PERFORMANCE OF CONTROL ROOM OPERATORS IN ALARM MANAGEMENT

Craig M. Harvey, Ph.D., P.E.
Dileep Buddaraju, MS student

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We’re All Humans So We Know Human Factors? Or Do We?

Let’s look at an example screen mockup
Let’s Turn to Alarm Systems
Regulations

- 49 CFR Parts 192 and 195 - Pipeline Safety: Control Room Management/ Human Factors
  - Alarm management – Each operator must have written alarm management plan to provide effective controller response to alarms.

- So question is what alarm rate with regulators use to consider you are in compliance?
Industry Requirements

- EEMUA standards:
  - An operator can handle 1 or 2 alarms per ten minutes efficiently
  - Can anyone meet that standard?

- Improvements needed in alarm management
  - Reduce nuisance alarms
  - Guide the operator in making decision
  - Introduce automation
  - Operator input when designing alarm systems
  - Alarm prioritization process
  - Alarm presentation design
Objectives

- Evaluate different alarm rates and its impact on the operator performance (response time, accuracy of response, acknowledge time).
- Determine the effect of alarms displayed in categorical and chronological alarm displays on the operator's performance.
- Compare Operators to LSU Students
## Participating Company Types

<table>
<thead>
<tr>
<th>Company</th>
<th># Operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline 1</td>
<td>10</td>
</tr>
<tr>
<td>Refinery 1</td>
<td>5</td>
</tr>
<tr>
<td>Pipeline 2</td>
<td>5</td>
</tr>
<tr>
<td>Pipeline 3</td>
<td>3</td>
</tr>
<tr>
<td>Refinery 2</td>
<td>2</td>
</tr>
</tbody>
</table>

Operators participated – 25
Excluded 2 operators data due to outlining data.
Experimental Method

- A demographic survey information was collected before starting the proceedings.
- All participants were trained about the steps to be taken and the navigation through the simulation before starting the experiments.
- Operators were given time to understand the simulation by giving them a demo and a practice experiment.
- Experiments were not started until the operators felt comfortable with the simulation.
Experimental Method

- All 6 experiments were randomized and tested on the operators.
- All operators were tested in the morning shift (from 6 AM). Small breaks were taken by the operators in between the experiments.
- After the experiments, a questionnaire was given to the operators asking for their feedback on the simulation.
Experiment Variables

- Independent Variables
  - Alarm rates
  - Alarm window

- Dependent Variables
  - Response time
  - Accuracy of response
  - Acknowledge Time
# Alarm Rates Tested

<table>
<thead>
<tr>
<th>Categorical display</th>
<th>Chronological display</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 per 10 minutes</td>
<td>15 per 10 minutes</td>
</tr>
<tr>
<td>20 per 10 minutes</td>
<td>20 per 10 minutes</td>
</tr>
<tr>
<td>25 per 10 minutes</td>
<td>25 per 10 minutes</td>
</tr>
<tr>
<td>30 per 10 minutes</td>
<td></td>
</tr>
</tbody>
</table>
Alarm Distribution

- Alarms were balanced to across different alarm rates to keep workload consistent.
Pipeline Overview
2nd Pipeline
Station Overview
Dehydrator
Tank Farm Downstream
Categorical Alarm Display

<table>
<thead>
<tr>
<th>Time/Date</th>
<th>Description</th>
<th>Event Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:39:48 AM</td>
<td>LEAK IN RIGLINE STATION 4</td>
<td>10:39:48 AM</td>
</tr>
<tr>
<td>10:39:48 AM</td>
<td>LEAK IN RIGLINE STATION 2</td>
<td>10:39:48 AM</td>
</tr>
<tr>
<td>10:39:48 AM</td>
<td>LEAK IN RIGLINE STATION 10</td>
<td>10:39:48 AM</td>
</tr>
<tr>
<td>10:39:48 AM</td>
<td>LEAK IN PLATFORM LINE STATION 3</td>
<td>10:39:48 AM</td>
</tr>
<tr>
<td>10:39:48 AM</td>
<td>LEAK IN PLATFORM LINE STATION 8</td>
<td>10:39:48 AM</td>
</tr>
<tr>
<td>10:39:48 AM</td>
<td>LEAK IN PLATFORM LINE TANKFARM 1.1</td>
<td>10:39:48 AM</td>
</tr>
<tr>
<td>10:39:48 AM</td>
<td>RIG LINE STATION 8 AT PUMP 45, &quot;POWER TRIP&quot;</td>
<td>10:39:48 AM</td>
</tr>
<tr>
<td>10:39:48 AM</td>
<td>PLATFORM LINE STATION 2 AT PUMP 5, &quot;POWER TRIP&quot;</td>
<td>10:39:48 AM</td>
</tr>
<tr>
<td>10:39:48 AM</td>
<td>PLATFORM LINE STATION 7 AT PUMP 12, &quot;POWER TRIP&quot;</td>
<td>10:39:48 AM</td>
</tr>
<tr>
<td>10:39:48 AM</td>
<td>PLATFORM LINE STATION 1 AT PUMP 2, &quot;POWER TRIP&quot;</td>
<td>10:39:48 AM</td>
</tr>
</tbody>
</table>

