Supervisory Control and Data Acquisition in Liquid Pipelines
Study Data Collection

- Accident review
- OPS data review
- Regulation review
- New data
  - Survey
  - Site visits
Accident Review

• Issues identified in these accidents
  – Critical events not alarmed
  – Significance of alarms not recognized
  – SCADA display not accurate
  – SCADA tool selection
  – Alarm formatting and frequency
  – Controller fatigue
  – Controller training
OPS Accident Data Review

- Examined data from 2002-2004
- SCADA/LDS detected leaks more quickly than other methods
- These leaks caused release of 4,000,000 gallons of product (59% of all product spilled)
• SCADA not mentioned in the regulations
• Regulations do address some aspects of SCADA
  – OPS training & SCADA guide
• Advisory bulletins on SCADA systems
SCADA Survey

- 67-item survey
- Survey sent to 91 control centers that control 169 pipelines
- Response rate was 87%
- Showed that 92% of companies use SCADA to control pipeline
### Varieties of SCADA Systems

- Accol 5.12
- Cimplicity Plant Edition V6
- DATAP
- Evolution Scada Veri 4.1
- FactoryLink 7.0
- FactorySuite 2000
- Fisher ROC
- FoxSCADA Rev 5.6.1.4
- Honeywell
- Honeywell Tdc-3000
- Hydril
- Intellution Fix Ver. 6.15, 6.1(2)
- Intouch 7.11
- Iris 76000
- Lookout
- Mini-Mast
- Modicon Plc/Plds
- MOSCAD Version 6.0

- Oasys 5.0, 5.2(8), 5.2.2(4), 6.0, 6.2(2)
- Open Vector- 3.62, 4.11 (2), 4.1.1, 4.2
- PlantScape
- PROCYS
- Process Window 2.35
- RealFlex 1.22, 4.2e1
- Rockwell RSView 32
- RS Logix V
- S/3 SCADA 4.11 [5.1]
- Series VII
- SetCom
- Telvent 5.2, 6.0.6.3
- TSS SCADA
- UCOS Version 3436.3
- US Data FactoryLink Ver3.02a
- Vector 3.6-2
- Wonderware (Intouch) 5.1b, 7.0, 7.1, 7.11, 7.2, 8.0(2), 2000
- X-MidSHIPS Version 4.1
<table>
<thead>
<tr>
<th>Percentage</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>92%</td>
<td>Remote valve operations</td>
</tr>
<tr>
<td>87%</td>
<td>Operating data acquisition</td>
</tr>
<tr>
<td>85%</td>
<td>Trends</td>
</tr>
<tr>
<td>65%</td>
<td>Basic volume balance</td>
</tr>
<tr>
<td>61%</td>
<td>Product level tracking</td>
</tr>
<tr>
<td>59%</td>
<td>Leak detection/computational pipeline monitoring systems</td>
</tr>
<tr>
<td>50%</td>
<td>Batch tracking</td>
</tr>
</tbody>
</table>
Control Center Site Visits

• 12 liquid pipeline control centers
• Variety of SCADA systems in use, commodity, and size of pipeline
• Visit was 1-2 days
• Interviewed a total of 69 persons
• Average experience 4.7 years
  – Controllers 7 years
  – SCADA manager 4 years
SCADA Personnel Interviewed

- Controllers (senior and junior)
- Shift supervisor
- SCADA manager
- SCADA technician
- Training manager
- Safety officer
Information Collected in Interviews

- Company background (history)
- Screen and alarm design
- SCADA system review
- Workstation design
- Personnel
- Controller training
- Work shift scheduling
Safety Issues

• SCADA issues
  – Graphic design
  – Alarm management
  – Leak detection

• Controller issues
  – Fatigue
  – Training
SCADA Related Issues

- Graphic design
- Alarm management
- Leak detection
SCADA Systems Basic

Control Commands
Valves, Pumps

Pipeline DATA
Pressure, Flow
SCADA Systems Large Center
SCADA System Small Center
SCADA Related Issues

