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Workshop Protocol

- Questions?
- Breaks?
- Share Your Experiences
- Expectations?
- Describe challenges you have had?
- Parking Lot
  - Additional Information?

Participation is encouraged
HCI Workshop Agenda

13:30

Introduction

13:50

Situation Awareness & Psychology Crash-course

14:30

HCI “Best in Class” Case Study

Break

15:00

HCI Effective Practices

15:30

Operator Interface

Alarm Management

Control Room & Console Design

Operations Procedures

16:40

Wrap-up
What is Human Factors?

**Human Factors** (Chapanis, 1985)
- Discovery and application of information about human behavior
  - abilities, limitations, and other characteristics
- To the design of:
  - tools, machines, systems, tasks, jobs and environments
- For productive, safe and effective human use

**Objectives** (Sanders & McCormick, 1993)
- Enhance the effectiveness and efficiency of human activities, often with focus on work.
- Enhance desirable human values including:
  - improved safety, reduced fatigue and stress, increased comfort, greater user acceptance, increased job satisfaction and improved quality of life
Human Centered Solutions

✦ We apply **human factors** principles and design methodologies to:

- Enhance **effectiveness** and **safety** of human activities in and around control rooms

- Control Room & Console Design
- Corporate Culture
- Process Control
- Roles & Responsibilities
- Operator Staffing & Workload
- Operating Procedures
- Training
- Alarms
- Operator Interface Design
- Management of Change
- Fatigue Management

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Abnormal Situation Management
A Joint Research & Development Consortium

Founded in 1994

Creating a new paradigm for the operation of complex industrial plants, with solution concepts that improve Operations’ ability to prevent and respond to abnormal situations.

www.asmconsortium.org

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Sources of Abnormal Events

People:
- Fail to detect problems in reams of data
- Are required to make hasty interventions
- May be unable to make consistent responses
- May be unable to communicate well

Established in literature; confirmed by 18 plant studies - US, Canada, & Europe
ASM & HCS

❖ Principal and Contributing Authors of ASMC Guidelines
  ➢ Effective Operations Practices
  ➢ Effective Console Operator Interface Design Effective Procedural Practices
  ➢ Effective Alarm Management Practices
  ➢ Effective Alarm Rationalization Practices
  ➢ Effective Change Management Practices in HMI Design

❖ Technical leadership and contributions as HCS on ASM Projects
  ➢ Procedural Operations
  ➢ Future Role of the Operator
  ➢ First-line Leadership
  ➢ ASM HMI Business Case Study
  ➢ Advanced Operator Interface Framework
  ➢ HMI Visualization Techniques
  ➢ Alarm Trend Display
  ➢ Alarm Sounds for Multi-Console Control Rooms™
  ➢ Root Cause Analysis & Process Safety Metrics
  ➢ Value of Integrated Trending in HMI
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  - Control Room & Console Design
- Wrap-up 16:40
What is Situation Awareness (for an individual)?

- Put simply, Situation Awareness is “knowing what is going on round you so you can figure out what to do” (Adam, 1993)
- Aviation research identified poor situation awareness as a key factor:
  - Military aviation mishaps (Hartel, Smith & Prince, 1991)
  - Accidents among major airlines (Endsley, 1995)
- These findings have motivated studies in decision-making and training methods to improve pilot situation awareness
Abnormal Situation Management

- A major responsibility of process operators is to prevent and respond to abnormal situations.

- Abnormal situations extend, develop, and change over time increasing the complexity of interventions.

- To prevent and respond to abnormal situations, operators must continuously maintain situation awareness:
  - Where the process is, where it is going, and how quickly it is going there.
  - What tasks to perform, how to perform them, and when to perform them.
SA Failure Studies in Aviation

- Research in the fields of military and civil aviation has identified situation awareness failures as the leading contributor to accidents.

