

Functional Versus Schematic Overview Displays: Impact on Operator Situation Awareness in Process Monitoring

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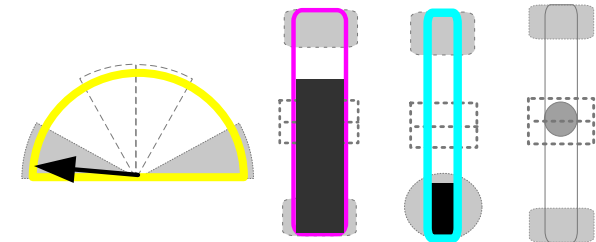
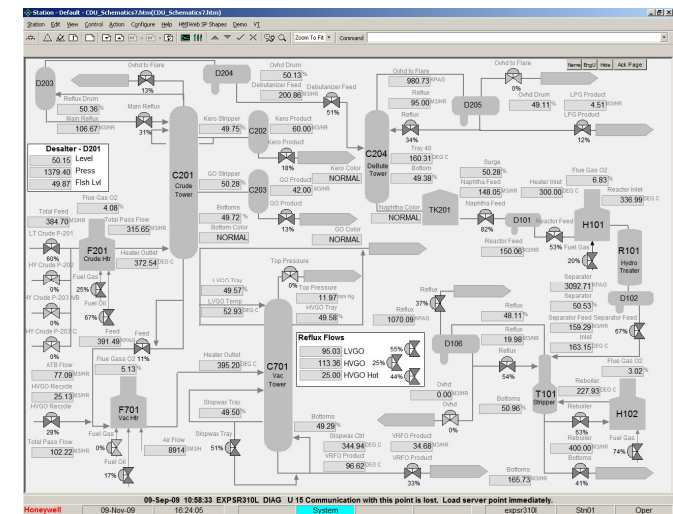
Introduction and Motivation

- **Monitoring the console overview display is the primary way operators maintain situation awareness (SA) of process conditions (Bullemer et al., 2008)**

- Most existing displays in practice today use traditional piping-and-instrumentation diagram (P&ID) based schematic displays

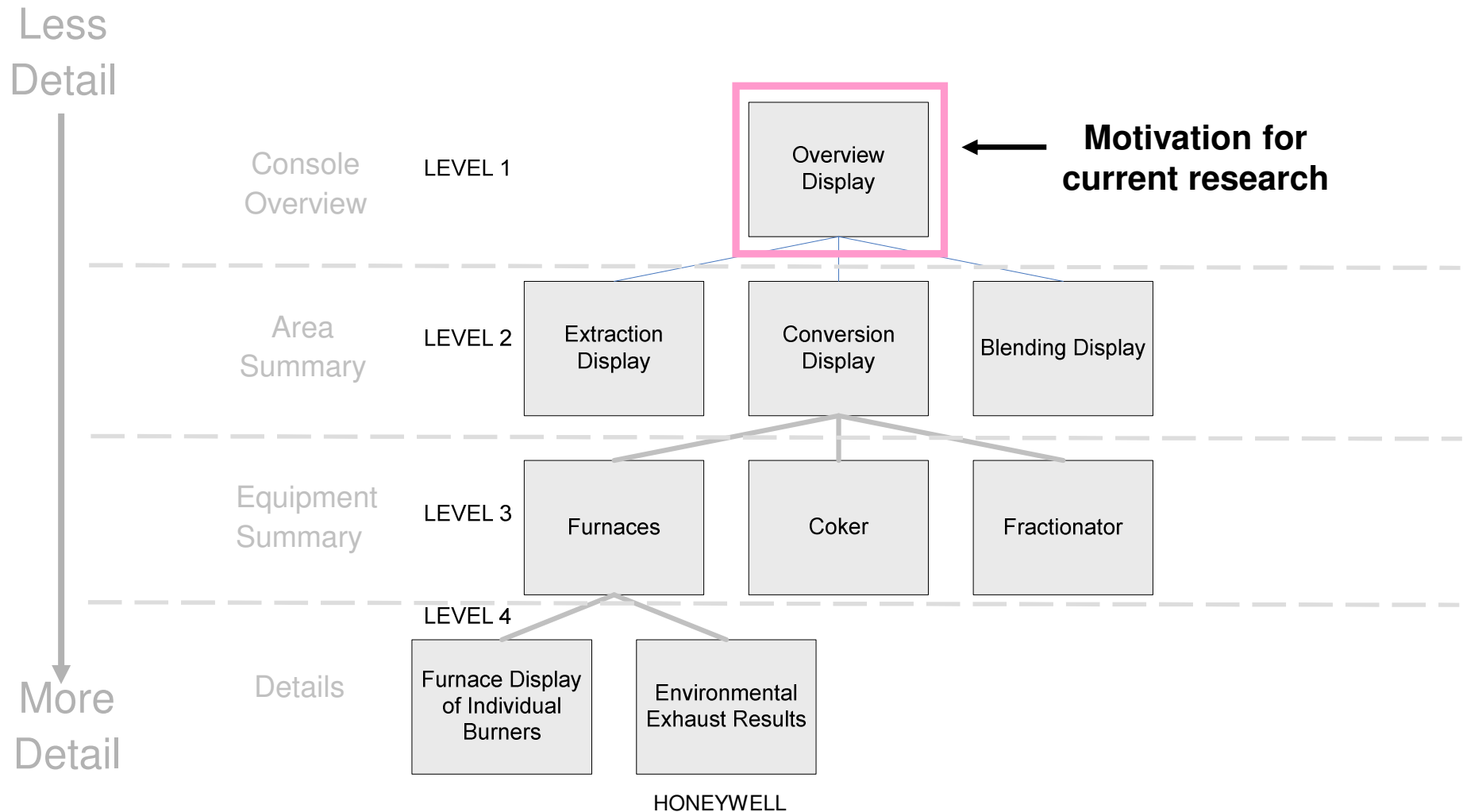
- ◆ Shapes for major equipment
- ◆ Process flow lines
- ◆ Numeric indicators for process values

