ASM® Consortium White Paper

Operator Interface Requirements:

Going Beyond the Obvious to Achieve Excellence

Last Revision Date: 17 January 2009
Version: 1.00
Filename: ASM Interaction Requirements White Paper_v100.doc

Written by: Peter Bullemer and Dal Vernon Reising
Human Centered Solutions, LLP
and
Melvin Jones
Sasol Synfuels, Ltd.

Paper being submitted for publication.

1 Abstract

There are several process industry-related guidelines and standards on how to best display information and support actions for the console operator. The Abnormal Situation Management (ASM®) Consortium also has an extensive guideline document on how to design effective displays for the console operator. While these guidelines and standards are effective at indicating good presentation practices, very little guidance is given regarding the selection of appropriate display content or display function. While not their primary function, plant P&ID's and associated control narratives have traditionally been assumed to form an appropriate basis for selecting display content and functionality. This is despite the inadequate coverage of operator needs in areas such as control building layout, control room layout and the console workspace itself which includes interface elements such as communication devices, switches and indicators, and applications on business PCs.

A theme of this paper is to go beyond the obvious sources to understand all of the console operators interface needs necessary to effectively support their work activities. Going beyond the obvious applies to both what is considered the operator interface and the sources used to determine requirements.

To identify all information and tools that support the activities of today's console operator, a designer should consider at least four sources of interface design requirements:

- collaboration and communication requirements within the operations team; and between the operations team and other supporting departments
- critical information and control actions to support crucial procedural operations
- critical information and control actions to support monitoring and control strategies common to the team of console operators
- equipment limits, operating envelopes, and functional relations between critical process variables to support more effective situation awareness

This paper introduces four methods from the field of human factors engineering, each of which is best suited for identifying interface design requirements for one of the four sources above. These methods were identified because of their effectiveness in coverage of the interface design requirements as well as their tractable nature when using the methods.

Because development teams often have limited time and resources, this paper provides guidance on which methods might be most useful for various kinds of design projects. In the case of operator graphic displays for example, guidance is provided on specific methods to use when designing overview displays versus equipment details versus task-based displays.

1 Introduction[1]

The design of an operator interface that enables efficient and effective job performance requires the ability to anticipate the operators' needs in interacting with computers and other individuals in the workplace. There are several industry-related guidelines and standards on how to best *display* information to the console operator. However, these guidelines and standards are developed to assist designers of operator interfaces after the interaction requirements have been defined and are typically limited to the scope of the operating graphic displays. In fact, there is very little guidance available on methods and techniques for determining *what* the content of the operator interface should be.

This paper presents an approach to operator interface design developed within the Abnormal Situation Management® Consortium to help the designer go beyond the obvious in defining requirements for the console operator interface. An overview of different systematic approaches for defining interaction requirements illustrates a more comprehensive view of the operator's needs, prior to initiating the design activity.

1.1 About the ASM® Consortium

The Abnormal Situation Management® (ASM®) Consortium (www.asmconsortium.com) is a long-running and active research and development consortium of 16 companies and universities concerned about the negative effects of industrial plant incidents. The consortium identifies problems facing plant operations during abnormal conditions, and develops solutions. Deliverables from the collaboration among member companies include products and services, guideline and other documents, and information-sharing workshops; all incorporating ASM knowledge.

An Abnormal Situation is a disturbance or series of disturbances in a process that cause plant operations to deviate from their normal operating state. The nature of the abnormal situation may be of minimal or catastrophic consequence. It is the job of the operations team to identify the cause of the situation and execute compensatory or corrective actions in a timely and efficient manner. A disturbance may cause a reduction in production; in more serious cases, the disturbance may endanger human life. Abnormal situations can extend, develop, and change over time in the dynamic process control environments increasing the complexity of the intervention requirements.

Abnormal situations are managed by **Prevention, Early Detection,** and **Mitigation**, in order to reduce unplanned outages and process variability that reduce profits and increase the safety and environmental risk to plant employees and local communities.

This paper first discusses what interaction requirements are and why these requirements are important for designing technology for the operations environment. Second, the paper presents the sources of interaction requirements that must be considered when designing solutions for the operations environment. The next four sections each present a unique technique for identifying interaction requirements, depending on the source of interaction requirements under consideration. Finally, the paper concludes with practical advice on when each technique would

[1] This paper is based on an earlier ASM Consortium proprietary publication: Bullemer, P., Reising, D. V., Errington, J., and Hajdukiewicz, J. (2004). *Interaction requirements methods for effective operator interfaces*. ASM Consortium Technical Book.

be appropriate, given the type of design project that might be undertaken, such as a control room renovation or a control system upgrade.

2 What are Interaction Requirements?

"Interaction requirements" is a phrase used to characterize three different kinds of functional needs that should be supported in the user interface for the console operator (Figure 1):

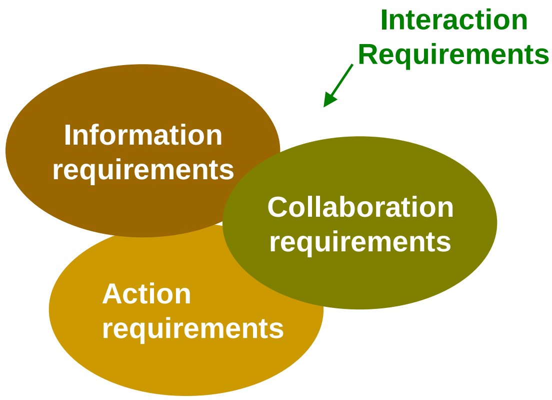

Figure 1 Interaction requirements representation in a Venn diagram illustrating the combination of three types of requirements.

- **Information requirements**—refer to the information that is needed to maintain situation awareness and make decisions appropriate to the task demands.
- **Action requirements**—refer to the software applications, procedures, or DCS "control handles" needed by an operator to act on a decision or perform specific tasks.
- **Collaboration requirements**—refer to communication and coordination needed by the operations team to complete the collaborative work processes.

Developing interaction requirements as a first step in the operator interface design process involves linking and aligning two main aspects of the work environment:

a) The *process environment*, i.e., the constraints associated with the complex production processes, the equipment, and the activities that need to be performed for both, and

b) The *operations environment*, i.e., the capabilities of the operations team and the automation, and the collaborations between both as part of an overall production system.

To support operator activities, information is required about the values and trajectories of the process state, its meaning with respect to business, operating and safety conditions, actions that can be taken and their consequences, and the activities of other team members and automation that can impact the process. This information partially defines the appropriate *content* in the interface. To be effective, the *form* of the information (i.e., how, when, and where it is displayed) needs to be compatible with the capabilities of the individual operator or the team. Matching these pieces—matching individual and team capability with the demands of the work processes—should result in enhanced operator performance under all operational modes.

An effective operator interface supports all of the operator's work processes and decisions. Consequently, a fundamental step in supporting the operator's work processes -- for normal, abnormal and emergency plant situations -- is determining the necessary and sufficient interaction requirements that support the operator's situation awareness, job objectives, and activity demands. Designing the operator interface that supports the operator's complete scope of work needs to address the interaction requirements for:

- Communication devices (e.g. radio, mobile devices, telephones)
- Operating display access, presentation and content
- Support applications
- Console workstation design
- Control room design

A simplified, recommended process for designing effective interfaces to support operator activities can be represented as distinct development phases (Figure 2). This document focuses on techniques for Phases 1 and 2.