- Graphic Design
- Alarm Management
- Leak Detection
Graphics Issues

- Screen clutter
- Color usage
- Number of colors
- Color-blind friendly screens
Screen Clutter
Color-Blind Accommodations
Previous Accident: Graphics

- Brenham, Texas
  - Using tabular piping display
  - Graphical display would have improved detection
  - Recommendation for graphical standards
    - P-92-22, Open—Acceptable Action
    - API developing recommended practice
Most companies do not review screens

- Yes: 36%
- No: 64%
Graphics Design Summary

- Accidents show the need to present data clearly
- Companies do not use standards to develop screens
- API currently working on a recommended practice
- OPS support of the recommended practice will improve graphics in the pipeline industry
SCADA Issues

- Graphic Design
- Alarm Management
- Leak Detection
Controllers on Alarms

• Alarm system the most important SCADA safety feature
• Too many alarms and nuisance alarms, sometimes more than 100 alarms in an hour
### SCADA Alarm Screen

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Group</th>
<th>Alarm Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/03/03 17:12:15</td>
<td>KENO_COLM 14</td>
<td>Columbus W NWB: BatchID/Valve Error - Meter 1 - Grade: Change to state CONFIG ERR</td>
</tr>
<tr>
<td>11/03/03 17:12:15</td>
<td>KENO_COLM 14</td>
<td>Columbus E NWB: BatchID/Valve Error - Meter 5 - Grade: Change to state CONFIG ERR</td>
</tr>
<tr>
<td>11/04/03 09:38:38</td>
<td>WABASH 12</td>
<td>Robinson_Wabash: Control Valve Percent Open - Valve 338: Value=83 PCT - analog device</td>
</tr>
<tr>
<td>11/04/03 09:38:31</td>
<td>WDRM_CLMT_10</td>
<td>Robinson_Wabash: Meter 2 Head A: Change to state INACTIVE.</td>
</tr>
<tr>
<td>11/04/03 09:38:31</td>
<td>WDRM_PATH_22</td>
<td>Wood River - Patoka: CPM - ALARM - 24hr (-0.69%)</td>
</tr>
<tr>
<td>11/04/03 09:07:57</td>
<td>SFWD_12</td>
<td>West_Delta_79A: Discharge Pressure: Value=127 PSI - analog LOW-LOW.</td>
</tr>
<tr>
<td>11/04/03 08:53:12</td>
<td>ESPAR_ALL</td>
<td>East_Sparta: Valve Control Disabled: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 08:52:34</td>
<td>SFWD_12</td>
<td>WD_Receiving: Control Valve Failure - Plains: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 08:47:51</td>
<td>BELL 4</td>
<td>Bellevue: Manifold Relief System High Nitrogen: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 08:39:06</td>
<td>SAMA_DET_16</td>
<td>Samaria: Tank 709 Safe Fill: Change to state LOW.</td>
</tr>
<tr>
<td>11/04/03 08:28:08</td>
<td>SFWD_12</td>
<td>WD_Receiving: Meter 3 Temperature Transmitter Failure: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 08:11:02</td>
<td>WDRM_CLMT_10</td>
<td>Catlin: Shutdown Unit 1: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 07:57:10</td>
<td>WDRM_CLMT_10</td>
<td>Catlin: Lockout Unit 1: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 06:00:01</td>
<td>RIO 8</td>
<td>Lima_RIO: Phase Failure: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 05:56:20</td>
<td>RIO 8</td>
<td>Lima_RIO: Meter 3 Flow Rate: Value=267.205 BPH - analog LOW.</td>
</tr>
<tr>
<td>11/04/03 05:56:05</td>
<td>RIO 8</td>
<td>Robinson_RIO: Meter 7 Flow Rate: Value=0 BPH - analog LOW.</td>
</tr>
<tr>
<td>11/04/03 05:45:05</td>
<td>MRTV_LIMA_22</td>
<td>Bryant: Lockout Unit 3: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 05:44:47</td>
<td>MRTV_LIMA_22</td>
<td>Elwood: Lockout Unit 1: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 04:58:25</td>
<td>OWEN_CBEG_24</td>
<td>Owensboro: Meter 14 Flow Rate: Value=2083 BPH - analog LOW.</td>
</tr>
<tr>
<td>11/04/03 04:44:28</td>
<td>COLUMBUS_M</td>
<td>Columbus_Meters: Seal Failure - Manifold Valve IM6: Change to state ALARM.</td>
</tr>
<tr>
<td>11/04/03 04:36:02</td>
<td>ROACHDALE_U</td>
<td>Roachdale: Unit 2 Percent Speed: Value=0 PCT - analog LOW.</td>
</tr>
<tr>
<td>11/03/03 19:58:36</td>
<td>KENO_COLM 14</td>
<td>Kenova: Pig Departure: Change to state ALARM.</td>
</tr>
<tr>
<td>11/03/03 19:45:50</td>
<td>KENO_COLM 14</td>
<td>Kenova: Illegal Valve Change: Change to state ALARM.</td>
</tr>
<tr>
<td>11/03/03 17:23:52</td>
<td>ESMD_TLSB_PROD</td>
<td>Youngstown: Manifold Relief System Low Nitrogen: Change to state ALARM.</td>
</tr>
<tr>
<td>11/03/03 17:11:45</td>
<td>HETH_DAYT_6</td>
<td>Columbus E NWB: No Flow Path EXISTS: Change to state ALARM.</td>
</tr>
<tr>
<td>11/03/03 17:11:44</td>
<td>HETH_DAYT_6</td>
<td>Columbus W NWB: Shutdown Booster 1: Change to state ALARM.</td>
</tr>
</tbody>
</table>
Station Screen Alarms