- Advances in visualization design and cognitive engineering methods have identified ways to improve the display design (e.g., Burns & Hajdukiewicz, 2004, Jamieson & Vicente, 2001, Vicente & Rasmussen, 1990)



Introduction and Motivation

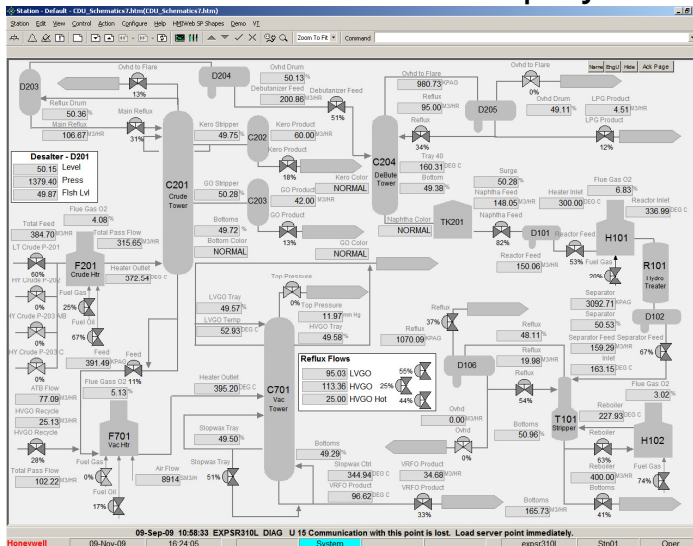
- An effective HMI display distributes information across a display hierarchy (Bullemer et al., 2008)



Research Objective

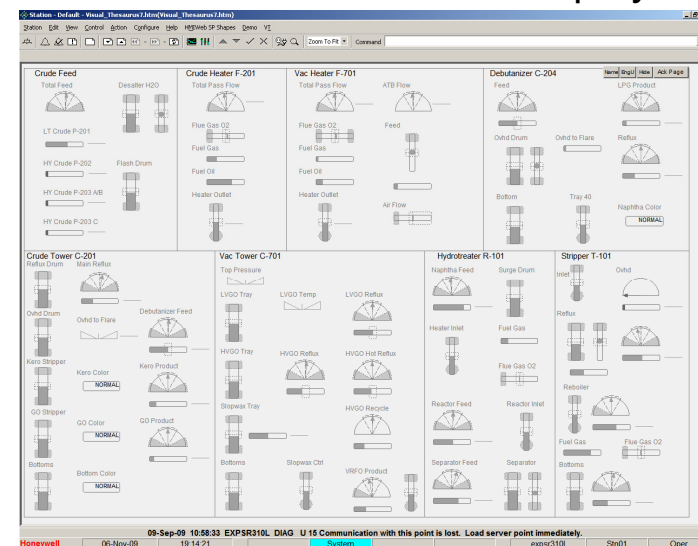
- Evaluate the effectiveness of a console overview display designed to support operator situation awareness during process monitoring activities using (Reising & Bullemer, 2008):
 - Display shapes designed to support qualitative perception of process conditions
 - Display arrangement around a functional organization of process information

Schematic Overview Display



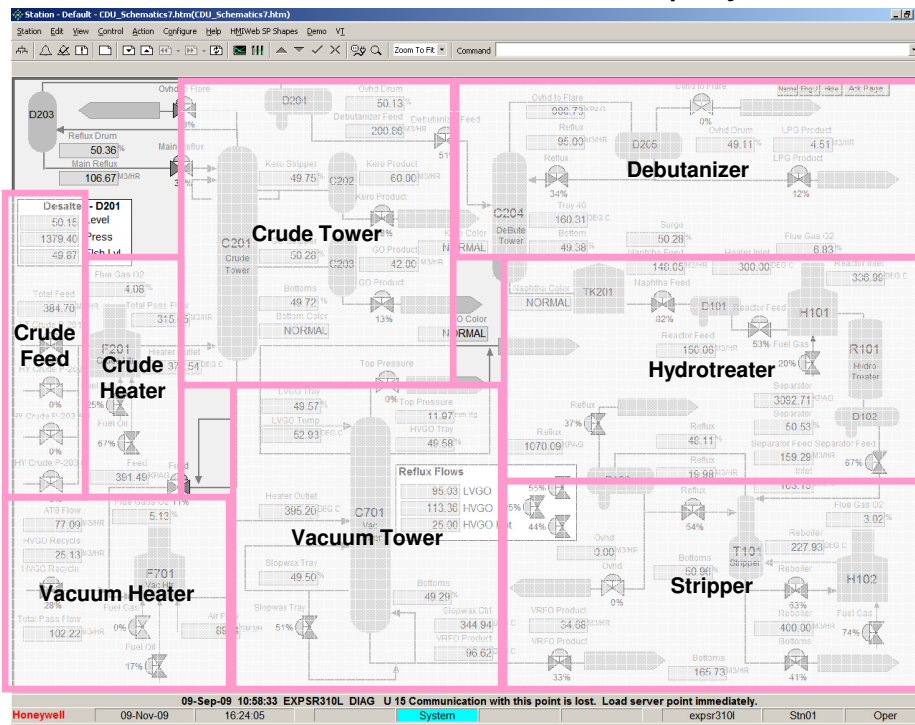
vs.

