Effective HMI Design for Safety-Instrumented Systems

Key Challenges and Requirements for Console Operator Situation Awareness

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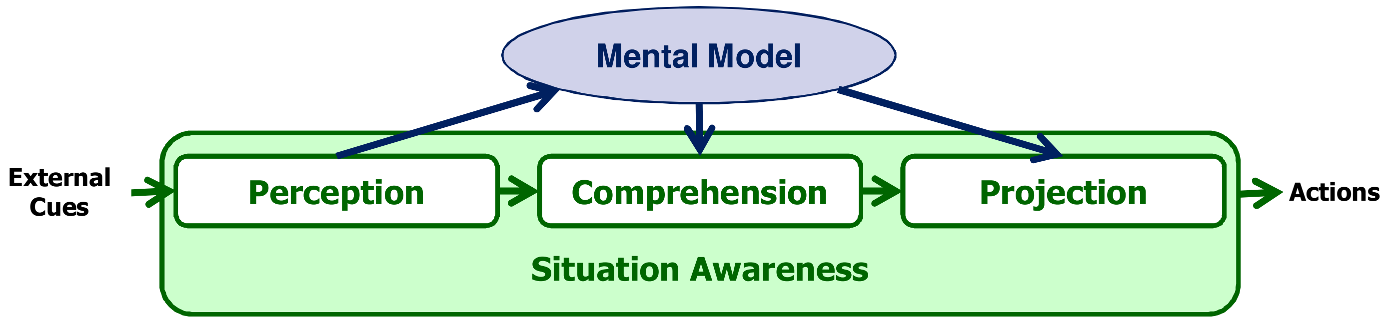
Presentation Outline

- Introduction & Project background
- Project Methodology
- HMI Requirements
- Gap Analysis
- Conclusions
- Questions / Discussion

What is Situation Awareness



- Put simply, Situation Awareness is "**knowing what is going on round you so you can figure out what to do**" (Adam, 1993)

- Research in military and civil aviation has identified that problems with situation awareness were the leading factor contributing to:
  - Military aviation mishaps (Hartel, Smith & Prince, 1991)
  - Accidents among major airlines (Endsley, 1995)

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*, *37*(*1*), 32-64.

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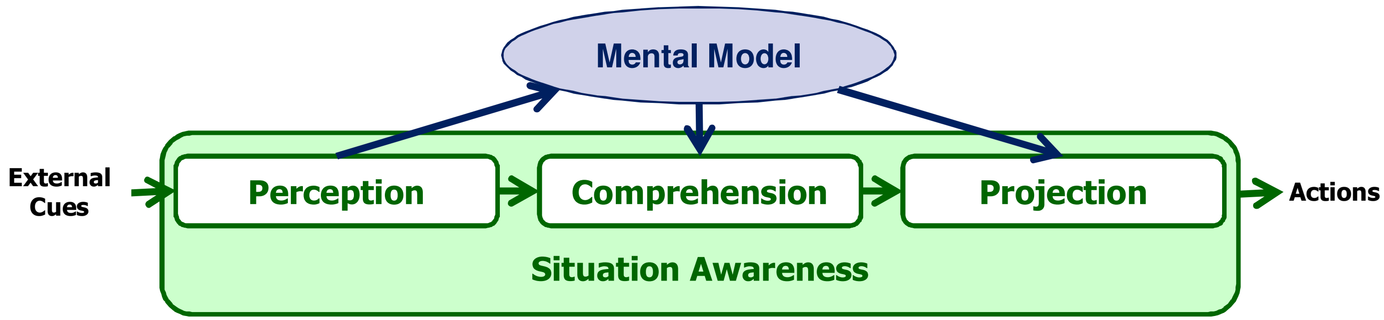

- **Level 1** SA = involves **perceiving** important information
  – Failure to perceive important information leads to the formation of an incorrect picture of what is going on
- **Level 2** SA = involves **comprehending** the perceived information with regard to specific job tasks and goals
  – Failure to accurately comprehend what is happening can lead to reasoning with an incomplete or inaccurate picture of what is actually happening
- **Level 3** SA = involves **projecting** where the situation is going
  – Failure to accurately predict what will happen can lead to initiating the wrong corrective actions

Project Motivation

- There is increasingly more extensive use of Safety-Instrumented Systems (SISs) in continuous process manufacturing plants
  - Greater challenge of presenting status and interrelations of the SIS elements on a day-to-day basis, in light of daily maintenance and production demands

