, Heat and C2 Flow 2,	✔												
Effluent Cooling: Cooling Water Flow, Heat Transfer 5, After Cooler Bypass, Reacted Feed Outflow, Reacted E2 Feed Flow, Heat Transfer 1, Flare Flow 3	✔												
Identify Generalized Function-Subsystem functions													
H2/CO Heat and Supply Input	✔							✔		✔			
C2 Heat and Supply Input	✔							✔		✔			
Reaction	✔						✔			✔			
Product Cooling	✔							✔					
Identify topological connections between Generalized Function-Subsystem functions													
H2/CO and C2 Supply Input effect Reaction	✔									✔			
Reaction effects Effluent Cooling	✔												
Effluent Cooling effects C2 Heat and Supply Input	✔										✔		
Identify values, and range of possible values, for the Abstract Function-Component functions													
Mass Source I (DMDS)	✔							✔		✔			
Mass Transport II (H2/CO stream)	✔							✔		✔			
Mass Barrier 413	✔										✔		
Mass Source II (Steam)	✔										✔		
Mass Sink I	✔												

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
Mass Source III (E2 H2/CO)	✔												
Mass Sink II (E2)	✔												
Mass Transport III (VH3)	✔												
Mass Transport V (TV440)	✔												
Mass Barrier II (PV441)	✔												
Mass Barrier III (CV6)	✔												
Mass Sink III (E319)	✔												
Mass Transport VII (FV413)	✔							✔		✔			
Mass Transport VIII (MOV)	✔							✔					
Mass Sink IV (Flare)	✔												
Mass Balance III (reaction)	✔	✔								✔			
Mass Barrier V (PV410A, PV410B)	✔												
Mass Transport IX (VM6, VM8)	✔												
Mass Barrier 412	✔												
Mass Source IV (CW)	✔										✔		
Mass Sink IV	✔												
Mass Transport X (VM13)	✔												
Mass Barrier VIII (PV412)	✔												
Mass Barrier 410/411	✔												
Mass Transport XI (C2 stream)	✔									✔			
Mass Source V (Steam)	✔												
Mass Transport XII (HV41001)	✔												
Mass Sink V	✔												
Mass Sink VI (Product out)	✔												
Mass Source VI (E2 Product)	✔												
Mass Sink VII (E2 Product)	✔												
Mass Transport XIII (VM1)	✔												

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
Energy Source I (DMDS)	✔												
Energy Transport II (H2/CO stream)	✔							✔					
Energy Balance 413	✔							✔			✔		
Energy Source II (Steam)	✔										✔		
Energy Sink I	✔												
Energy Source III (E2 H2/CO)	✔												
Energy Sink II (E2)	✔												
Energy Transport III (VH3)	✔												
Energy Transport V (TV440)	✔												
Energy Barrier II (PV441)	✔												
Energy Barrier III (CV6)	✔												
Energy Sink III (E319)	✔												
Energy Transport VII (FV413)	✔							✔					
Energy Transport VIII (MOV)	✔							✔					
Energy Sink IV (Flare)	✔												
Energy Balance III (reaction)	✔	✔		✔				✔					
Energy Barrier V (PV410A, PV410 B)	✔												
Energy Transport IX (VM6, VM8)	✔												
Energy Balance 412	✔							✔			✔		
Energy Source IV (CW)	✔							✔					
Energy Sink IV	✔												
Energy Transport X (VM13)	✔												
Energy Barrier VIII (PV412)	✔												
Energy Balance 410/411	✔							✔			✔		
Energy Transport XI (C2 stream)	✔												
Energy Source V (steam)	✔												
Energy Transport XII (HV41001)	✔												

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
Energy Sink V	✔												
Energy Sink VI	✔												
Energy Source VI	✔												
Energy Sink VII	✔												
Identify Abstract Function-Subsystem functions													
Mass & Energy Source 1	✔							✔					
Mass & Energy Source 2	✔							✔					
Mass & Energy Balance	✔							✔					
Mass & Energy Sink	✔							✔					
Identify connections between General and Abstract Function-Subsystem functions													
Mass & Energy Source 1: H2/CO Heat & Supply	✔												
Mass & Energy Source 2: C2 Heat & Supply	✔												
Mass & Energy Balance: Reaction	✔												
Mass & Energy Sink: Cooling	✔												
Identify topological connections between Abstract Function-Subsystem functions													
Mass & Energy Sources 1 & 2 both affect Mass & Energy Balance 1	✔							✔					
Mass & Energy Balance 1 affects Mass & Energy Sink 1	✔							✔					
Mass & Energy Sink 1 affects Mass and Energy Source 2	✔							✔					
Identify value, and range of possible values, for Functional Purpose function													
Target and current value of C2H2 content upon leaving the AHR system	✔	✔								✔			
Identify Connections between Abstract Function and Functional Purpose functions													