Functional Overview Display

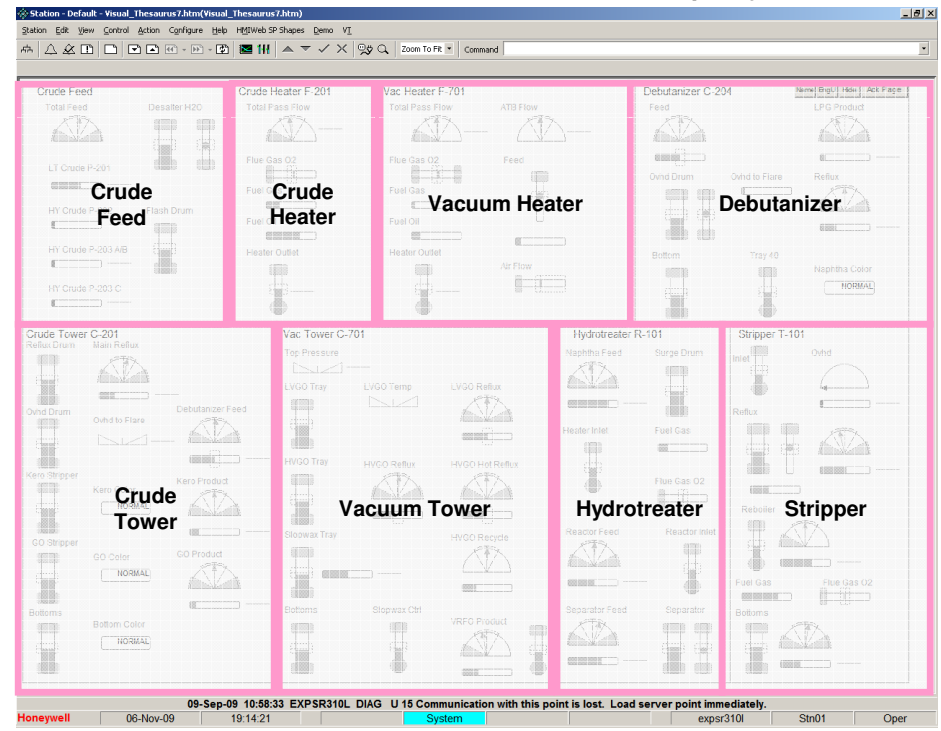


- **Compare Schematic and Functional overview displays**
 - Variables are the same
 - Main equipment areas are the same
 - Differences are visualization technique and functional arrangement

Schematic Overview Display



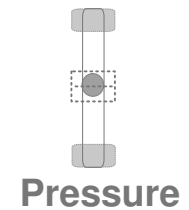
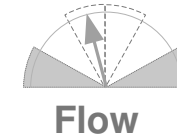
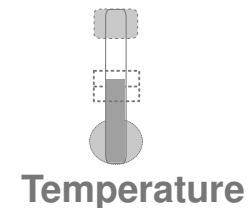
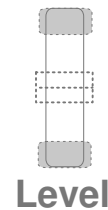
Functional Overview Display



Overview Display Qualitative Shapes

- There are 8 new display objects that were used in the Functional overview display (see Reising & Bullemer, 2008 for design details):

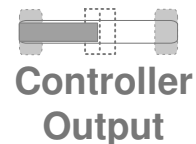
- Gauge objects:



- Qualitative objects:



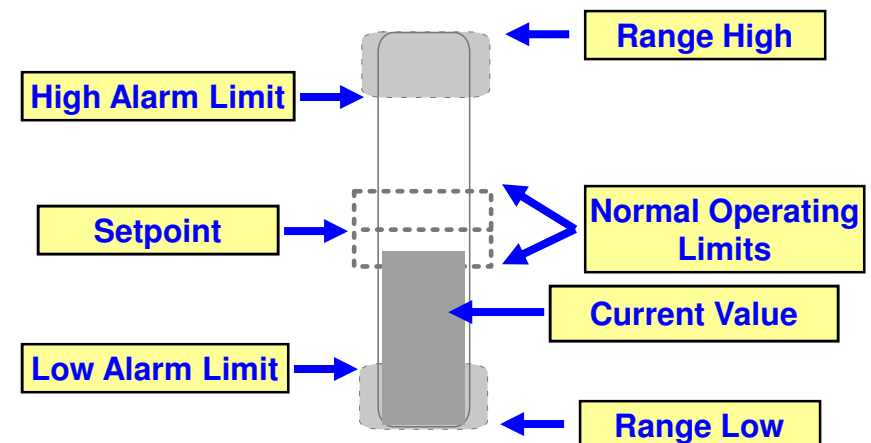
- Controller objects :



Overview Display Qualitative Shapes

- **Information in the new display shapes is presented in such a way that operators can qualitatively perceive:**

- normal operating limits
- alarm limits
- how close the process is relative to the limits
- how quickly the process is moving towards / away from the limits



- **Hypothesis:** New display shapes should support qualitative perception of process conditions, resulting in improved operator SA while monitoring overview displays

Overview Display Qualitative Shapes

- **Detecting deviations to variables can be supported in different ways in the Level 1 overview displays:**

Schematic Overview Display

Operators must assess process variation relative to their memory of operating ranges and alarm limits

45.01

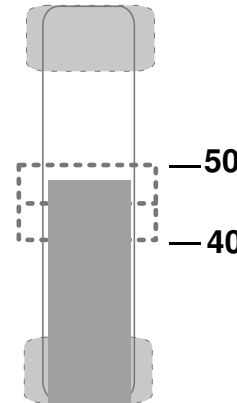
Normal variation

Operators must judge whether an abnormal condition is occurring (cognitively demanding)