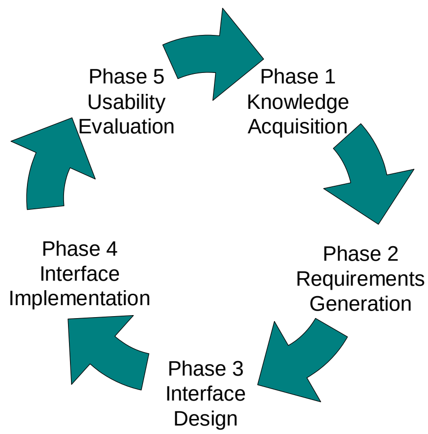

Figure 2 Process for developing operator interface design including phases for generating interaction requirements.

The outputs of each phase provide inputs into the next phase. The first phase consists of knowledge acquisition of the operations positions under consideration. This knowledge includes all sources of information regarding the work activities of individuals being supported by the interface design. The result of this knowledge acquisition phase provides the inputs to the second phase, formal requirements generation. The results of the knowledge acquisition need to be converted into specific requirements for interface functionality. The third phase, interface design, involves the translation of these interaction requirements to specific design elements in the operator interface. The output of this phase is typically a design specification. The final phase, usability evaluation, assesses whether the operator interface design adequately meets the interaction requirements. At this point, the developer may revisit one or more of the previous phases in addressing issues identified in the usability evaluation. It is often a good idea to iterate through this development cycle with different segments of the operator interface.

2.1 Challenges Associated with Current Practices

A common approach to designing the operator interface is to develop the three key elements around successful operator interface deployment somewhat independently. These three key elements are the control room, the console work area and the DCS operating displays. Often the control room and console work area are either designed or implemented before the developer starts working on the operating graphic displays. Consequently, significant design constraints have already been established by the time the developer is considering requirements for the operating graphic displays. Some weaknesses of this approach include:

- The placement of console work areas does not adequately support the collaborative interactions between operations team members in the control room
- The placement of functional areas adjacent to the control room (such as field operator work area, permit-to-work desk, supervisor’s office, the rack room, applications room, kitchen, and toilets) do not adequately support the operator work processes
- The acoustics and lighting schemes around console work areas are suboptimal
- The layout of the console work area is inefficient such as business PC location, height of computer screens, space for multiple workers, access to hardwired switches and indicators, and positioning of video monitors.
- The number of computer screens is insufficient to support all of the operating display types that are needed for simultaneous viewing

The above challenges pertain to effective design for the console operator’s scope of work with respect to all of the interface elements. Moreover, there are some additional challenges associated with common practices in the design of the operating graphic displays themselves.

Probably the most common technique for determining content for operating graphic displays is to use the plant Piping and Instrumentation Diagrams (P& IDs). P&IDs are an important source of domain information for the console operator interaction requirements. To that extent, these diagrams are complete with respect to information on the process equipment, process instrumentation, the flow of materials and the control schemes. However, when the documents are used directly to design displays without first defining interaction requirements, the result can lead to poorly designed displays. These diagrams are designed specifically for the task of building process plants not for performing the duties of a console operator. Hence when a designer literally copies contents of P&IDs to operating displays, the content does not always effectively support the operator’s interaction needs—strongly related pieces of equipment on separate displays for example. As an extreme, the authors have seen an operating display with one piece of equipment, a pump, because that is how the P&ID drawing was laid out. While this example is certainly an extreme case, using only the P&IDs can lead to failures to support all of the operator interaction requirements such as:

- Executing multiple control actions from single view for a frequently performed procedural task such as drum switching, furnace decoking or plant startup
- Viewing overview displays with less detail than shown in P&IDs
- Viewing process data shown in the context of important operating envelopes such as specific operating or equipment limits
- Viewing important functional relations such as material or pressure balance, process or storage capacity

In some cases, operator interface designers will ask an operations representatives directly what information needs to be in a display to identify additional requirements not represented in a

P&ID. In general this practice is good but it is also limited to the ability of these representatives to have good introspection into the entire operations team's needs. Without a systematic approach to eliciting this operator input, the operator displays may be ineffective for supporting the scope of all interaction needs. In fact, this type of approach tends to create a huge burden of post-design rework, as operators use the displays, discover gaps, and then broker for changes to be made.

To identify all information and tools that need to be designed in to today's console, an operator interface designer should consider at least four sources of interaction requirements:

- collaboration and communication requirements within the operations team – and between the operations team and other supporting departments
- critical information and control actions to support crucial procedural operations
- critical information and control actions to support monitoring and control strategies common to the team of console operators
- equipment limits, operating envelopes, and functional relations between critical process variables to support more effective situation awareness

In the next section, we will provide a framework for understanding all of the console operator needs with specific examples of interaction requirements in each area.

3 Sources of Interaction Requirements

The operator interface developer may use alternative methods when generating interaction requirements to support the scope of operator activities. We present four general methods to consider (see Figure 3), corresponding to each of the four requirements sources outlined in the "Challenges" section:

1) **Team—**model the operations team structure and how the members communicate with each other on activities that can impact the process. Team definitions include the roles and responsibilities of each member and how they interact and coordinate actions to manage the manufacturing or production process.

2) **Procedural—**model the task structure and content contained in plant procedures for normal, abnormal and emergency operations activities.

3) **Strategy—**model the various ways of achieving job goals that are not explicitly addressed in plant procedure documents. Strategies represent the kinds of decisions and activities that operators perform in achieving their job responsibilities in important operating contexts.

4) **Process—**model the constraints and functions associated with the manufacturing or production process independent of whom or what is controlling it. The composition of the plant processes comprises the major determinate of the desirable process behaviors, the specific information available, and the available control actions.

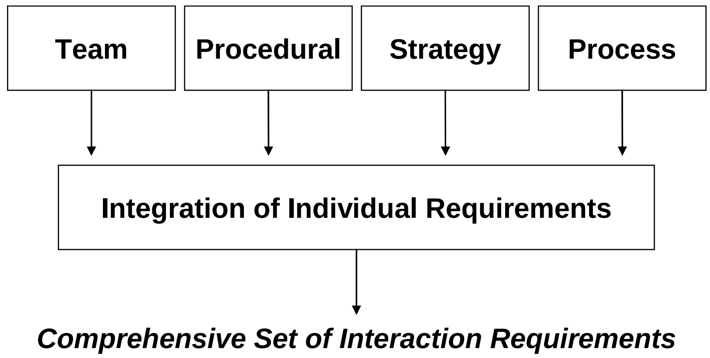

Figure 3 Method classes for generating interaction requirements.

The remainder of this section discusses each method in terms of

- A general description and rationale for the technique
- The work process to follow in performing the technique
- The site resources need to perform the methodology
- Examples of derived interaction requirements

For the latter bullet, the example interaction requirements that are presented are associated with typical work processes and activities. These examples illustrate the appropriate level of detail for output of a given method. Our intent is to aid the reader in understanding what is meant by interaction requirements and not to provide a comprehensive list.

3.1 Identifying Team Requirements

Team requirements provide the analyst with the understanding necessary to address the larger needs of the operator work environment, including control room design, console design, console layout, and the location and use of shared displays, if they are necessary. Included in this method is an assessment of the operating team structure, roles and responsibilities, and how team members collaborate in performing normal and abnormal operations activities. The Contextual Design technique models aspects of the team work environment: the culture, the physical environment, the patterns of team interaction and communication, and the basic tasks involved in getting work done.