- One study found that **88% of major airline accidents involving pilot error were problems with SA** rather than decision making or flight skills (Endsley, 1995).
SA Failure Studies in Aviation

- NASA Aviation Safety Reporting System reports show the following Situation Awareness causes of accidents

**Perception (76%)**
- Information not observed
- Information not available
- Information difficult to detect
- Memory error
- Misperception of information

**Comprehension (19%)**
- Misinterpretation of data
- Over reliance on expectations
- Incomplete/incorrect mental model

**Projection (5%)**
- Attention overload
- Over-reacting to current trends
- Incomplete/incorrect mental model
Transmission Pipeline Rupture (CA)

- In 2010, a 30-inch diameter segment of a gas transmission pipeline ruptured in a residential area in San Bruno, CA resulting in gas release, explosion & fire
- Investigations found multiple root causes, however a few were related to control room operations:
  - Operators lacked assigned roles & responsibilities
  - Operators did not notice the dropping pressures at one station after the rupture
  - Alerted by staff at another facility so it took longer to stop the flow of gas to the rupture site – Level 1 SA Perception Failure
- What would have helped:
  - Specific assignments or operators to dedicated areas
  - An overview display showing critical process values (e.g., dropping pressures) to help operators perceive important/critical information
Improving Situation Awareness

Four basic principles for improving situation awareness:

1. Employ what we know of human information processing to influence information perception

2. Understand the influence mental models have on operator performance and evaluating information

3. Understand how alertness can effect human performance and situation awareness, and how alertness levels can be influenced

4. Understand what comprises effective teamwork required for situation awareness and abnormal situation management recovery
Attention influences each of the information processing elements
## HCI Workshop Agenda

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<th>Time</th>
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<tr>
<td>- Control Room &amp; Console Design</td>
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<td>- Operations Procedures</td>
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</tr>
<tr>
<td>Wrap-up</td>
<td>16:40</td>
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</tbody>
</table>
Operator Interface Case Study
ASM Consortium® HMI Evaluation

Objective

- Develop a case study to illustrate the potential impact of Human-Centered Operator Interface concepts
  - Hypothesis: the human-centered style of operator interface improves operator performance for incident avoidance and in abnormal situations, in comparison to the traditional design

Approach

- Compare operator performance in high fidelity simulator environment with two HMI styles

The Side-by-Side Comparison

Traditional Console Simulator

Human-Centered Console Simulator

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Operator Interface Case Study

Biases against our Hypothesis...

✦ As a comparison, these “traditional” displays represent a “better practice” than the industry norm for operating schematics
  ➢ This fact makes for a conservative comparison in this study’s performance testing

✦ This unit’s training simulator console more closely matched that of the actual plant than that of the Human-Centered interface
  ➢ This fact made the study an even more conservative evaluation of the hypothesis
Operator Interface Concept

Key Design Features

- Single, Integrated View of Multi-Level Hierarchy
- Simultaneous views of increasing detail
  - Level 1 – Console Overview
  - Level 2 – Unit Summary
  - Level 3 – Equipment detail
  - Level 4 – Group & Point detail
- Effective Window Management and Layout
- Effective Navigation Scheme
- Visual Coding Scheme
- Integrated alarm management
- Integrated Trending
Case Study Experimental Design

- The case study involved 2 groups of operators
  - Pre-test – Establish if there were any differences in operations and plant experience between the 2 groups
  - Scenario testing – Establish if there were any performance difference in incident detection, incident prevention between the 2 interfaces
    - Tested the operators on 4 matching scenarios

- A total of 21 operators:
  - 10 for the Traditional interface design
  - 11 for the Human-Centered interface design
Case Study Scenarios

- Used 4 scenarios in the operator performance evaluation
  - Scenarios were matched so that there was a similar development time and matching instrumentation
    - This allowed for better isolation of the effect between the operator interfaces on operator performance for each scenario

- The 4 scenarios were
  - A main process steam turbine vacuum problem
  - A main process compressor suction pressure transmitter drift
  - A main process compressor discharge pressure safety valve (PSV) passing to flare
  - A turbo expander bypass valve drift open
Case Study Results

Pre-Test Results

Group Comparison Metrics

- No average differences between the two groups of operators for:
  - Number of years experience as an operator
  - Number of years experience as an operator at this company
  - Number of years experience as a console operator
  - Number of areas qualified in
Case Study Results
Scenario Evaluation Results

Operator performance measure: **Time to Orient**

- Overall, the operators using the Human-centered interface were *more* proactive, orienting to the problem an average of 4 minutes faster.