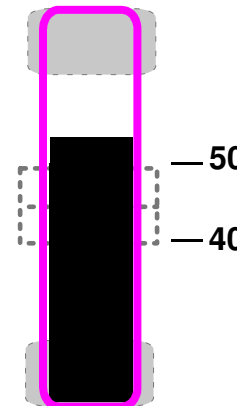
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Abnormal Process deviation

Functional Overview Display



Operators can perceive normal and abnormal variation relative to visual elements (operating range and/or alarm limits) in the shape

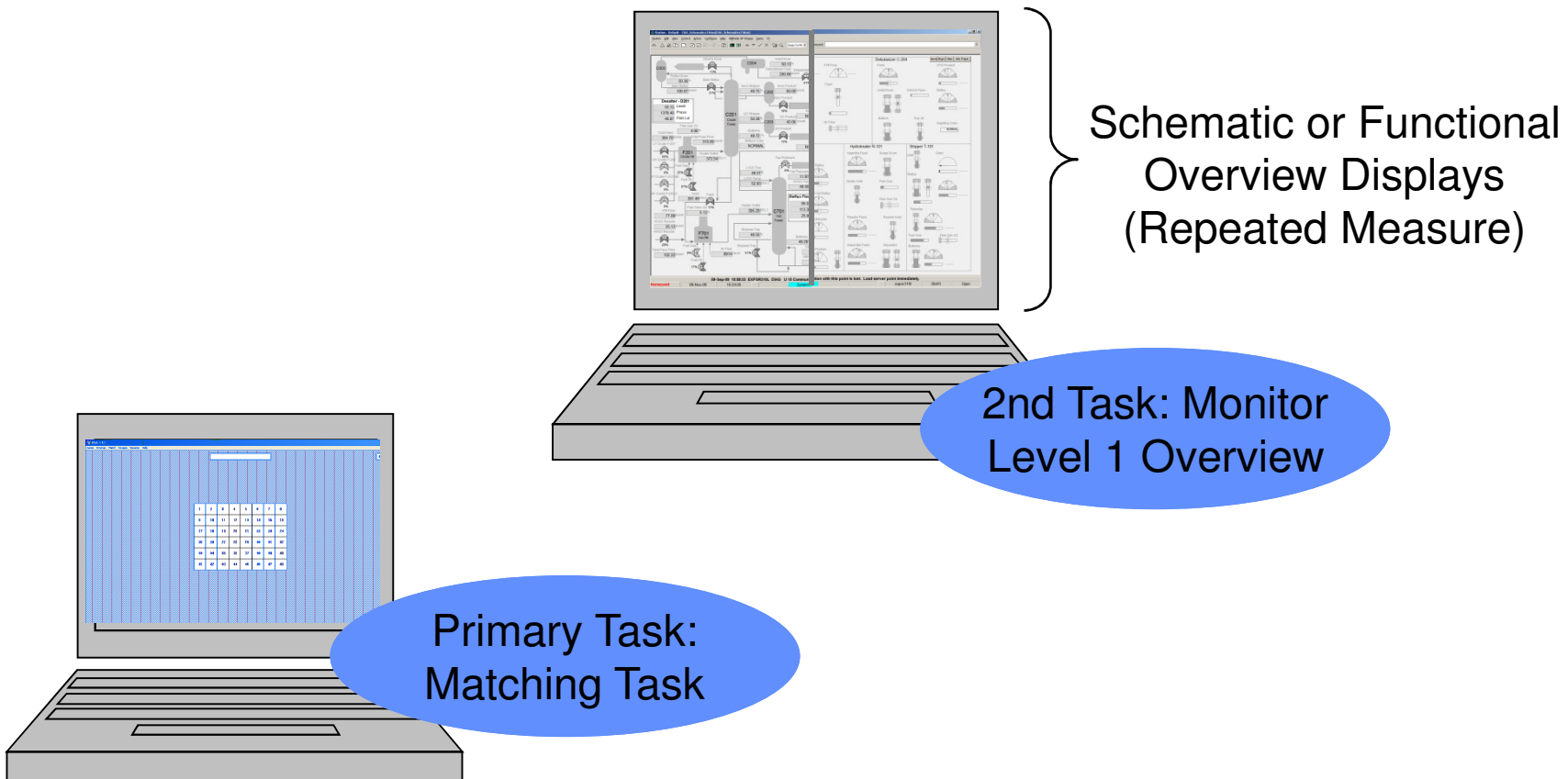


Operator attention is drawn to abnormal process deviations and alarms using visual cues