3.1.1 Work Process

The sequence of activities described below is recommended in conducting a Contextual Design approach (for more information, see Holtzblatt and Beyer, 1996):

- **Understand the Context of Operations—**the initial modeling step is to understand how the organization influences and constrains the way operators work. A good starting point is a brief overview from an operations management representative on operating policy and practices including operations job positions, shift team composition, team roles and responsibilities, decision-making authority, performance incentives, and communication policies. The analyst should review policy documents that explicitly express expectations and constraints as well as interview a representative sample of operations staff to understand individual's perceptions of these expectations and constraints. In conducting the interviews, the analyst should identify the influencers who affect or constrain the work of console operators. Influencers could be individuals or groups such as operations management, planning group, supervisors, head operators and process engineers. In addition to identifying the influencers, the analyst should identify the direction and the nature of the influence. The following kinds of influences tend to impact interaction requirements:

- **Standards and policy** that define and constrain how work is done, such as Lockout-Tag out procedure for preparation for maintenance activity
- **Decision-making authority** , including organizational structure and roles & responsibilities, to decide who will do what work such as planners setting production targets
- **Organizational values** that set expectations for how people will interact and work such as *safety before production*
- **Personal preferences** that set expectations for how people do their jobs such as following procedures on paper rather than on computer screen

- **Understand the Physical Work Environment—**the second step is to obtain an understanding of the structure of the console operators' workplace. Since communications activity is of particular interest for this inquiry, the placement of communication devices and communications linkages to collaborative work groups should be mapped out. The following kinds of distinctions are important to understanding potential interaction requirements:
  - **Places** that work occurs such as buildings, rooms, consoles, offices, & workstations
  - **Physical structures** that limit and define the space such as doors, walls, security access systems, walk ways, cubicles and console orientation
  - **Communication channels** to coordinate work with others such as face-to-face, line of sight, phone, radio, e-mail, logs and PA systems
  - **Work objects** that people create, modify, and review in support of their work such as reports, instructions, lab results and schedules
  - **Layouts** of the places, physical structures, communication channels and work objects relative to each other

- **Understand the Console Operator Work Objects—**after the high-level characterization of the physical work environment, the analyst should develop more detailed characterization of the important console operator work objects. The specific objects that are modeled will depend on the scope of the design activity. Some possible work objects to study include the console workstation layout and content, the control system operating displays, operating log books, and communications equipment, such telephone, radio and CCTV. The following distinctions are important to capturing interaction requirements:
  - **Information** presented by the object such as the content of a form or workstation devices
  - **Parts** of the object relevant to usage such as operating display types or document format
  - **Structure** of the parts to support intended or actual usage such as the navigation scheme for guiding access to the operating displays
  - **Adaptations** of the object to improve effectiveness for the user such as post-it notes with quick reference guides or duct tape to prevent accidental toggling of a switch

- **Understand Console Operations Work Flow—**this step continues the development of an understanding of patterns of communications and how work is coordinated. The goal is to represent the patterns of collaboration independent of time so they can be optimized and effectively supported in the design of the console operator work objects. The following distinctions are important to understanding interaction requirements:
    - **Roles** represent job functions that are associated with console operations such as console operator, field operator, and team leader
    - **Responsibilities** consist of a list of what is expected of the individual roles such as coordinate execution of procedures, issue permits to work, review all management of change notices, and monitor control system performance
    - **Flow** of communications between people includes informal discussion, coordination or passing of e-mails
    - **Work objects** are the things that are thought about or manipulated in doing work
    - **Communications topic or action** represent the detail of conversations or purpose of coordination
    - **Breakdowns** are the barriers to effective communications or collaborative flow

- **Understanding Work Sequences—**the final modeling activity is to capture important action sequences. A sequence model represents the steps by which work is done, the triggers that kick off a set of steps and the intents that are being accomplished. As mentioned above, this part of the Contextual Design method dovetails with the high level task understanding or strategic activity. For purposes of focusing this effort, the analyst can focus on the communications and coordination activity identified in the previous step. The important distinctions for modeling work sequences include:
    - **Intent** is the goal to be achieved by performing the activity
    - **Trigger** is the condition for initiating the sequence of activities
    - **Steps** are the actions actually performed
    - **Order** illustrates the transitions between steps and potential dependencies between steps
    - **Breakdowns** are the ways in which the work sequence could fail to achieve objectives

- **Interpreting the Work Models for Interaction Requirements—**each of the prior steps produce five different perspectives on the work of console operations. The final step is to interpret these models from an integrated viewpoint for interaction requirements for the console operator. The analyst should review the models and identify implications for interaction requirements. From a participatory perspective, the analyst should involve operations representatives in the review of interaction requirements for acceptability. If it is known that any of the work models will change due to upcoming projects or future initiatives, the analyst should take the expected changes into account in defining interaction requirements. Table 4 presents illustrative examples of interaction requirements for communications activities of the console operator within the operations environment.

Table 4 Communications interaction requirements for the console operator.

Interaction Requirements	Context of Operations	Physical Work Environment	Work Flow	Work Sequence
Shift Handover	Capability to record more information for next shift (i.e., in- progress procedure status)	Provide adequate work space at the console to support all individuals present for shift handover	Provide structured shift handover report to support brief handovers: • recent control changes • off-normal controllers • disabled alarms	
	Capability to track changes to plant information based on past reviews			
Information Exchange	Provide electronic logbook that structures reports for more complete reporting	Provide site access to electronic logbook to reduce unnecessary traffic into control room	Provide operator with online access to operating instructions at the console	
	Access to plant data for field operations	Provide structured logbook that supports such information types as: • equipment status / failure • production rate, target, changes • process changes (e.g., lowered steam header pressure) • safety / environmental events • plant line-ups	Provide structured entry of information into log books	
	Easy access to maintenance work order system w/ quick index to request status	Provide windows in conferencing, kitchen and exercise areas for visual sight lines to console	Ensure work order requests are easily accessible and capture all necessary information	
	Access to summary reports from side-wide incident reporting system	Move tables further from consoles to reduce console operator distractions	Generate summary of daily work authorizations to the console operator	
Plant Documents	Easy access to online procedures in format appropriate for use	Provide console operator with online access to plant documents	Provide shared access to procedure documents for shift team members	Provide online procedures in format appropriate printing and online use

For purposes of the example in Table 4, we are focusing mainly on interaction requirements for communications and collaboration that can be derived from the four modeling techniques illustrated in the previous section. The reader should not interpret the content of the table to be an all inclusive set of requirements that may be derived from the four modeling techniques but more as an illustration of the kinds of requirements that may be identified. The presentation of the results in this format is intended to help the reader compare how the four techniques contribute together to understanding the interaction requirements. The analyst may find other format more conducive to supporting the analysis process and communicating findings to others.

3.1.2 Resources

In the initial stages of data gathering, operations management is a good place to obtain organizational policy documents and organizational expectations for operations staff. A representative of management is also valuable for reviewing models as well as their interpretation in the form of the interaction requirements.

The bulk of the data gathering should be conducted in the context of observing and interviewing operations staff at work. When developing models of key work objects, the analyst should also interview people in the organization responsible for the development and maintenance of those work objects. For example, the operator display developers are good resources for understanding the intent and conventions for the existing design.

3.2 Identifying Procedural Requirements

Procedural requirements provide the analyst with an understanding of the important groupings of monitoring and control parameters to develop effective display layout schemes, an understanding of time-critical operations to develop procedural automation requirements, and collaboration-critical operations to develop communication requirements. Process industry sites have invested a significant effort in the development of procedures to guide and direct operations activity. The procedural approach provides an opportunity to leverage these plant documents in identifying interaction requirements.