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
That changes in mass into and out of the reaction balance can affect the functional purpose.	✔									✔			
The fact that use of a mass sink (specifically, the flare can prevent bad product from flowing out of the AHR).	✔			✔						✔			
Control task requirements not included in ADS													
FC135.SP		✔	✔		✔	✔				✔			
FC135.OP		✔	✔		✔	✔				✔			
Error (FC135.SP - FC135.PV)			✔			✔				✔			
FC-135 control mode (manual/auto/cascade/backup)		✔	✔			✔							
TC-410 SP		✔	✔		✔	✔				✔			
TC-410 OP		✔	✔		✔	✔				✔			
Error (TC-410 SP - TI-410 PV)			✔			✔				✔			
TC-410 control mode (manual/auto/cascade/backup)		✔	✔			✔							
TIC440.SP		✔	✔						✔				
TIC440.OP			✔							✔			
Status of TI-440 PV versus 0 C and 25 C			✔						✔				
TC-440 control mode (manual/auto/cascade/backup)			✔			✔							
H2/C2 weight ratio SP		✔	✔		✔	✔				✔			
H2/C2 weight ratio PV		✔	✔		✔	✔				✔			
H2/C2 weight ratio error (SP-PV)			✔			✔				✔			
H2/C2 weight ratio OP (to FC413 SP)			✔		✔	✔				✔			
WRC411 control mode		✔	✔			✔							

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
(manual/auto/cascade/backup)													
FC413.SP			✔		✔	✔				✔			
FC413.OP			✔		✔	✔				✔			
Error (FC413.SP-FC413.OP)			✔			✔				✔			
FC-413 control mode (manual/auto/cascade/backup)		✔	✔			✔							
HS-416 A status		✔	✔										
FLS-411 SP			✔			✔							
EV-413A SP			✔			✔							
ZSC-413 A status			✔							✔			
C2 low flow manual bypass status		✔	✔			✔							
C2 low flow SP (FC-411)			✔			✔							
PC-412 OP			✔		✔	✔				✔			
PC-412 SP		✔	✔		✔	✔				✔			
PC-412 PV		✔	✔		✔	✔				✔			
FC-411 OP			✔		✔	✔				✔			
FC-411 SP			✔		✔	✔				✔			
MAX (PC-412.OP, FC-412.OP)			✔		✔	✔				✔			
PC-412 control mode (manual/auto/cascade/backup)		✔	✔			✔							
HV-41001 OP		✔	✔	✔	✔	✔							
HV-41001 control mode (manual/auto/cascade/backup)		✔	✔			✔							

IR	ADS	HTA	CTA	Schematic	Trend	Detail	RxProfile	M&E	Paulsen	H2Balance	HX	Procedure	MOV
MS410.OP		✔	✔			✔	✔					✔	✔
MS411.OP		✔	✔			✔	✔					✔	✔
MV-410 control mode (manual/auto/cascade/backup)			✔			✔							
MV-411 control mode (manual/auto/cascade/backup)			✔			✔							
Unique HTA items													
Procedure steps		✔										✔	
Sequence constraints on procedure steps		✔										✔	
Overview of procedure steps with notation of current step		✔										✔	
Panel/Outside Operator roles and responsibilities		✔										✔	
Acetylene outlet analyzer update schedule		✔								✔			
Hydrogen outlet analyzer update schedule		✔								✔			
Carbon dioxide analyzer update schedule		✔								✔			
Position of MOV valve during swing		✔			✔								✔
Timer on MOV movements		✔											✔
Status of E2 H2 production		✔											
Status of double-block & bleed and vent on reactors		✔										✔	
Location, control, and status of 1" pressure-up lines on reactors		✔										✔	
Column Totals:	260	132	73	99	65	84	14	35	22	81	36	25	10

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