- Anecdotally, for the first scenario with the Traditional console, an alarm rang in which oriented them to the problem faster, but...
  - They didn’t solve the problem faster! (see Next slide)
Case Study Results
Scenario Evaluation Results

Operator performance measure: **Total Completion Time**

- **41% Less time** to deal with the event and as a group, were *more consistent* in doing so!
  - An average of 10.6 minutes vs. 18.1 minutes

- **38% improvement** in detecting event before alarm

- **26% higher** success rate
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## Effective Display Design Principles

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<th>Design Principles</th>
<th>Categories</th>
<th>SA Stages</th>
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</thead>
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<tr>
<td>1. Support the Operators</td>
<td>Display Types</td>
<td>✓</td>
</tr>
<tr>
<td>Scope of Work</td>
<td>Display Content</td>
<td>✓</td>
</tr>
<tr>
<td>2. Take advantage of Human &amp; Computer strengths</td>
<td>Display Style</td>
<td>✓</td>
</tr>
<tr>
<td>3. Provide Information, Not just Data / Put data in Context</td>
<td>Display Layout</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Use of Color</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Use of Symbols &amp; Process Connections</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Use of Text &amp; Numbers</td>
<td>✓</td>
</tr>
<tr>
<td>4. Make Job-related Tasks Efficient</td>
<td>Navigation</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td>Interaction with Displays</td>
<td>na</td>
</tr>
</tbody>
</table>
Scope of Work vs. Screen Use

- Typical ‘thinking’ when talking about graphics... single screen-single display thinking

Typical Console screen use

Supporting SA & Scope of Work

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The Display Hierarchy maps to console screen use to support Situation Awareness

- Support Proactive Monitoring with Level 1 displays that are always present
- Support Control, Troubleshooting, Proactive Panel rounds, with Level 2, 3 and 4 displays

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Impact of Colour Schemes

How many abnormal conditions exist in this process unit?

- emergency priority
- high priority
- low priority

The answer requires:

- perception to scan all of the elements on the display to discern which are alarms
- cognition to sum them versus normal shapes (levels)
- cognition to sum them
Most common form is dichromatism
- About 8 - 10% in males and up to 0.8% in females
- Lack the red-green colour vision channel (blue-yellow intact)

Dichromats

Green-Yellows & Yellow-Reds are confused
Saturated Greens & Reds are confused
Redundant Visual Coding of Alarms

- Presentation of alarm information is critical to the operator’s understanding of the underlying process disturbances and impacts.

(a) Use of shape, orientation and colour – less effective technique

(b) Coding of alarms with colour, text and shape – more effective technique
Potential Immediate HMI Improvements

- Integrated Trending
  - Dedicated overview trend screen
  - Automatic Detail trend

- Creation information hierarchy
  - Make important information **stand-out**

- Create display hierarchy
  - Include “at-a-glance” overview display

- On-screen navigation
  - Supports Situation Awareness mental model

- Educate Users & Display designers in human information processing
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Role for Alarms

- Good alarm systems signal the operator to intervene before:
  - **Significant escalation** from minor disturbances
  - Potentially dangerous **situations escalate** to plant trip or plant incident

- Alarms are necessary for Operators when:
  - **Workload** levels become **too high** to effectively monitor all points and conditions on their own
  - Attention is focused elsewhere
Common Problems with Alarms

- Standing Alarms
- Nuisance / Chattering Alarms
- Alarm Floods
- Alarm System Design
  - Multiple alarms for single event
Multiple Alarms for Single Action
“Belt and Suspenders”