3.2.1 Work Process

- **Understand the Process Area—**the analyst should know what the main processing units are, how they interconnect, what the primary function is and different operating modes. In addition to understanding the normal functioning of the process units, the analyst should try to understand challenges in operating the process such as bottlenecks, key control schemes and common failure modes. A high-level familiarity with the process unit terminology, functionality and abnormal behaviors is important to pursuing the next analysis step of reviewing the process area procedure documents.
- **Review Coverage of Procedure Documents—**the analyst develops an understanding of the scope of operating contexts and activities that are covered in the plant procedure documents for the console operator's area of responsibility. Before moving on to the development of the task hierarchy, the analyst should prioritize the list of procedures to scope the level of effort. In many plants, the analyst could spend several hundred hours analyzing all of the procedures. The analyst should focus the effort by identifying specific areas of the plant that have time critical operations or have frequent planned activities. This selection process should be done through interviews with operators to identify specific procedural operations that can have the most impact on day to day activities and upset situations requiring timely responses.
- **Develop a Task Hierarchy—**this step is key to developing a representation that illustrates how the various activities specified in the procedure documents relate to the console operators responsibilities in operating the process area. The Hierarchical Task Analysis technique is a process of developing a description of the console operator tasks in terms of (for more information, see Kirwan and Ainsworth, 1992):
    - ***Operations*** as things that operators do to achieve goals

- ***Plans*** as statements of the conditions that need to be satisfied before a set of operations are performed to attain an operating ***goal***

So the analyst starts with the identification of the highest level goal for the process area. This goal is then described in terms of a set of operations and associated plans that specify the conditions for executing the individual operations.

Table 5 Example of a set of operations and plans for achieving a goal.

Goal	Operations	Plans
G1. Operate Acetylene Hydrogenation Reactor	O1. Startup O2. Normal O3. Abnormal O4. Emergency O5. Shutdown	P1. On supervisor request, do O1 P2. When temperatures, pressures, H_2, and CO levels are normal, do O2 P3. Upon fault or disturbance detection, do O3 P4. Upon unexpected power loss, cooling water loss, feed compressor trip, temperature or pressure excursions above safety limits, do O4 P5. Upon supervisor request, do O5

Figure 4 shows the results of the task hierarchy analysis in graphical form.

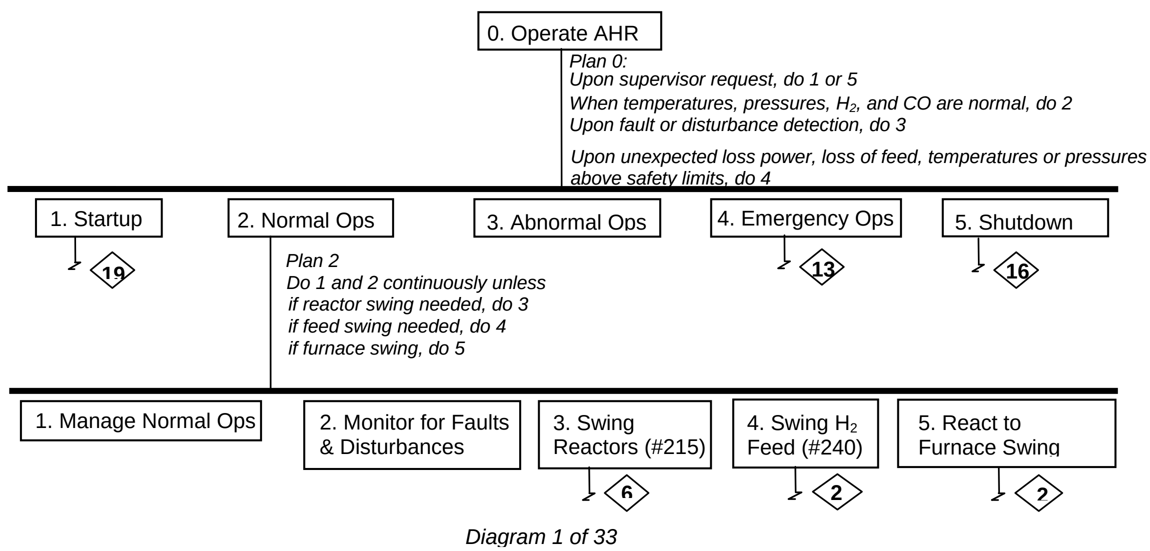

Figure 4 The results of the task hierarchy analysis in graphical form.

The stopping point for the branches in the hierarchy of goals, plans and operations is when all of the console operations procedures are linked into the hierarchy. The catalog of procedures created in the previous step will be useful in understanding which procedures are embedded within operations of other procedures via the branching calls. In addition, there may be some operations that do not have formal procedures, e.g., fault management. In these cases, the strategy approach should be used to further elaborate these operations to identify interaction requirements.

- **Analyze the Procedures for Interaction Requirements**—the final step is to characterize the interaction requirements associated with the procedures identified at the end points of the task hierarchy. From an interaction requirements point of view, the analysts should identify specific parameters that need to be monitored or manipulated at specific steps (i.e., sub-operations) of the procedure. For monitoring, the analyst should identify the kinds of assessments and judgments that must be made such as comparing to operating limits, safety limits, and rate of change. For manipulations, the analyst should capture the specific controls that need to be manipulated with attention to potential simultaneous access requirements. This is critical because it is rare that operators are performing an activity in isolation. Often the difficult procedures are done simultaneously on different process units, e.g., swinging a furnace may involve starting one up and at the same time bringing another down. Hence, the access requirements are compounded across multiple units presenting a significant challenge in the typical operator display designs.

Often, guidelines and standards identify the requirement for task-oriented displays, which are primarily meant to overcome the difficulty in manipulating several different displays simultaneously to accomplish the task at hand. However, these guidelines and standards do not mention how to ensure coverage of the required tasks, and examples given are often fairly generic (e.g., furnace swing, start-up). Because all regular operations tasks should be captured in the plant's procedures, this technique is appropriate for ensuring coverage of all possible task-based interactions.

An advantage of this technique is that the analyst can capture important groupings of monitoring and control parameters to develop the effective display layout schemes. After the initial pass through the procedures for interaction requirements, review the list of requirements with an operations representative with experience at console operations. The operations representative can help identify any monitoring or manipulation activities not explicitly captured in the procedures as well as provide information on the timing requirements across the procedural steps.

Table 6 Interaction requirements list from analysis of procedure for swinging reactors (modification of representation in Miller and Vicente, 1999).

Task	Timing	Role	Interaction Requirements
2.3 Swing Reactors (SOP #215)			• Access to procedure to review sequence of activities, safety information and preliminary activities for reactor swing • Monitor process indicators relative to prerequisites to verify readiness for swinging: o Reactor Inlet temperature relative to target (45 deg. C) o H2 ratio relative to threshold (3.0) o Reactor Poisoning: Efficiency of catalyst (moles of acetylene) selectively converted to ethylene o Delta T calculation. 50-60% at start; 0 or negative is threshold • Access to field operators to notify them of intent to execute procedure and verify reactor regeneration status • Access to cracking console operator of intent to swing reactors
2.3.1 Do safety precautions			• No requirements

Task	Timing	Role	Interaction Requirements
2.3.1.1 Review EM.3 procedure	Sequential	CO, FO	• Access to EM.3 procedure
2.3.1.2 Ensure PSV-410 for fresh reactor is in service	Sequential	FO	• Access field operator to confirm off-line reactor is lined up for service: o Get PSV410 status (pressure relief valve for the reactor)
2.3.1.3 Double block regeneration inlet and outlet w/ bleeds open and tagged for fresh reactor	Sequential	FO	• Access field operator to confirm off-line reactor is lined up for service: o Verify regenerator inlet and outlet status and tags
2.3.1.4 Redirect fire monitor to fresh reactor	Sequential	FO	• Access field operator to redirect fire monitor: o Verify monitor is in correct position
2.3.1.5 Ensure double block & bleed valves and tags remain in place for regeneration system on stale reactor	Sequential	FO	• Access field operator to confirm on-line reactor is lined up for swing: o Verify block and bleed valves and tag status
2.3.1.6 Monitor bed temps and vents	Continuous	CO (temps), FO (vents)	• Monitor process functional indicators for abnormal conditions relative to limits and targets throughout swing procedure: o reactor bed temps o temp runaways (delta temp over time) o high temps (>inlet temp on fresh reactor) o temp anomalies (evidence of poisoned catalyst) • Access field operator for status indicators in the field throughout swing procedure: o vent status o flow status

3.2.2 Resources

The process operations training manuals and process flow diagrams (PFDs) are valuable resources for obtaining a fundamental understanding of a process area and Process Safety Management documentation such as HazOps, PSSR, PHAs, etc. In addition, the analyst should use the plant's operations specialist, operations team leaders and process and applications engineers as valuable sources of information and access to existing documentation on the process area.