- In particular, how to best support an operator's situation awareness of the SIS status and the risk profile in the light of maintenance overrides (MOs)
  - Daily decision-making activities for the operators in terms of
    - » how many MOs are in
    - » how many more MOs can be put in, both overall and in specific equipment areas
    - » what is the coverage of the changing protective envelope

Project Motivation

- Compounded by the common situation wherein the SIS and Distributed Control System (DCS) platforms are not seamlessly integrated
  - Neither physically or via the Console Operator’s Human-Machine Interface (HMI) itself
  - Increases the complexity of simultaneously interacting with both systems in the event of a SIS trip or alarm condition

Project Objective

- Develop understanding of key challenges & requirements for the Console Operator's HMI for both
  - DCS & SIS that impacts an operations team's ability to
    - » Operate within an expected safe envelope while faced with daily production and maintenance activities
    - » Maintain situation awareness of the associated changing risk profiles

Study Methodology

- The study was conducted as a Practices Assessment of four ASM operating member sites
  - 2 sites were located in North America
  - 2 sites were located in the UK

- Assessed
  - Operator-reported challenges
  - Operator-reported use requirements
  - Current DCS and SIS HMI design practices

- Structured Interview format with Operators and Engineers around defined Use Cases

Use Cases

- Operational Scenarios (based on modes of operation or operator activity) were the basis for operator requirements analysis
  - Start of Shift
  - Corrective Maintenance
  - System Testing
  - Respond to pre-trip alarm
  - Verify trip effects
  - Determine trip cause
  - Conduct process unit start-up

Artifacts Assessed

- Collected and assessed
  - DCS operating display examples for equipment with SIS applications
  - DCS HMI design for the operator console
    - Overview display use
    - Operating display practices
  - SIS HMI design for the operator console
  - Maintenance override policies, practices & procedures
  - Trip response policies, practices & procedures
  - Start-up & Permissive management polices, practices & procedures

HMI Interaction Requirements

- Example Requirements definition
  - **Use Case:** Respond to Pre-trip Alarm

Operator Task	Operator Activity	Interaction Requirements
Detect pre-trip active alarm	• Confirm detection of active pre-trip alarm	• Provide control to silence alarm audible and indication of alarm acknowledge status
	• Identify alarm as SIS pre-trip alarm	• Provide indication of #SIS pre-trip alarms, their location and excursion direction (hi/lo) • Provide indication in alarm description that parameter is pre-trip alarm
Evaluate pre-trip alarm	• Determine current PV associated with parameter relative to alarm threshold	• Provide indication as to whether parameter is deviating significantly from other parameters in the voting logic (if appropriate)
	• Determine whether real process disturbance of instrumentation problem • …	• Provide indication of trip threshold for parameter and voting logic (if appropriate) • Provide indication of effects associated with the parameter in alarm

Overview of Requirements by Scenario

	Number of :		
Use Scenario	**Operator Tasks**	**Task Activities**	**HMI Requirements**
Start of Shift	**2**	**4**	**6**
Corrective Maintenance	**3**	**7**	**21**
System Testing	**3**	**4**	**11**
Respond to Pre-trip Alarm	**2**	**7**	**9**
Verify Trip Effects	**2**	**5**	**7**
Determine Trip Cause	**2**	**3**	**7**
Conduct Process unit Start-up	**3**	**6**	**23**

- The number of unique HMI requirements = **43**

HMI Display Formats Observed

- Three basic types of HMI displays were analyze against the HMI requirements
  - DCS operating displays
  - SIS 'Logic' diagrams
  - SIS 'Cause-and-Effect' matrices