✧ Potential Causes
  ➢ Alarms identified from HazOp or Engineering Design
  ➢ Alarms added following HazOp or incident reviews

✧ Potential Effects
  ➢ **Delayed** operator action
    • “I’ll wait for the next alarm”
  ➢ Alarm limits are set within normal operating region

✧ Leading Remedies
  ➢ Develop and apply Alarm Philosophy
    • One alarm for one action
  ➢ Alarm Rationalization
Alarm Improvement Planning

Goal:
- Minimize the size and frequency of alarm floods (principal requirement)
- Minimize the average alarm rate (secondary requirement)
- Provide consistent information and guidance to the operator on the potential consequence of an abnormal event and the time available to respond
- Have no negative impact to running plant

Multi-step approach
1. Benchmark Current Alarm Performance
2. Apply Immediate Improvements
3. Strategic Improvements
Step 1: Benchmarking

Main Activities:
- Review alarm philosophy
- Review DCS implementation
- Establish current alarm performance (normal and peak alarm rates)
  - Compare to industry metrics (average alarms, peak alarms, time in upset, etc.)
- Setup interim performance monitoring Reports
Step 2: Immediate Improvements

- Main Activities:
  - Apply “Alarm Tuning” settings to immediately reduce alarm rates:
    - On-Delay, Off-Delay, Alarm Deadbands, PV Filter
  - Setup weekly “Worst Actor” review meeting at the console
    - Address top 10 alarms from previous week
  - Use alarm benchmarking tools to track performance changes
  - Implement Low-stress alarm sounds (Patterson Protocol)
ASM Consortium study\(^1\) showed that application of alarm tuning can significantly reduce alarm rates.

<table>
<thead>
<tr>
<th></th>
<th>Plant B-1</th>
<th>Plant B-2</th>
<th>Plant D-1</th>
<th>Plant D-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ten min. peak reduction</td>
<td>62%</td>
<td>80%</td>
<td>25%</td>
<td>23%</td>
</tr>
<tr>
<td>Hourly peak reduction</td>
<td>34%</td>
<td>71%</td>
<td>16%</td>
<td>19%</td>
</tr>
<tr>
<td>Total original alarms</td>
<td>1320</td>
<td>4410</td>
<td>210</td>
<td>332</td>
</tr>
<tr>
<td>Total alarms after debounce</td>
<td>986</td>
<td>2185</td>
<td>180</td>
<td>275</td>
</tr>
</tbody>
</table>

Alarm Sounds
Today’s Typical Auditory DCS Alarms

- In multi-console control rooms, operators can have difficulty determining *whose console* is generating the alarm

- “Standard” alarms are **abrupt, often loud**
  - Can generate a startle-reaction and
  - Can contribute to heightened operator stress levels

- Continuous, loud, high-pitched sounds can **interrupt the operator’s ability**
  - To *communicate* with other people and
  - To maintain their *concentration*

- Example of a ‘out-of-the-box’ WAV file:  

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The **aviation industry** has developed a protocol for addressing many of these challenges (the Patterson Protocol)

- Uses multiple **acoustic properties**
  - To alert people to the **urgency** of the situation
  - To attract attention without being aversive to the individuals responding an abnormal or emergency situation
  - To easily identify the **console** with the alarm

**Example Alarm Sounds via Patterson Protocol**

- Priority: **Low**  **High**  **Urgent**

Step 3: Strategic Improvements

Main Activities:

- Alarm Rationalization
  - Preparation
  - Rationalization
  - Sign-off
  - Training
  - Implementation
- Implement dynamic alarming
  - Identified during rationalization and weekly worst actor reviews
Alarm Improvement Impact

Target: less than 1 alarm / 10 min (144 /day) per console
Potential Immediate Alarm Improvements

- Establish alarm performance benchmark
- Apply “Alarm Tuning” settings
  - On-Delay, Off-Delay, Alarm Deadbands, PV Filter
- Setup weekly “Worst Actor” review meeting at the console
- Use alarm benchmarking tools to track and report performance changes
- Implement Patterson’s alarm sounds
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- **Wrap-up**  
  - 16:40

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Work Environment

- The work environment enhances operations team situation awareness by supporting:
  - operator alertness
  - efficient work practices
  - collaborative interactions (including with other disciplines)
  - abnormal situation prevention and response.