For this method, the procedure developer will be the most valuable resource available to the analyst. In fact an effective tactic is for a human factors specialist to team with the procedure developer to conduct the procedural analysis. For example, a procedure developer with experience in console operations can be instructed on the technique and conduct the document analysis with guidance from a human factors specialist.

Hence, the procedural approach is a knowledge acquisition technique that requires access to operations subject matter experts, operators and operations support staff to identify the interaction requirements associated with plant procedural operations. For a given console operator area, the analyst should expect to spend about 1-2 weeks on this activity if the activity is scoped to focus on startup, planned, and upset response activities. Depending on the quality of the procedures, the analyst may need to spend more time with operators or subject matter experts to obtain accurate and complete information.

3.3 Identifying Strategy Requirements

Strategy requirements provide the analyst with an understanding of the operator's explicit and implicit strategies for performing activities to achieve goals that are not governed by formal procedures. The notion of strategy is used here to denote the collection of actions taken and decisions made by operators to achieve a job goal that is not explicitly addressed in plant procedure documents in an effective, optimal manner. Monitoring process conditions and troubleshooting an abnormal process condition are two examples of operator activities where competent operators might have different techniques, or strategies, for accomplishing the goal. The strategy requirements method provides an opportunity to leverage operator expertise in identifying interaction requirements that would improve the design of effective operator interfaces. Often, when operator expertise is identified as critical to design, the "critical" characterization is done in the context of differences between expert and novice operators. However, equally important to analyze and understand are differences in strategies between expert operators. This technique is capable of addressing both distinctions: between experts and between experts and novices.

3.3.1 Work Process

A strategy requirements analysis is accomplished through interviewing, document review, and observation (for more information on scenario-based analysis see Carroll, 1995). The major steps are:

- **Understand the Process Area—**the first step is to obtain a high-level understanding of the process area within the scope of responsibility of the console operator. In addition to understanding the normal functioning of the process units, the analyst should try to understand challenges in operating the process such as bottlenecks, key control schemes and common failure modes.
- **Understand Operating Practices—**the analyst should also gain familiarity with the operating practices within the process area that may impact operations strategies. Operating practices such as operations job positions, shift team composition, team roles and responsibilities, decision making authority, performance incentives, and communications policies.
- **Understand the Work Environment—**a third step to gaining console operator job familiarity involves learning about the design of the console operator work environment. In particular, the analyst should understand the layout of the operator workstation, current operator display design both for the control as well as support applications, communications devices and protocol and control room layout and functional adjacencies.
- **Identify and Define Key Operating Scenarios—**this step sets the stage for the specific contexts to investigate operator strategies. With operations representatives, the analyst

identifies key operating scenarios for the process area that are not covered by procedural activities. If a new process unit is being integrated into the console operator's area or new roles and responsibilities are being proposed, these future scenarios should be identified as well. As a starting point, the analyst should seek to identify at least 3-4 scenarios for each the main activity areas of Process Operations Monitoring, Process Optimization and Abnormal Situation Response in the console operator's process area. With the assistance of the operation representatives, these 9-12 scenarios can be discussed in terms of potential impact on plant performance to help prioritize and focus the final selection. Each scenario should include a description of the triggering conditions for operator response, i.e., how would the initial symptoms appear in the case of an abnormal condition or process operations constraint.

- **Conduct Scenario Interviews—**the analyst interviews console operators to capture descriptions of their activities in each scenario. If process simulation platform is available, the scenarios interviews are best conducted in a simulation environment using the actual operator interface. Otherwise, the interviews should be conducted at the console operator workstations to enable walk through of the current operator interface. In addition to capturing the operator actions, the analyst should try to capture the key data or information used to trigger activities as well as how the work environment is used in performing the activities such as display navigation, control moves, and display arrangements.
- **Analyze the Interview Data for Strategies—**this step entails examination of the interview summaries for each scenario for strategic behavior. The notion of strategy is used here to denote the organization of actions to achieve a goal in an effective, optimal manner. So, first the analyst needs to identify what the operator goal was for each scenario. And, second, what guiding principles can explain the organization or sequencing of actions performed in the pursuit of the goal. For example, a guiding principle may be to minimize cost or time or likelihood of error. After each interview summary is analyzed for strategies, the analyst identifies common strategies and most effective strategies. Finally, the analyst should determine what role the existing interface plays in motivating the strategy, that is, is it driven by operational policy, common failure modes of the process or the layout of the existing operator interface.
- **Analyze the Strategy Summary for Interaction Requirements—**the final step is to characterize the interaction requirements associated with the operator strategies. At this stage, collaboration with operations representatives is important for determining the need to support the identified strategies in the operator interface design. As mentioned in the previous step, some assessment is required to determine to what extent the operator strategies are motivated by the existing interface design. In the case of these strategies, there may be ways to improve the support for the operator strategies, (i.e., making the operator interface more aligned with execution of the goals through the design of new data visualization techniques, new display layouts or new input techniques) or there may a desire to eliminate the need for the strategy by improving the operator interface design (i.e., making the operator interface more consistent with the job requirements may eliminate strategies that are essentially workarounds for a poor interface design or obsolete in the case of a panel board).

3.3.2 Example

Table 7 Interaction requirements derived from the proactive monitoring strategy.

Strategy Element	Interaction Requirements
Establish the normal baseline for control settings and process status	• View key process functions and status indicators, key process set points and measurements at start of shift (or since last change in operating regime) that covers the scope of process units under operator's responsibility, including upstream feeds and downstream products outlets • Access process parameters logged by field operators, view parameters relative to baseline values, and identify significant changes • Access equipment and process logs for reports of recent problem areas - view specific to point, equipment component, unit or area • View lab analysis results, request re-sampling if results are suspect or track down information if results slow in getting posted
Scan key process indicators for abnormal every 30 minutes	• Compare key process functions and status indicators, key process set points and measurements to baseline values, and their change in the last 30 minutes, if any • View relation between current key process values and target ranges • View relation between current key process values and defined limits
Determine instrument versus process problem	• Access specific process indicators to view values over time • View dynamic relation of abnormal process indicator relative to associated controller set point and outputs • View dynamic relation of process relative to defined limits • Manipulate control parameters to assess operational status of equipment

3.3.3 Resources

The scenario-based approach is a knowledge acquisition technique that requires access to operations subject matter experts, operators and operations support staff to develop the suite of scenarios to use as well as to provide the description of operator activities for each of the scenarios.

In developing the suite of scenarios, operations specialist, operations team leaders and process engineers are valuable sources of information on normal and abnormal situations that have significant impact on unit performance. These individuals are also useful in the final step of defining interaction requirements because of their broader perspective on operating philosophy and their ability to envision for the opportunities to improve on existing practices.

As described in the work process section, if there is a simulation of the process, the simulation training area is an important facility for conducting observations and interviews. Otherwise, the analyst should conduct the interviews in front of an operator console or panel board to enable the operator to conduct a simulated walk through the existing operator interface. In many sites, there may only be 4-6 qualified console operators so there are a limited number of individuals potentially available to support this scenario interview and strategy identification activity.

3.4 Identifying Process Requirements

Process requirements provide the analyst with an understanding of process and equipment conditions that must be communicated to operators, enabling them to understand the situation, evaluate action alternatives, and predict the response of a particular control action.