Method: Apparatus

• Dual-Task Setup

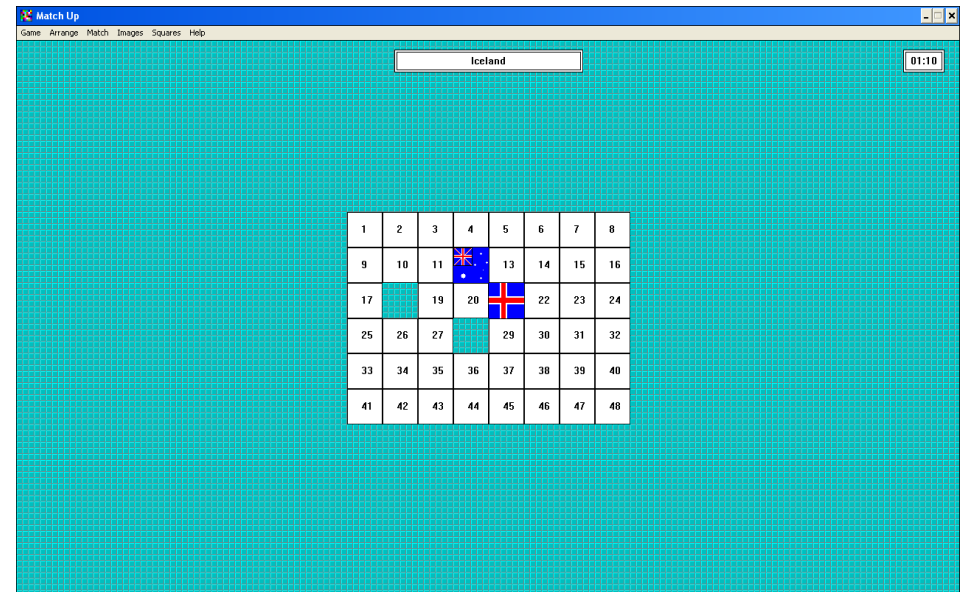
- Rationale: Operators rarely monitor without simultaneously doing other critical tasks (e.g., completing standard operating procedures, managing field activity, etc.)



Method: Primary Task

- **Primary task was a visuo-spatial (flag) matching task:**

- Requires similar cognitive processes as console operations activities (Pringle, 2000)
 - ◆ Working memory
 - ◆ Visual search
 - ◆ Attention
- Reduced operator training time compared to a more realistic primary task such as a procedure
- Reduced the complexity and cost of developing the evaluation protocol
- Is a measurable and quantifiable cognitive test



Method: Secondary Monitoring Task

- **Secondary task was to monitor process scenarios created using a commercial process simulator**
 - Four scenarios were developed by introducing upsets in the plant
 - ◆ Two levels of complexity based on number of process deviations
 - ◆ A process deviation was defined as a condition where a process variable changes either from normal to abnormal, abnormal to alarm condition, a low to a low-low alarm, or a high to a high-high alarm, and vice versa
 - Short steady state scenarios were also created for reference
 - Scenarios were presented as pre-recorded videos on a laptop
 - ◆ Operator monitored the videos and were tasked with maintaining awareness of the process deviations

Method: Experimental Design

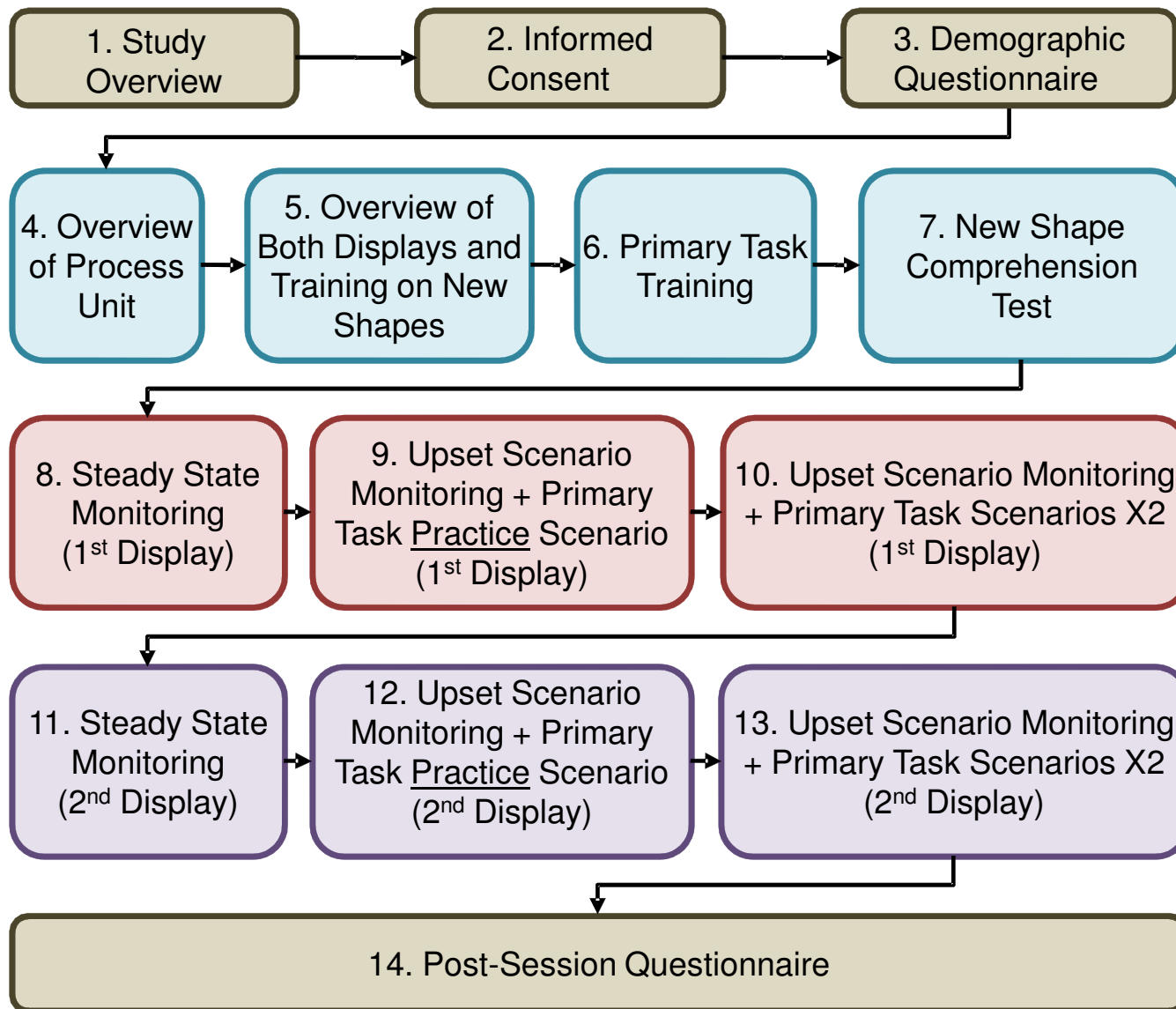
- **Repeated Measures Design**

2 (Display: Schematic, Functional) X 2 (Scenario Complexity: Low, High)