Clock: 001:00:33
# Chronological Alarm Display

<table>
<thead>
<tr>
<th>Time/Date</th>
<th>Description</th>
<th>Event Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:00:24 AM</td>
<td>PLATFORM LINE STATION 2 AT PUMP 5, &quot;BYPASS VALVE MALFUNCTION&quot;</td>
<td>11:00:24 AM</td>
</tr>
<tr>
<td>10:58:18 AM</td>
<td>RIG LINE STATION 1 AT PUMP 29, &quot;POWER Trip&quot;</td>
<td>10:58:18 AM</td>
</tr>
<tr>
<td>10:57:48 AM</td>
<td>PLATFORM LINE STATION 10 AT PUMP 25, &quot;POWER Trip&quot;</td>
<td>10:57:48 AM</td>
</tr>
<tr>
<td>10:57:34 AM</td>
<td>RIG LINE STATION 9 AT PUMP 49, &quot;BYPASS VALVE MALFUNCTION&quot;</td>
<td>10:57:34 AM</td>
</tr>
<tr>
<td>10:58:56 AM</td>
<td>RIG LINE STATION 4 AT PUMP 36, &quot;DISCHARGE VALVE MALFUNCTION&quot;</td>
<td>10:58:56 AM</td>
</tr>
<tr>
<td>10:58:53 AM</td>
<td>PLATFORM LINE STATION 16 AT PUMP 25, &quot;SUCTION VALVE MALFUNCTION&quot;</td>
<td>10:58:53 AM</td>
</tr>
<tr>
<td>10:56:33 AM</td>
<td>RIG LINE DEHYDRATOR AT PUMP 66, &quot;DISCHARGE VALVE MALFUNCTION&quot;</td>
<td>10:56:33 AM</td>
</tr>
<tr>
<td>10:56:26 AM</td>
<td>PLATFORM LINE STATION 2 AT PUMP 5, &quot;SUCTION VALVE MALFUNCTION&quot;</td>
<td>10:56:26 AM</td>
</tr>
<tr>
<td>10:56:21 AM</td>
<td>LEAK IN RIGLINE STATION 4</td>
<td>10:56:21 AM</td>
</tr>
<tr>
<td>10:55:03 AM</td>
<td>RIG LINE STATION 1 AT PUMP 28, &quot;POWER Trip&quot;</td>
<td>10:55:03 AM</td>
</tr>
<tr>
<td>10:55:26 AM</td>
<td>RIG LINE STATION 4 AT PUMP 37, &quot;SUCTION VALVE MALFUNCTION&quot;</td>
<td>10:55:26 AM</td>
</tr>
<tr>
<td>10:54:14 AM</td>
<td>PLATFORM LINE STATION 6 AT PUMP 14, &quot;SUCTION VALVE MALFUNCTION&quot;</td>
<td>10:54:14 AM</td>
</tr>
<tr>
<td>10:54:06 AM</td>
<td>PLATFORM LINE STATION 8 AT PUMP 19, &quot;DISCHARGE VALVE MALFUNCTION&quot;</td>
<td>10:54:06 AM</td>
</tr>
<tr>
<td>10:54:00 AM</td>
<td>PLATFORM LINE STATION 8 AT PUMP 20, &quot;DISCHARGE VALVE MALFUNCTION&quot;</td>
<td>10:54:00 AM</td>
</tr>
<tr>
<td>10:53:56 AM</td>
<td>PLATFORM LINE STATION 5 AT PUMP 13, &quot;BYPASS VALVE MALFUNCTION&quot;</td>
<td>10:53:56 AM</td>
</tr>
<tr>
<td>10:53:48 AM</td>
<td>RIG LINE STATION 9 AT PUMP 47, &quot;SUCTION VALVE MALFUNCTION&quot;</td>
<td>10:53:48 AM</td>
</tr>
<tr>
<td>10:53:26 AM</td>
<td>RIG LINE STATION 8 AT PUMP 49, &quot;SUCTION VALVE MALFUNCTION&quot;</td>
<td>10:53:26 AM</td>
</tr>
<tr>
<td>10:53:03 AM</td>
<td>PLATFORM LINE STATION 2 AT PUMP 5, &quot;POWER Trip&quot;</td>
<td>10:53:03 AM</td>
</tr>
<tr>
<td>10:52:09 AM</td>
<td>PLATFORM LINE STATION 1 AT PUMP 2, &quot;POWER Trip&quot;</td>
<td>10:52:09 AM</td>
</tr>
<tr>
<td>10:51:17 AM</td>
<td>PLATFORM LINE STATION 9 AT PUMP 22, &quot;BYPASS VALVE MALFUNCTION&quot;</td>
<td>10:51:17 AM</td>
</tr>
<tr>
<td>10:50:57 AM</td>
<td>PLATFORM LINE STATION 1 AT PUMP 1, &quot;DISCHARGE VALVE MALFUNCTION&quot;</td>
<td>10:50:57 AM</td>
</tr>
<tr>
<td>10:50:51 AM</td>
<td>RIG LINE STATION 8 AT PUMP 45, &quot;SUCTION VALVE MALFUNCTION&quot;</td>
<td>10:50:51 AM</td>
</tr>
<tr>
<td>10:50:41 AM</td>
<td>RIG LINE STATION 8 AT PUMP 49, &quot;SUCTION VALVE MALFUNCTION&quot;</td>
<td>10:50:41 AM</td>
</tr>
<tr>
<td>10:49:46 AM</td>
<td>RIG LINE STATION 4 AT PUMP 36, &quot;BYPASS VALVE MALFUNCTION&quot;</td>
<td>10:49:46 AM</td>
</tr>
<tr>
<td>10:49:16 AM</td>
<td>RIG LINE TANK/FARM 2 AT PUMP 36, &quot;SUCTION VALVE MALFUNCTION&quot;</td>
<td>10:49:16 AM</td>
</tr>
<tr>
<td>10:49:16 AM</td>
<td>PLATFORM LINE STATION 6 AT PUMP 16, &quot;DISCHARGE VALVE MALFUNCTION&quot;</td>
<td>10:49:16 AM</td>
</tr>
</tbody>
</table>