Process requirements are based on process dynamics, engineered constraints and equipment limits. Generally speaking, the industry's primary means for communicating what might be considered process requirements has come in the form of process alarms and schematic displays. The alarms are typically presented in an alarm summary display indicating limit excursions on process measurements such as pressure, temperature, level and flows. The schematic displays take the form of graphical drawings of equipment, supplemented with readouts for raw measured values such as pressure, temperature, flow rate, and volume. These schematics do not explicitly communicate functional information -- the dynamics, limits, and envelopes -- for acceptable performance. As a result, when operators are required to solve a problem, they must rely on their own potentially incomplete and inaccurate mental models that they have formulated over the years as a result of their training, operational experiences, and self-determined operating rules.

The recommended technique for identifying process requirements is *Work Domain Analysis* (Vicente, 1999), based on the abstraction hierarchy analysis technique (Rasmussen, Pejtersen, & Goodstein, 1994). The advantages of this approach are: (1) it covers the range of process requirements and (2) it explicitly relates the functional process requirements to the equipment components, making the analysis relevant to knowledge that is accessible to site operations personnel. The Work Domain Analysis (WDA) technique reveals fundamental, underlying constraints and relations of the process that form the "forcing functions" for what an operator can and cannot do with respect to controlling and maintaining the process in acceptable envelopes of performance.

The WDA technique produces a two dimensional matrix that categorizes the process interaction requirements. The first dimension, the *Functional* Hierarchy, breaks down the system using a why-how criterion, starting with the system goals and purposes, and then first principles, general processes, equipment capabilities, and finally physical parameters of components. The second dimension, the *Structural* Hierarchy, parses the plant equipment into structural levels of increasing detail: systems, subsystems, sections, etc. down to the component level. These two ways of decomposing the system are then combined orthogonally into a matrix with the vertical and horizontal dimensions of the matrix representing the Functional and Structural hierarchies respectively. Combined, these two multilevel decompositions describe how the processing unit is structured, and thus provides a normal basis that operators can use to interact with that unit**.**

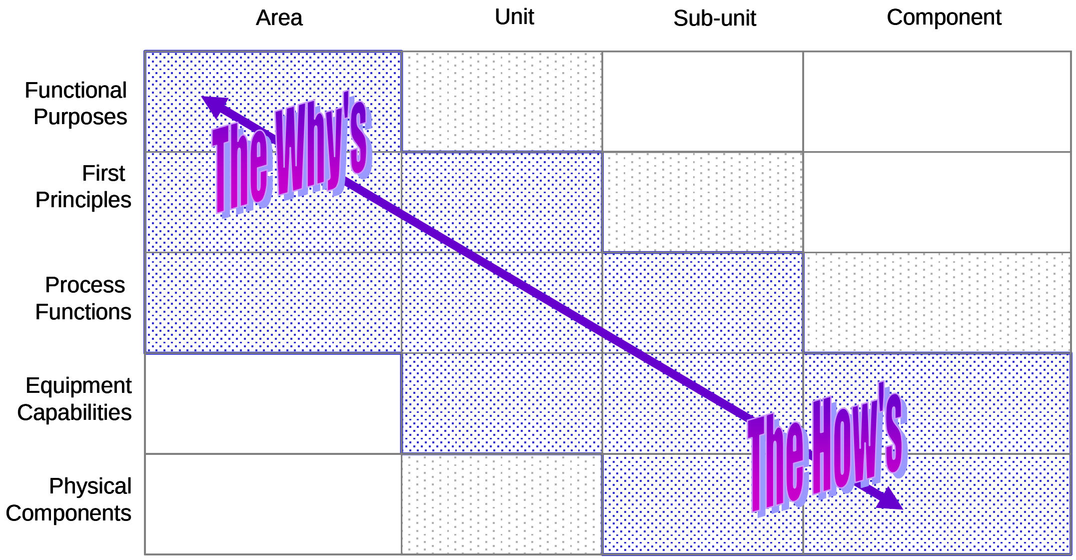

Figure 5 General example of the WDA Matrix, presenting the orthogonal functional and structural dimensions. Moving on the diagonal to the upper-left answers why a function or equipment is needed. Moving on the diagonal to the lower-right answers how a purpose or function is achieved by the equipment.

The following are short explanations for each of the five levels comprising the means-ends dimensions:

- **Functional Purposes:** The reasons for the plant's existence and safe operation.
- **First Principles**: Conservation relationships (e.g., mass, energy, momentum) that govern the functioning of the plant.
- **Process Functions**: Engineered processes required for maintaining balances and supporting the purposes of the plant (e.g., distilling, reacting, drying, recovering, refrigerating, flashing).
- **Equipment Capabilities**: Equipment functions and capabilities that support the plant processes (e.g., reactor, compressor, expander, column, heater, condenser)
- **Physical Components**: Physical location, appearance, and specifications of equipment and components of the plant.

3.4.1 Work Process

A work domain analysis is accomplished through interviewing, document review, and observation. The major steps are:

- **Develop an understanding of the Process—**the analyst needs to obtain a high-level understanding of the process area within the scope of responsibility of the console operator. In particular the analyst should:
  - o Know the main processing units, their interconnections, and their primary function
  - o Gain an understanding of the normal operation of the area and operational challenges such as bottlenecks, key control schemes, and common failure modes

  - Become familiar with the process unit terminology, functionality and abnormal behaviors from reviewing the PFDs and training manuals
- **Introduce analysis process to Operations members to be interviewed—**the analyst introduces the operations and engineering representatives to the analysis process; the analyst will rely heavily on both of these groups to complete the analyses. The analyst should explain items such as:
  - the rationale for the method in terms of the additional interaction requirements that are produced from the Work Domain Analysis
  - how the results support the scope of console operator needs
  - how the interaction requirements from the Functional Purpose, First Principles, and Process Functions levels from the Functional Hierarchy -- which are often missing from today's console -- can be used to design a console overview display and unit-level summary displays
- **Identify structural (equipment) hierarchy & verify accuracy—**working in consultation with operations representatives the analyst creates the Structural Hierarchy. The key activities in this step include:
  - Define the process from the highest or area level to the lowest or most detailed level. The detail at the lowest level is comparable to that found on a typical detailed process schematic display.
  - Capture all the *process flows*, whether instrumented (or not) or controlled (or not) in a hand-drawn sketch with the operators.

  The results of this step -- which is effectively ensuring that the analyst is working from up-to-date PFDs and P&IDs -- will be used later to identify the specific functional relations in the Functional Hierarchy.

- **Identify functional hierarchy & verify accuracy—**the objective of this step is to identify the specific functional relations for the span of control of the operator. In collaboration with engineering representatives (e.g., process engineers, control engineers), the Functional Hierarchy is drawn out for each of the four levels of abstraction. This definition step is important for generating the linkages between equipment component resources and plant operations functions (i.e., the different levels of abstraction) that enable the operator to get different views of the plant that are useful depending on job specific objectives and needs.
- **Identify critical information from the hierarchy models—**the goal of this step is identify the critical process instrumentation that is needed for the process. To do this, the following two techniques can be used together:
  - Compare the instrumentation available versus the information required as identified in the Functional Hierarchy.
  - Ask the subject matter expert (operator or engineer) to identify the most critical information required for monitoring this process in the contents of the WDA results. Moreover, the subject matter experts are asked to NOT limit their responses to information that is currently being provided on their console or panel.

  The information obtained in each of the above steps is crucial and provides key insights into the operation of the area. The first step provides an unbiased, system perspective, of the information required; whereas the second step incorporates valuable experience-based knowledge of a plant's quirks and nuances (e.g., pump A is run more often than pump B because it is more reliable) that unbiased methods could never capture. By combining the critical information from both steps, the analyst identifies the "blind spots" in the current instrumentation that is available and critical information for an overview display.