Repeated Measures Counter-Balancing Scheme				
<i>Complexity Order 1</i>	<i>Low</i>	<i>High</i>	<i>Low</i>	<i>High</i>
Display Order 1	Schematic	Schematic	Functional	Functional
Display Order 2	Functional	Functional	Schematic	Schematic
<i>Complexity Order 2</i>	<i>High</i>	<i>Low</i>	<i>High</i>	<i>Low</i>
Display Order 1	Schematic	Schematic	Functional	Functional
Display Order 2	Functional	Functional	Schematic	Schematic

Primary task completed for all trials

Method: Procedure



Method: Participants

• Participant Demographics

- 18 professional operators from two ASM member refining sites
- All operators were familiar with simulated process plant operations

Demographic Variable	Mean or N	SD or %
Age (years)	42.56	8.48
Current Unit Experience (years)	10.11	8.35
Other Unit Experience (years)	6.11	7.30
Field Experience (years)	6.03	7.04
DCS Experience (years)	6.67	4.80
Computer Experience (hours/day)	4.28	4.17
Normal Vision		
Yes	17	94.4%
No	1	5.6%

Method: Performance Measurement

- **Primary Task**

- Total number of correct flags matched during scenarios

- **Secondary Task**

- Operators' SA was measured (Level 1 and Level 2)
 - ◆ Detection of process deviations (Level 1 SA) by talking aloud
 - ◆ Responding to probes (Level 2 SA) at pre-determined pauses during the scenarios

Example of the Level 2 SA probes:

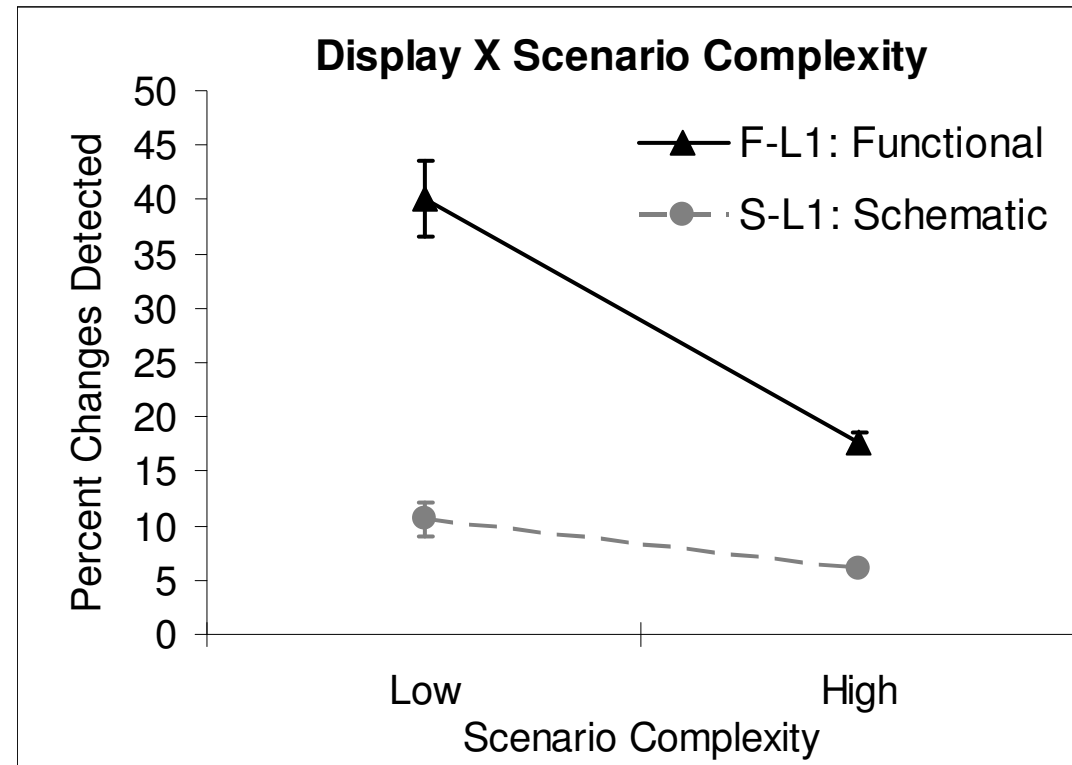
When the freeze happened, *ATB flow in the vacuum heater* was:

- » In normal state
- » In abnormal state
- » In alarm state
- The accuracy of operator responses for Level 1 and 2 was an indicator of situation awareness
 - ◆ Accuracy was assessed relative to what actually happened in each scenario video

Results: Level 1 SA

- **Accuracy of talk aloud responses relative to actual process changes that occurred**