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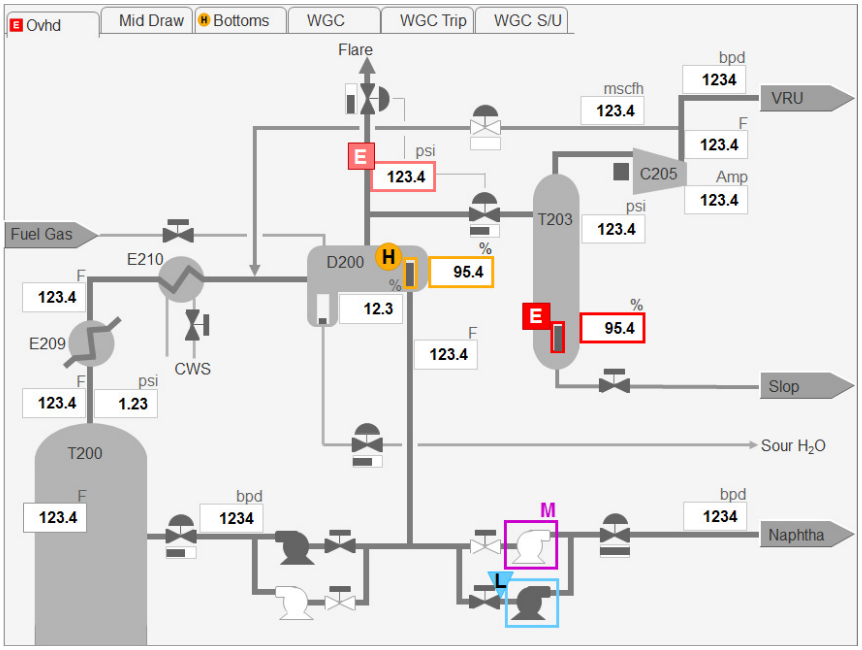

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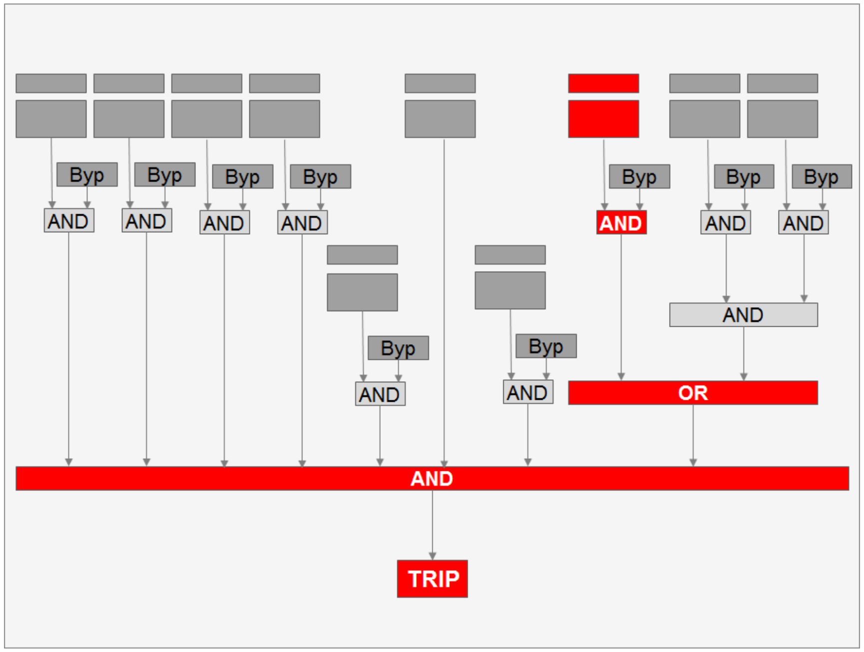