- **Identify interaction requirements for the operator interface design—**the objective of the final step is to find the interaction requirements associated with the Functional and Structural hierarchies that resulted from the WDA. In collaboration with engineering representatives and operations in general the following kinds of information are obtained:
    - limits or constraints on the identified process variables
    - known equations or formalism for the functional relations between these variables
    - representations of the functional relations, limits, and constraints available, such as performance curves, phase diagrams, and efficiency graphs

Table 8 Interaction requirements following linkages between cells Figure 5.

WDA Level	Element	Interaction Requirements
Functional Purpose	Maximize conversion of feed to product	• View conversion rate of feed to product relative to desired and minimum conversion rate • View yields of desired product and by-products
First Principles	Mass balance	• View Mass balance relationship in terms of position relative to normal; where deviation in output does not match input, indicating a loss of material between boundaries of the area
Process Functions	Feed Input	• View volume (or volumetric flow rate) of feed input to area • View change in volume (or volumetric flow rate) over time (trend) relative to target values and limit values (show low and high volume limits since both can cause disturbances in the process) • View volume for each source of feed input • Access control mechanism to manipulate desired feed volume on each source of feed input • View descriptive labels for feed sources
Equipment Capabilities	Feed Piping	• View feed streams from source vessel or equipment components to first area vessel or feed header • View descriptive labels for feed streams • Monitor system pressures and temperatures against piping specifications
	Feed Pump	• View working status of feed pump • View cavitation and surge limits on pump • View indication as to whether pump is field or console controlled • If console controlled, access control mechanism to start and stop pump • View availability and maintenance status of backup pump (Lock-Out/Tag-Out: LOTO) • Inspect lubrication system for mechanical problems • Monitor pump for mechanical problems (bearing temperature, vibration, fouling)
	Feed Control Valve	• View valve status in terms of position and % open • View indication as to whether valve is field or console controlled • If console controlled, view indication as to whether valve is in manual or automatic control; access mechanism to switch between manual and automatic control; view indication of the process parameter(s) or program controlling the valve; access mechanism to set target valve under automatic and OP% under manual control • View control bypass valve status • View flow controller status: is it in normal mode, is it in initialization, wind-up protection, or drifting from set point

3.4.2 Resources

Plant documents provide the analyst with necessary background information to better understand the plant processes and operations. The following resources should be available and used as sources of data:

- Process Flow Diagrams (PFDs)
- Piping & Instrumentation Diagrams (P&IDs)

- Unit Manuals
- Training Manuals (used fairly extensively to help complete the Functional and Structural decompositions)
- Operating procedures (to some extent)
- All PSM documentation including HazOp and/or Alarm Objective Analysis (AOA) documents (or comparable analysis results) that contain references to limit sets on critical variables
- Subject Matter Experts: Operators, Engineers, Operations Trainers and Specialists

Console operator participation is also critical for gaining acceptance of the ultimate operator interface design, as well as for understanding how the design will impact the performance of operations. The console operators are often best able to envision how work would be positively or negatively influenced by a design feature.

4 Using the Methods in a Project

Combining all of the analysis methods creates an integrated set of interaction requirements, linking the process that needs to be managed and controlled with aspects of how the operations team works. Consequently, the selective use of all four methods will increase the likelihood of designing operator interfaces that effectively support the scope of console operator activities. However, at the onset, the attempt to use all of the methods simultaneously might seem to be a bit onerous. In this section, the methods are compared in terms of their potential contributions to support the interaction requirements of the different types of operator activities. Additional information is provided to help in selecting techniques depending on the nature of the project.

4.1 Comparison of Methods

The four types of methods vary in terms of how completely each method reveals activity-specific interaction requirements from the process and team members (See Table 9). With respect to completeness of coverage of the overall console operator interaction requirements for a specific type of activity, the qualitative terms *none*, *sparse, moderate,* and *comprehensive* are used to give a relative indication of the level of coverage. The values in Table 9 represent the authors' assessment of the best case scenario for a given method.

When examining the four methods from the perspective of completeness in coverage of interaction requirements, it appears that the process approach has the most complete coverage across the activity areas. Intuitively, this makes sense because the operators' activities are ultimately driven and constrained by the process design and its current state of operation. Moreover, the three other methods will become extremely resource intensive if they are applied to all known or anticipated operating situations. Hence, the process method that represents attributes of the manufacturing process that motivate operator actions can provide a powerful tool for identifying interaction needs without conducting an exhaustive analysis of all operator activities.

Table 9 Comparison of method types in terms of coverage of interaction requirements for the console operator activity areas.

Activity	Team	Procedural	Strategy	Process
Situational Awareness and Response				
Process Operations Monitoring	Sparse	None	Moderate	Comprehensive
Process Optimization	None	None	Sparse	Moderate
Abnormal Response	Sparse	Sparse	Moderate	Moderate
Emergency Response	Moderate	Comprehensive	Moderate	Moderate
Planned Procedural Operations				
Preparation for Maintenance	Sparse	Moderate	Moderate	Sparse
Planned Operations	Sparse	Moderate	Moderate	Moderate
Planned Startup / Shutdown	Sparse	Comprehensive	Sparse	Moderate
Communications				
Shift Handover	Comprehensive	None	Moderate	Moderate
Information Exchange	Comprehensive	None	None	None

To help understand where the other techniques can best complement the process method, the following comparative observations may be useful:

- The procedural, strategy and to some extent team methods are well suited for anticipated modes of operation.
- Most importantly, the process and strategy methods are best suited for supporting the novel, adaptive problem solving activities required for the unanticipated, abnormal events that expert operators have developed over the years. The significance of this failure mode coverage should be underscored as one of the most significant contributions from the general interaction requirements approach. While impossible to design for 100% coverage, applying these techniques can address factors that contribute to many of the large and potential disastrous situations.
- However, the strategy method can support identification of interaction requirements that enable generic problem-solving and diagnostic activities including mental computations or comparisons that may not be obvious from the process method.
- In addition, the process analysis will not provide insight as to how the process might behave under failure modes. However, an operator with experience in dealing with failure modes will develop "rules of thumb" or strategies for dealing with the way the plant behaves under critical or likely failure modes.
- The procedural method complements the process method even though they may often identify common or redundant elements. Specifically, the procedural method can help in determining the specific arrangement of indicators and control handles derived in the process method to create more efficient display layout to execute procedural activity; the designer

should be selective in choosing procedures that are critical such as emergency responses or abnormal conditions around critical equipment, or frequent routine operations.

- The team method is strongest for interaction requirements pertaining to the communications activity such as shift handover or information exchange activity that are not exposed in the other methods.
- The team method is critical in the design process for a control building, control room and console work space.

4.2 Selection of Methods

In an ideal world where resources are not an issue, the designer would have the best success by using all four techniques in an integrated manner. In such a scenario, the designer would start with the process method, transition to the team method, and fine-tune the requirements with the procedural and strategy methods. The reality is that many projects do not have the resources available or time to apply all of these methods. Hence, the designer needs to develop an approach that may use some or portions of the methods to stay within resource constraints.

Table 10 Suggestions for use of methods by project elements for identifying interaction requirements associated with given operator activities.