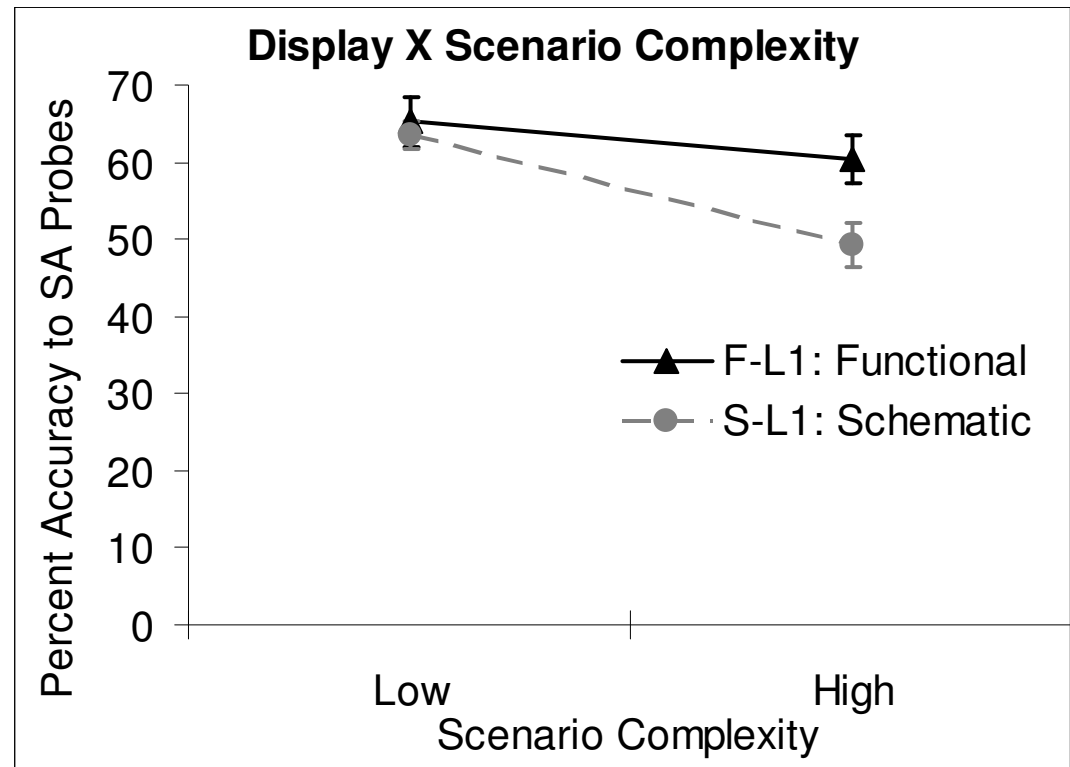
- Significant Main Effect
 - ◆ More changes detected using Functional Display ($p < .0001$)
 - ◆ More changes detected during Low complexity scenarios ($p < .0001$)
- Significant Interaction
 - ◆ Higher relative performance improvement using the Functional display during Low complexity scenario ($p < .001$)



Results: Level 2 SA

- **Accuracy of responses to probe questions averaged across two pauses in each scenario**

- Significant Main Effects
 - ◆ More accurate probe responses using Functional Display ($p < .05$)
 - ◆ More accurate probe responses during Low complexity scenarios ($p < .004$)



Results: Primary Task Flag Matches

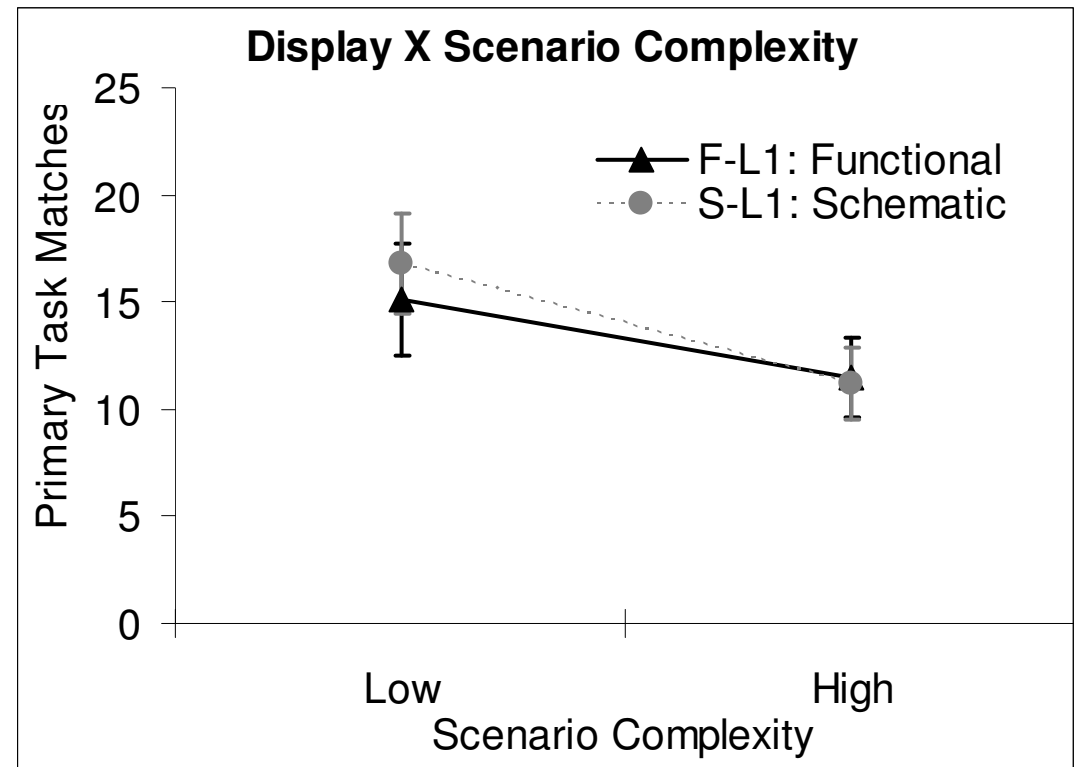
- **Number of correct flag matches made during the scenario**

