Human Performance Modeling for User Interface Evaluation in Plant Operations

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Estimation of Human Performance
- Accomplishment of a task by human operator.
  - Perceptual performance
  - Cognitive performance
  - Memory performance
  - Motion performance
- Estimation approaches.
  - Experimental approach
  - Subjective approach
  - Model-based approach

Research Framework

Knowledge Bases and Procedures
- Knowledge bases:
  - Variable information (VI-KB)
  - User interface information (UI-KB)
  - Alarm management (AM-KB)
  - Failure-symptom (FS-KB)
- Procedures:
  - Normal state monitoring (NSM)
  - Abnormal state supervising (ASS)

Currently, we focus on the UI evaluation during the course of fault detection and identification (FDI).
### Link Network in FS-KB

- **Failure causes layer**
- **Symptoms layer**

- \( AS_{i,j} = f(FL_i, SL_j) \)
- \( FL_i \): number of symptoms for the \( i \)th failure
- \( SL_j \): number of failure causes related to the \( j \)th symptom

### Abnormal State Supervising Procedure

- Obtain a symptom \( S_m \) from an alarm message according to the AM-KB.
- Find all suspect failure causes that are linked to \( S_m \) by the descending order of \( AS \).
- Reject or confirm the suspect failure causes sequentially by their corresponding symptom(s).
- Identify a failure cause whose total \( AS \) value exceeds a specified threshold.

### Analysis of Fault Detection and Identification (FDI) Task

- Decompose physical and mental tasks for FDI.
  - Perception subtask
  - Cognition subtask
  - STM subtask
  - LTM subtask
  - Physical subtask
  - Mental subtask

### Workload Estimation

- Workloads are estimated according to requirements of mental and physical subtasks.
- Based on the workload estimation of each subtask, the operator model totalizes workloads for several subtasks with one goal (a step in FDI track).
- All subtasks are recorded and an FDI track is produced after an evaluation scenario.
- Changes in workloads during the course of FDI are obtained.

### Evaluation Procedure

- Build the HMI model and UI-KB for the UI system.
- Build VI-KB, AM-KB, and FS-KB based on process and alarm system.
- Build ASS procedure according to the experiences of plant operations.
- Through FDI simulation, we can obtain the track of human behavior with changes in physical and mental workloads, and time until identifying a failure cause.
- Based on the FDI performance, evaluate the UIs including the alarm system and improve them if necessary.
- All above steps are repeated until an acceptable result is obtained.

### Case Study

- **Evaluation of:**
  - An overview panel
  - Alarm system
- Investigate FDI behavior by the operator model
Alarm Messages for Original UI System

<table>
<thead>
<tr>
<th>No.</th>
<th>Time</th>
<th>Elapsed time (sec.)</th>
<th>Item</th>
<th>Item description</th>
<th>Alarm</th>
<th>Alarm description</th>
<th>Item</th>
<th>Alarm description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12:31:44</td>
<td>317</td>
<td>F204</td>
<td>Air flow</td>
<td>LL</td>
<td>PV low-low alarm</td>
<td>A201</td>
<td>94</td>
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<td>2</td>
<td>12:29:58</td>
<td>211</td>
<td>F204</td>
<td>Air flow</td>
<td>LO</td>
<td>PV low alarm</td>
<td>A201</td>
<td>104</td>
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<tr>
<td>3</td>
<td>12:29:48</td>
<td>201</td>
<td>P203</td>
<td>Furnace pressure</td>
<td>LO</td>
<td>PV low alarm</td>
<td>A201</td>
<td>201</td>
</tr>
<tr>
<td>4</td>
<td>12:28:11</td>
<td>104</td>
<td>A201</td>
<td>Flue O₂</td>
<td>LL</td>
<td>PV low-low alarm</td>
<td>A201</td>
<td>317</td>
</tr>
<tr>
<td>5</td>
<td>12:28:01</td>
<td>94</td>
<td>A201</td>
<td>Flue O₂</td>
<td>LO</td>
<td>PV low alarm</td>
<td>A201</td>
<td>123</td>
</tr>
</tbody>
</table>