Project Elements	Team	Procedural	Strategy	Process
New unit or plant	(1) Communications	(1) Emergency Response (2) Planned Procedural Operations	(2) Process Monitoring & Response (3) Communications	(1) Process Monitoring & Response
New or upgraded field instrumentation	(1) Communications	(2) Planned Procedural Operations	(3) Communications	(1) Process Monitoring & Response
New or upgraded control system	(3) Communications	(2) Emergency Response (3) Planned Procedural Operations	(2) Process Monitoring & Response (3) Communications	(1) Process Monitoring & Response
New or renovated central control building	(1) Communications	(2) Emergency Response (3) Planned Procedural Operations	(1) Communications	
Revised staffing	(1) Communications	(1) Emergency Response (2) Planned Procedural Operations	(2) Process Monitoring & Response (3) Communications	

Assuming limited resources are available, the nature of the project is a basis for making decisions on how to use the four methods. In Table 10, a specific mix of the methods based on the nature of the plant project is recommended. Moreover, the focus areas for each project type are indicated in increasing scope, recognizing that sites and projects will have limited resources and time. For a given project type, those focus areas designated with (1) should be done as a minimum design effort. Including areas indicated by (2) and (3) increase the coverage of the interaction requirements to be addressed and moves towards a best practice for design. For example, for a new unit or plant, at a minimum, the team technique should identify requirements that result from Operations communications, the procedural technique should be used to identify requirements for emergency response situations and procedures, and the process technique should be used to identify requirements for the process monitoring & response activities of the operator. If time and resources allow, the site or project would then use the procedural technique for planned operations and the strategy technique for process monitoring and response activities. In the optimal situation, where the site or project has the necessary resources, the strategy technique would also be used to identify requirements that result from Operations communications.

New unit or plant (Row 1 in Table 10). A project may involve the building of a new plant or the integration of a new process unit into an existing plant. The minimum analysis would involve the process method to capture interaction requirements for building the operator displays to support running the new plant or unit. In addition, the team approach will facilitate the understanding of the interaction requirements for communication activities for the new plant or unit. In the case of a new unit, the analysis can enable an understanding of how best to integrate with existing unit responsibilities. If this is a greenfield plant, and there is no existing process or team to assess, the analysis will need to proceed from whatever plans are available and the vision of the project people.

New or upgraded field instrumentation (Row 2 in Table 10). A project may install new field instrumentation or involve the upgrading of existing field instrumentation. The change in field instrumentation is most likely to influence the specific parameters appearing in the field operator console. In addition, if the instrumentation upgrade involves smart instruments and fieldbus technology, there will be a significant opportunity to overwhelm the console operator with data. The analyst will need to make decisions regarding what information should go to the console operator, maintenance or reliability engineering. Hence, the team approach will help in clarifying roles and responsibilities and supporting information requirements involving the new field instrumentation data (e.g., sending fieldbus data to a maintenance workstation and not to the operator console).

New or upgraded control system (Row 3 in Table 10). A project may install a new distributed control system (DCS) or involve upgrading an existing DCS. The migration from analog panel displays to the digital computer screens presents the biggest challenge for accurately identifying interaction requirements for the new system. In this type of scenario, the analyst must rely more on envisioning than on analyzing the use of existing technology. In any scenario involving the upgrade, it will be important to conduct the process method to capture the minimum set of requirements. The other methods can be more useful in a scenario where the upgrade is from one DCS to another.

New or renovated control building (Row 4 in Table 10). A project may involve building a new central control building or renovation of an existing facility. Control building changes create opportunities for improvements in console location and design, console consolidation, traffic flow patterns to minimize distraction, and lighting and noise management, to name just a few. Communication activities will be most affected by a migration to a central control building or upgrading of an existing facility. The team approach will provide the most useful information for achieving effective collaboration. In addition, the shifting of team member location may influence ability to execute emergency procedures as written.

Revised staffing (Row 5 in Table 10). A project may involve reducing total number of operators or balancing workload across the existing operating staff. The team method will support clarification of requirements to support communication activity following a change in operations staffing. The procedural method is recommended for also assessing the needs associated with emergency response.

For many projects, there may be an initiative to go beyond the way work is currently being done. Hence, the designer may need to go beyond the descriptive information captured using these methods. At minimum, the descriptive approach can establish a baseline for the way things are today. This baseline can provide the discussion basis for identifying existing limitations and triggering ideas on how to make improvements.

Another aspect of selecting methods pertains to the specific aspects of interest in designing the operator interface. Table 11 presents a recommendation of technique selection based on the type of operator interface being designed. The recommended order of application above still applies in developing the requirements for the interface types.

Table 11 Suggested use of method by operator interface types.

Interface type	Team	Procedural	Strategy	Process
Control Room	✓		✓	
Console Workstation	✓			✓
Span of Control Overview Display (Type 1)	✓		✓	✓
Area Level Summary Display (Type 2)		✓	✓	✓
Equipment Detail Display (Type 3)				✓
Point Detail Display (Type 4)		✓	✓	✓
Ancillary Function Display (Type 5)		✓	✓	
Applications	✓	✓	✓	
Work tools	✓	✓	✓	

For those readers who may not be familiar with the concept of five operating display types, the difference between Types 1-4 is the level of abstraction where transitioning from Type 1 to Type 4 is from broad to specific scope.

- The Type 1, Span of Control Overview, displays provide information support for the scope of operational responsibility of a single console operator and are typically a read only display with high level qualitative information.

- The Type 2, Area-level Summary, displays provide interaction support around major operating equipment groups (e.g., a fraction tower, group of furnaces, or group of reactors) and are considered the operator's primary operating display with both functional and control-specific information.
- The Type 3, Equipment-level Detail, displays are detailed operating displays that provide detailed views of sub units, equipment, and related controls and indications. Type 3 displays are generally used to support planned operations and diagnostic activities that are not time critical.
- The Type 4, Point Detail, displays are detailed views that support manipulation of point values or configuration options and viewing detailed point status information, such as a change zone or faceplate.
- The Type 5, Ancillary Function, displays provide related or ancillary information that is useful for operating a particular section or piece of equipment within a unit such as alarm summary, controller group display, procedure specific display, or safety system permissives.

5 Conclusion

The theme of this paper is to go beyond the obvious sources to understand all of the console operators interface needs necessary to effectively support their work activities. Going beyond the obvious applies to both what is considered the operator interface and the sources used to determine requirements.

The designer should keep in mind that the traditional sources of information such as P&IDs and control narratives while useful provide for only a fairly narrow understanding of the interface needs. Moreover, a production facility relies on a significant level of manual actions, either through the response of the panel operator, direction to the field operations, manual readings or maintenance. All these actions are coordinated through the console operators in the control room and control building facilities and ultimately, the console operator interface. As such, the scope of the interface requirements definition needs to be broader than typically considered by designers in the process industries.

Four different methods from the field of human factors engineering are described to help the interface designer understand the broader concept of the operator interface and the potential sources of information. These methods were identified because of their effectiveness in coverage of the interface design requirements as well as for their tractable, pragmatic nature for non-human factors experts. Specifically, the team, procedural and strategy methods enable capture of important elements of the console operator workflow and workplace that are not coded into the automation system and are most likely missed in examination of the typical sources. Going beyond the obvious will enable the interface designer to achieve excellence in meeting the console operator needs.

6 References

Carroll, J. M. (Ed.). (1995). Scenario-based design: Envisioning work and technology in system development. New York: John Wiley & Sons, Inc.

Holtzblatt, K. and Beyer, H. (1996). Contextual design: Principles and practice. In D. Wixon, and J. Ramey, (Eds.), *Field Methods for Software and Systems Design.*, New York: John Wiley & Sons, Inc.

Kirwan, B. and Ainsworth, L. K. (Eds.) (1992). *A guide to task analysis*. London: Taylor & Francis, Ltd.

Rasmussen, J., Pejtersen, A. M., & Goodstein, L. P. (1994). *Cognitive Systems Engineering*. New York: John Wiley & Sons.

Vicente, K. J. (1999). *Cognitive work analysis: Toward safe, productive, and healthy computer-based work*. Mahwah, NJ: Lawrence Erlbaum Associates.