**Alarm Controls:**
- Ack Selected
- Ack Displayed
- Ack ALL

**Time:** 00:14:49
Hypothesis 1: Accuracy

- **Hypothesis 1:** Differences exist in participant accuracy of response. \((H_0: \text{no difference}, \ H_1: \text{not equal})\)
- One way ANOVA test was completed using a 0.05 level of significance.
- Can’t conclude that there is difference between the groups \((p>0.05)\)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display-Rate</td>
<td>5</td>
<td>0.004577</td>
<td>0.000915</td>
<td>0.5270</td>
<td>0.7560</td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td>18390</td>
<td>31.939759</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td></td>
<td>18395</td>
<td>31.944336</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Hypothesis 1: Accuracy

- No significant difference in operator accuracy found with the increase in the alarm rates.

- Possible reason: complexity of the simulation and the operators tasks designed were simple compared to what they were used to in real world scenario.
Hypothesis 2: Response Time

- Hypothesis 2: There will be increase in participant response times with alarms displayed in chronological than categorical display. (H0: no difference, H1: not equal)

- ANOVA Results:
Hypothesis 2: Display Type

- Tukey’s mean test

<table>
<thead>
<tr>
<th>Level</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1_25</td>
<td>21.791222</td>
</tr>
<tr>
<td>2_25</td>
<td>21.720513</td>
</tr>
<tr>
<td>2_20</td>
<td>20.658811</td>
</tr>
<tr>
<td>1_20</td>
<td>20.386734</td>
</tr>
</tbody>
</table>

- Compared alarm rates 20, 25 as they were tested in both the alarm displays.
- Results show that statistically there are no differences in operator performance between displays, but the means were slightly better in categorical display for higher alarm rate (25)
Hypothesis 3: Alarm Rates/Display Type Combined

- Hypothesis 3: Operator response time will change with increased alarm rates. (H0: no difference, H1: not equal)
- Results of an ANOVA test for differences in participant response time.