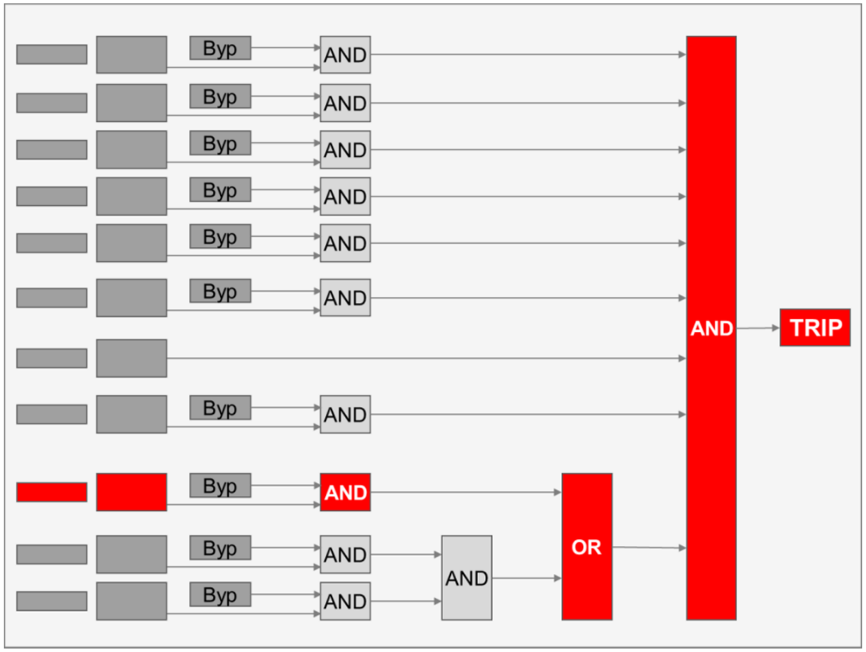

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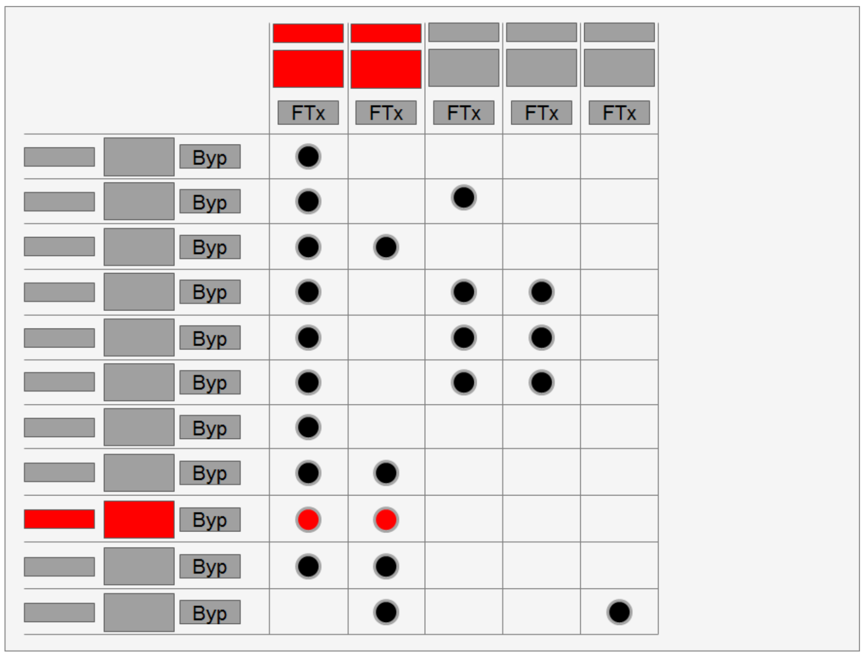

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- In terms of practices observed, the project identified
  - **32** design features for **HMI DCS displays**
  - **80** design features for **HMI SIS displays**
  - **3** design features for **Console-mounted hardware**

  Note: More than one feature is typically required to satisfy the Interaction Requirements presented above

Best Practices Observed

- Best Practices observed for DCS HMI displays
  - In "typical" Process Flow / Piping & Instrumentation diagram formats
    - » SIS Elements included
      - **Isolation / Shutdown valves**
      - Indication that there were SIS **measurements associated with a DCS measurement**
      - Indication that a regulatory control **valve received input from the SIS**
      - Indication that the **commanded state was not achieved** (e.g., fail-to-close)

- Best Practices observed for SIS HMI displays indicated
  - » **Pre-trip and Trip limit** values
  - » **Voting logic** (e.g., 1oo2, 2oo3)
  - » Dynamic voting **logic as result of a bypass** (e.g., 2oo3 → 1oo2)
  - » **Active Bypasses** & their impact on the potential safeguards
  - » **First Out indications** for Trip initiation
  - » **Command-disagree status** on Effects elements (e.g., fail to close, fail to start)

Best Practices Observed

- Best Practices observed for HMI Start-Up displays
  - Showing **start-up steps** in sequence
  - Showing **permissive status** for the respective step
  - Permitting **bypass activation**, if required for step

- Best Practices observed for Alarm System design
  - » **Deviation alarms** between redundant SIS measurements
  - » **Deviation alarms** between a DCS measurement and the associated SIS measurement(s)
  - » **Pre-trip alarms** on DCS measurements for associated SIS measurements
  - » Alarms for **command-disagree status** for SIS effects

Past & Current HMI Short-comings

- Integrated HMI System
  - **An overview of where the process is** within the SIS envelope and movement towards an SIS boundary not clearly evident to operator
  - **SIS instruments not easily identified** within DCS HMI system
  - Lack of **HMI consistency** (SIS integration into DCS environment)
  - Not showing **SIS startup up timers, trip limits and permissive logic** in DCS displays
  - Not **providing first out capture** in the SIS
  - Not **transferring first out capture** information to DCS
  - Not **providing shutdown flags to DCS to position control valves** on an SIS trip
  - **Poor HMI representation and navigation** for State transition Logic, Sequential function logic, Voting Logic
  - **Poor Trending capabilities** for SIS inputs—either because those inputs are not historized or no standard trend link/access from SIS faceplates
    - » e.g., Operator forced to enter whole path to trend parameters