- Significant Main Effects

- ◆ More flag matches during Low complexity scenarios ($p < .004$)

- **NOTE: No differences between displays ($p > .05$)**

- ◆ Operators maintained equivalent primary task performance with both displays



- **Using the Functional Overview Display improved operator SA compared to the Schematic Display**
 - Qualitative shapes and Functional arrangement together improved performance – but which is more impactful?
 - ◆ Subjective feedback from operators suggests shape design was the contributing factor to the performance improvement
 - ◆ Validates previous studies that show direct perception of process constraints (alarms, targets, setpoints) improves monitoring performance (see Burns & Hajdukiewicz, 2004 for review)
 - ◆ Performance improvement using Functional display despite more operator familiarity and experience with traditional schematic displays

Situation Awareness Performance			
	Schematic (S – L1)	Functional (F – L1)	Difference (%)
Percentage of changes detected (Level 1 SA)	11.9%	28.8%	+16.9%
Percentage Accuracy to Probes (Level 2 SA)	56.4%	62.8%	+6.4%

Practically significant according to ASM member companies

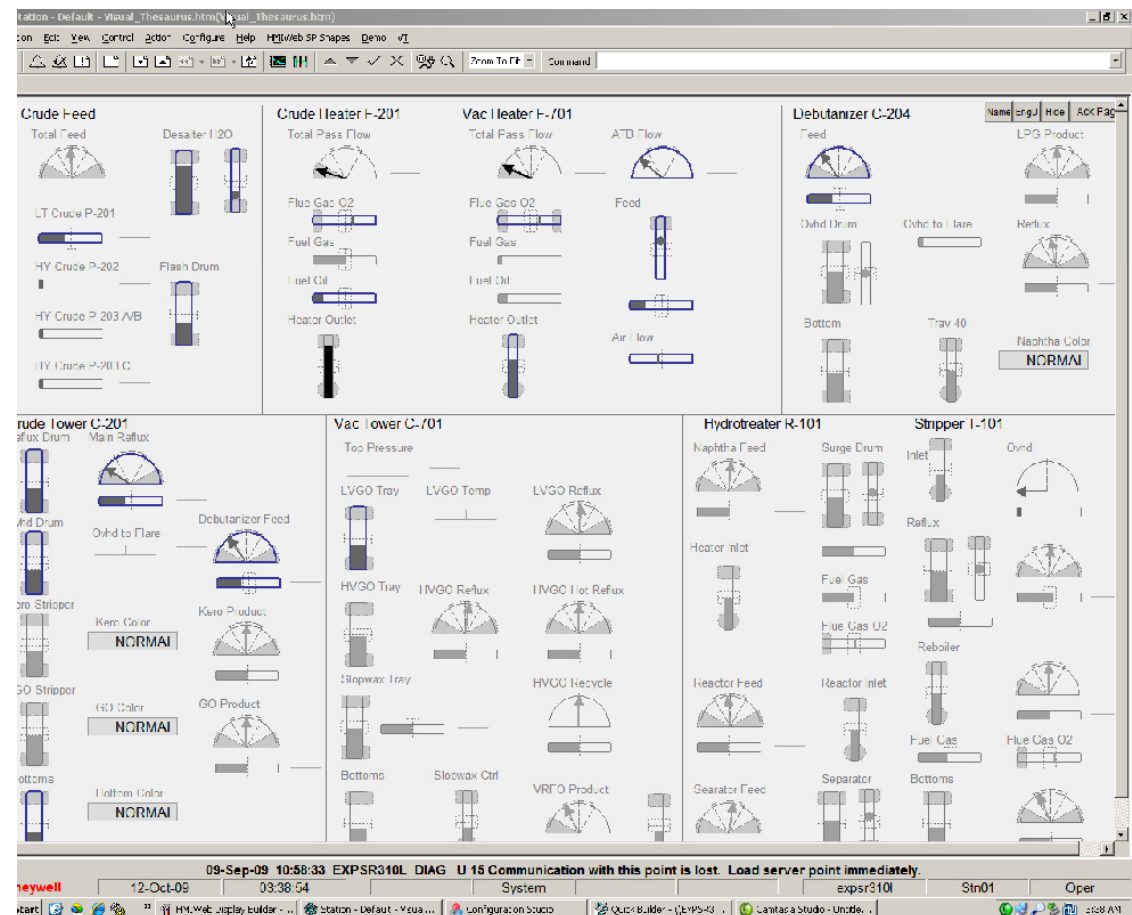
Discussion

- Relatively higher performance impact using Functional Overview Displays for Low complexity scenarios

- ◆ Functional display with qualitative shapes may become visually overwhelming for high complexity scenarios

- ◆ Suggests room for additional design improvements such as:

- Integrated shapes
 - Color/salience scheme adjustments
 - Different layout configurations



Limitations and Future Research

- **Limitations:**

- Display arrangements were not equivalent (confounded)
 - ◆ Pragmatic considerations were the driving factor
- Realism of primary flag matching task
 - ◆ Provided experimental control and was used to increase workload
 - ◆ Did not show differential performance for displays so does not impact overall findings relative to SA performance improvement

- **Future Research:**

- Quantify impact of different display arrangements
 - ◆ Keep shapes constant
- Quantify impact of different display design methods
 - ◆ Traditional engineering practices vs. Cognitive Work Analysis practices
- Identify optimal shape design for different process variables
 - ◆ Temperature vs. Flow vs. Pressure vs. Level

Acknowledgments

- **Thanks to George Gabaldon for his assistance in the overview display design process**
- **Thanks to the HFES reviewers for their insightful comments**
- **This study was funded by the ASM® Consortium, a Honeywell-led research and development consortium**
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