- Solution Elements:
  - Collaboration between supervision, console and field
  - Lighting, Acoustics & Climate Ergonomics
Starting from the Console Chair

Devices:

- Video Monitors
- DCS Monitors
- Large Monitors
- Standard Keyboards
- Hardwired Alarms & Switches
- Radio, Phone & Intercom
- PC Workstation
- Desktop
- Task Lighting
- Team Meeting Table

Users Supported

- Primary Operator
- Secondary Operator
- Engineer or Technician
  - Plus Eng. Support Room

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Control Suite Design

HCI / Console Design – Viewing Angles

- Vertical View

- Horizontal View
Environmental Design – Lighting

- Ambient Light levels should be 400-600 lux to support visual acuity
  - Task lighting required when levels are below ~300-400 lux

- Challenge to Ambient Light Levels with Black or White Background Displays
  - Luminance Contrast causes eye strain & fatigue
  - Occurs when ambient light is high and background illumination is low or vice versa
Environmental Design – Acoustics

- Ambient noise levels should be ~50-55 dB
  - The three largest sources of ambient noise are typically
    - HVAC vibrations propagating through ductwork
    - Control room equipment fans
    - Plant equipment noise
- ‘High activity’ noise levels should be < 60 dB
- Abatement strategies
  - Sound-absorbing materials on surfaces
  - Remoting CPUs outside of the control room (also helps with Climate!)
  - Directional speakers for electronic ‘noise’
  - Effective arrangement of Consoles
- Console-specific alarm tones
Environmental Design – Climate

- As a guide, ‘comfortable’ means—
  - Temperature should be between 18.0 C and 22.0 C
  - Relative humidity from 40 percent to 65 percent
  - Airflow between 0.10 and 0.15 m/s

- Workplace environment controls should be adjustable at each console
  - Personal heaters, vented air, ...

- Ensure HVAC diffusers are not located directly above operator sitting positions
  - i.e., avoid uncomfortable drafts

- Control room & equipment rooms should be on separately controlled zones
Potential Immediate Control Room Improvements

- Provide adequate number of workstations and screens
- Address control room environmental issues to support situation awareness
  - sound levels
  - light levels
  - vibration
  - other
- Provide sit-stand console
- Setup field operator work area
- Manage/ minimize traffic flow around the console
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Texas City 2005 – Final Report

- “During the startup, operations personnel pumped flammable liquid hydrocarbons into the tower for over three hours without any liquid being removed, which was contrary to startup procedure instructions.”
- “Other key safety preparations listed in the startup procedures were omitted or ineffectively carried out.”
- “Starting, but then stopping, the unit was unusual and not covered in the startup procedures, which only addressed one continuous startup.”
- “In the previous five years, most of the 19 startups had deviated from written procedures.”
- “Management had allowed operators to make procedural changes without performing proper Management of Change (MOC) analysis, thereby encouraging operators to make unplanned (and potentially unsafe) deviations during startup”
- 15 Killed and 180 Injured


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Use and Maintenance of Procedures

- Key challenges with the use and maintenance of procedures:
  - High costs associated with the maintenance of procedures.
  - Ease of access to up-to-date procedures
  - Procedures tend to be used infrequently
  - Low compliance with policy in using and referencing procedures
“In addition to being readily available, procedures must be clear. ... If the user does not understand a procedure, or does not have confidence in its accuracy, the procedure will most likely not be used or it will be used incorrectly.”

Potential Immediate Procedure Improvements

- Setup industry specific Philosophy & “Style Guide”
  - Including procedure classification to build-in compliance
- Train Procedure Writers, Reviewers & Users
- Initial focus on Emergency / Startup / Shutdown procedures
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