![Analysis of Variance Table]

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display-Rate</td>
<td>5</td>
<td>80236</td>
<td>16047.3</td>
<td>18.3135</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>18</td>
<td>16114315</td>
<td>876.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td>18</td>
<td>16194551</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Hypothesis 3: Alarm Rates

- **Tukey’s mean test**

  - With increase in alarm rate the mean response time was significantly different.
  - As the alarm rates increased, operators response time to low priority alarm rates increased slightly as they spend more time to solve high priority alarms.

<table>
<thead>
<tr>
<th>Level</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>A 25.451819</td>
</tr>
<tr>
<td>125</td>
<td>B 21.791222</td>
</tr>
<tr>
<td>225</td>
<td>B 21.720513</td>
</tr>
<tr>
<td>220</td>
<td>B C 20.648531</td>
</tr>
<tr>
<td>120</td>
<td>B C 20.386734</td>
</tr>
<tr>
<td>215</td>
<td>C 18.932269</td>
</tr>
</tbody>
</table>
Response Time by Alarm Rate

Response Time in Seconds

Alarm Rate

Categorical Display
Chronological Display
Response Time by Alarm Priority

![Bar Chart]

- **Response Time Priority Wise**

- **Display Type - Alarm Rate**:
  - 1_20
  - 1_25
  - 1_50
  - 2_15
  - 2_20
  - 2_25

- **Priority Levels**:
  - Low
  - Medium
  - High
Response Time by Age

- 12 Operators - <= 40
- 11 Operators - > 40
Acknowledge Time Results

Average Acknowledge Time

1 Categorical
2 Chronological
Operators overwhelmingly preferred the categorical display.

Those that preferred the chronological stated found it easier to handled high frequency (low) alarms easier with this display.

![Alarm Display Preference Chart]

- **Categorical**: 20 (80%)
- **Chronological**: 5 (20%)
Operators Comments on the Simulation

- Operators liked the colors used in the simulation due to less eye strain.
- Recognized higher alarm rates as compared to lower alarm rates.
- Most of the operators/supervisors liked the categorical display.
Limitations for this Project

- Simulation complexity
- Shift hours were only daytime and short time period (6-7 hours)
- 25 male operators
Student v. Operator Analysis

- Student data used from first alarm studies conducted in 2009
- Operator data collected during 2010-2011 alarm study

![Diagram showing dependent and independent variables]

- **Dependent Variables**
  - Alarm Rates: 10 and 20 alarms per 10 minutes
  - Alarm Windows: Categorical and Chronological Display

- **Independent Variables**
  - Operator Performance:
    - Time Taken to Acknowledge Each Alarm
    - Response time to initiate corrective action
    - Fraction of Abnormal Situations Successfully Dealt With
    - Accuracy of Response
## Reaction Time (RT) Results

### Fixed Effect Tests

<table>
<thead>
<tr>
<th>Source</th>
<th>Nparm</th>
<th>DF</th>
<th>DFDen</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student(S)/Operator (O)</td>
<td>1</td>
<td>1</td>
<td>170.6</td>
<td>8.9883</td>
<td>0.0031*</td>
</tr>
<tr>
<td>Alarm Rate</td>
<td>1</td>
<td>1</td>
<td>154.6</td>
<td>23.5202</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Student(S)/Operator (O)*Alarm Rate</td>
<td>1</td>
<td>1</td>
<td>154.6</td>
<td>4.6785</td>
<td>0.0321*</td>
</tr>
<tr>
<td>Cat.(2)/Chron(1)</td>
<td>1</td>
<td>1</td>
<td>192.4</td>
<td>4.5963</td>
<td>0.0333*</td>
</tr>
<tr>
<td>Student(S)/Operator (O)*Cat.(2)/Chron(1)</td>
<td>1</td>
<td>1</td>
<td>192.4</td>
<td>0.2371</td>
<td>0.6269</td>
</tr>
<tr>
<td>Alarm Rate*Cat.(2)/Chron(1)</td>
<td>1</td>
<td>1</td>
<td>154.6</td>
<td>1.7920</td>
<td>0.1826</td>
</tr>
<tr>
<td>Student(S)/Operator (O)<em>Alarm Rate</em>Cat.(2)/Chron(1)</td>
<td>1</td>
<td>1</td>
<td>154.6</td>
<td>0.1605</td>
<td>0.6893</td>
</tr>
</tbody>
</table>