FS links for FDI from A201 Alarm

- Normal
  - $A_S = 0.097$
  - $A_S = 0.072$
  - $A_S = 0.068$
  - $A_S = 0.038$

- Turbine degradation (FL=21)
- Oil heater failure (FL=14)
- FOPs trip (FL=11)
- IDF trip (FL=7)

FDI Track for the Original UI System

- Switch to alarm summary panel
- Eliminate noisy & flash signal
- Switch to fuel supply panel
- Switch to ventilation panel
- Search VI - KB
- IDF icon
- Reject
- FOPs trip (AS=0.072) & rejection condition
- FOP icons
- Search VI - KB
- Confirm oil heater malfunction
- F202. PV
- Search VI - KB
- T204. PV
- Search VI - KB
- R034. CPV
- Search VI - KB
- P204. PV
- Search VI - KB
- F203. MV
- Search VI - KB
- F202. MV
- Search VI - KB
- F204. MV
- Search VI - KB
- F202. PV
- Search VI - KB

Problems and Solutions

- Important process variables A201 and A202 are not shown on the original overview panel.
- The first alarm does not have close relation with the actual failure cause.
- Switching between panels increases memory workload.
- Add A201.PV and A202.PV on overview panel.
- Supply shortcut buttons and area on overview panel.
- Modify alarm limitations for two process variables—burner-head pressure P204.PV and fuel temperature T204.PV.

Workload Graph

- Mental workload
- Physical workload

Workload Graph for the Original UI System

Modified Overview Panel
Alarm Messages

<table>
<thead>
<tr>
<th>No.</th>
<th>Time</th>
<th>Elapsed time (sec.)</th>
<th>Item</th>
<th>Alarm</th>
<th>Alarm description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8:47:51</td>
<td>202</td>
<td>P203</td>
<td>LO</td>
<td>PV low alarm</td>
</tr>
<tr>
<td>2</td>
<td>8:46:14</td>
<td>105</td>
<td>A201</td>
<td>LL</td>
<td>PV low-alarm</td>
</tr>
<tr>
<td>3</td>
<td>8:46:04</td>
<td>95</td>
<td>A201</td>
<td>LO</td>
<td>PV low alarm</td>
</tr>
<tr>
<td>4</td>
<td>8:44:42</td>
<td>13</td>
<td>T204</td>
<td>LO</td>
<td>PV low alarm</td>
</tr>
<tr>
<td>5</td>
<td>8:44:36</td>
<td>7</td>
<td>P204</td>
<td>HI</td>
<td>PV high alarm</td>
</tr>
</tbody>
</table>

FS Links for FDI from P204 Alarm

<table>
<thead>
<tr>
<th>No.</th>
<th>Time</th>
<th>Elapsed time (sec.)</th>
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<th>Alarm</th>
<th>Alarm description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8:47:51</td>
<td>202</td>
<td>P204</td>
<td>LO</td>
<td>PV low alarm</td>
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<td>A201</td>
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<td>A201</td>
<td>LO</td>
<td>PV low alarm</td>
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<tr>
<td>4</td>
<td>8:44:42</td>
<td>13</td>
<td>T204</td>
<td>LO</td>
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<td>HI</td>
<td>PV high alarm</td>
</tr>
</tbody>
</table>

FDI Track for the Modified UI System

Comparison of Workload Graphs

Conclusions

- A human-machine system framework is proposed to evaluate human performances in an emergency.
- In a preliminary case study, the FDI track is shortened, and workloads decrease after the evaluation and improvement based on the operator model.
- The case study shows its usefulness to support the design and evaluation of user interfaces in plant operations.

Future Work

- Investigate more case studies.
- Improve the workloads estimation.
- Implement attention resource allocation.
- Improve the fidelity of human model by experiments.