Past & Current HMI Short-comings

- Alarm System design
  - Not setting up **deviation alarms** between SIS and matching DCS measurements
  - **Poor alarm rationalization** between DCS and SIS
    - Many redundant alarms on inputs and effects (e.g., DCS pre-trip, SIS pre-trip, trip, motor shutdown, …)
  - Failure to generate **command-disagree alarms** to notify operator that a Shutdown or Trip has not been completed successfully
    - e.g., Shutdown Compressor Vent valve did not Open when commanded to Open
  - Not **transferring** SIS Pre-Trip and Trip **limits** to the DCS

- Some Positives:
  - **Integration** of SIS and DCS through the DCS HMI
  - **Transition diagrams** of the SIS logic in DCS
  - Access to **voter blocks** etc. via DCS

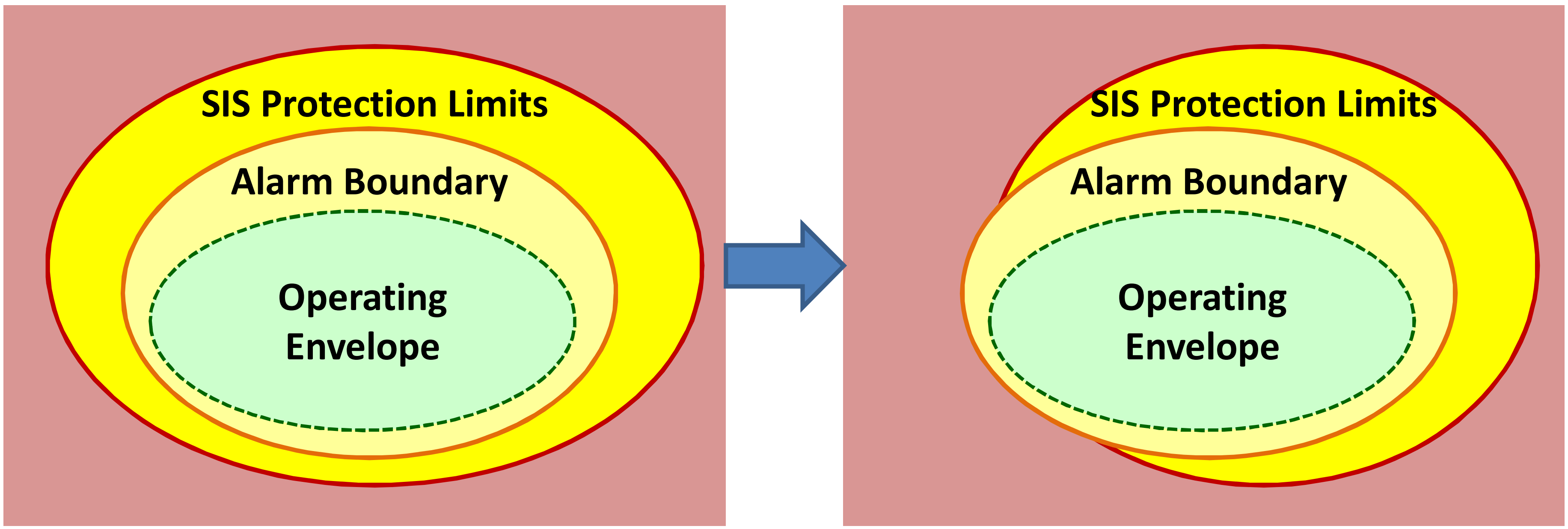
Task-Based Display Solution Required

- This research characterizes the value of identifying interaction requirements for supporting console operator use cases for different modes of operation to design HMIs that include SISs

- Moreover, an industry-typical HMI design format based on Cause-Effect matrices was demonstrated to typically address fewer of the requirements—only 37 of the 43—than a "Best Practice" Task-based layout designed explicitly for supporting operator decision-making and required actions
  - Emphasis needs to be added to non-Trip scenarios for the SIS lifecycle, such as maintenance, testing and start-up

Task-Based Display Solution Required

- Need for continued improvement of supporting "Big Picture" Situation Awareness of where and how close to the safety envelopes operators are working, particularly in the context of maintenance overrides / bypasses



Questions & Discussion

Please ask questions or offer comments

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Thank Your for Attending

- **Where to get more information**
  - ASM Consortium – www.asmconsortium.org

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