*p ≤ 0.05 – Significant Items*
### RT - Alarm Rates v. Student/Operator

<table>
<thead>
<tr>
<th>Level</th>
<th>Least Sq Mean (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student,20</td>
<td>93.016354</td>
</tr>
<tr>
<td>Operator,20</td>
<td>47.676607</td>
</tr>
<tr>
<td>Student,10</td>
<td>31.785469</td>
</tr>
<tr>
<td>Operator,10</td>
<td>24.217462</td>
</tr>
</tbody>
</table>

- Students and Operators reaction time for solving an alarm can not be distinguished from one another except at the alarm rate of 20 alarms per 10 minutes
- Students performed significantly slower than operators at 20 alarms per 10 minutes
RT – Categorical v. Chronological Displays

<table>
<thead>
<tr>
<th>Level</th>
<th>Least Sq Mean (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronological (1)</td>
<td>A 58.611384</td>
</tr>
<tr>
<td>Categorical (2)</td>
<td>B 39.736562</td>
</tr>
</tbody>
</table>

Categorical display reaction time was significantly quicker than Chronological display for solving an alarm.
## Acknowledgement Time (AT) Results

### Fixed Effect Tests

<table>
<thead>
<tr>
<th>Source</th>
<th>Nparm</th>
<th>DF</th>
<th>DFDen</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student(S)/Operator (O)</td>
<td>1</td>
<td>1</td>
<td>160.2</td>
<td>0.7331</td>
<td>0.3932</td>
</tr>
<tr>
<td><strong>Alarm Rate</strong></td>
<td>1</td>
<td>1</td>
<td>148.9</td>
<td>17.1171</td>
<td><strong>&lt;.0001</strong>*</td>
</tr>
<tr>
<td>Student(S)/Operator (O)*Alarm Rate</td>
<td>1</td>
<td>1</td>
<td>148.9</td>
<td>2.7399</td>
<td>0.1000</td>
</tr>
<tr>
<td><strong>Cat.(2)/Chron(1)</strong></td>
<td>1</td>
<td>1</td>
<td>180.2</td>
<td>8.6734</td>
<td><strong>0.0037</strong>*</td>
</tr>
<tr>
<td>Student(S)/Operator (O)*Cat.(2)/Chron(1)</td>
<td>1</td>
<td>1</td>
<td>180.2</td>
<td>0.3802</td>
<td>0.5383</td>
</tr>
<tr>
<td>Alarm Rate*Cat.(2)/Chron(1)</td>
<td>1</td>
<td>1</td>
<td>148.9</td>
<td>2.4676</td>
<td>0.1183</td>
</tr>
<tr>
<td>Student(S)/Operator (O)<em>Alarm Rate</em>Cat.(2)/Chron(1)</td>
<td>1</td>
<td>1</td>
<td>148.9</td>
<td>0.3674</td>
<td>0.5454</td>
</tr>
</tbody>
</table>

*p ≤ 0.05 – Significant Items*
## AT – Alarm Rates

<table>
<thead>
<tr>
<th>Level</th>
<th>Least Sq Mean (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 in 10 minutes</td>
<td>A 84.093530</td>
</tr>
<tr>
<td>10 in 10 minutes</td>
<td>B 37.423023</td>
</tr>
</tbody>
</table>

Users acknowledged alarms for the 10 alarms in 10 minutes rate significantly quicker than 20 alarms in 10 minutes.
Categorical display alarms were acknowledged significantly quicker than Chronological displayed alarms.
Students v. Operators Conclusions

- Operators perform better than students at higher alarm rates.
- The Categorical display performed better than the Chronological display regardless of the user.
Overall Research Limitations

- Constrained experiments by alarm rate driven from EEMUA
- Simple Systems compared to real world systems
Future Research

- Alarm Management
  - Time pressure
  - Female operators participation
  - Simulation complexity
  - Shift length
  - Shift hours

- Human fatigue
  - Regulation: Fatigue mitigation – Implement methods to reduce risk associated with controller fatigue.
  - PhD Student working on
    - Fatigue Readiness to Perform
    - Eye Tracking to measure fatigue for operators
    - Handheld worn tools to measure circadian rhythm
  - Recent FAA events will cause DOT to explore further

- Shift Change

- Operator Selection/Performance
Outcomes

- Current Publications

- Working Publications
  - Journal article on student study work in draft form to be submitted this summer
  - Journal article on operator work being created for submission this summer.