Upstream Gravitometer Alarms:
- PLC Fail
- AC Power Failure
- PLC Battery Failure
- PLC Module Failure
- PLC Memory Protect Switch

Mainline High Pressure @ 550 PSI
Mainline Relief System High Nitrogen @ 625 PSI
Mainline Relief System Low Nitrogen @ 575 PSI
Mainline Pressure Relief @ 600 PSI
Manifold High Pressure @ 200 PSI
Manifold Relief System High Nitrogen @ 275 PSI
Manifold Relief System Low Nitrogen @ 225 PSI
Manifold Pressure Relief @ 250 PSI

Barrel Alarms
- Valve Alarms
- Sump Control Failure

Alarms
### Event History - Patoka - Owensboro 20" Crude: 01/27/2000 06:00 thru 14:27

<table>
<thead>
<tr>
<th>Date</th>
<th>Station</th>
<th>Description</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:02:15</td>
<td>Owensboro</td>
<td>Incoming Gravity</td>
<td>Value=33.78 API - analog LOW</td>
</tr>
<tr>
<td>6:02:32</td>
<td>Owensboro</td>
<td>Manifold Valve B10</td>
<td>Issued command OPEN by siefker at FPLXOS5</td>
</tr>
<tr>
<td>6:02:41</td>
<td>Owensboro</td>
<td>Meter 5</td>
<td>PMC-093-1933-OWT: Automatic track completed: pumped 125030.0 BBLS</td>
</tr>
<tr>
<td>6:02:49</td>
<td>Owensboro</td>
<td>Manifold Valve B10</td>
<td>Discrete command TRANSIT - success</td>
</tr>
<tr>
<td>6:03:23</td>
<td>Owensboro</td>
<td>Manifold Valve B10</td>
<td>Discrete command OPEN - success</td>
</tr>
<tr>
<td>6:03:33</td>
<td>Owensboro</td>
<td>Manifold Valve B7</td>
<td>Issued command CLOSE by siefker at FPLXOS5</td>
</tr>
<tr>
<td>6:03:40</td>
<td>Owensboro</td>
<td>Meter 5</td>
<td>PMC-093-1933-OWT: Automatic track completed: pumped 125200.0 BBLS</td>
</tr>
<tr>
<td>6:04:48</td>
<td>Owensboro</td>
<td>Incoming Gravity</td>
<td>Value=33 API - analog deviation return to normal</td>
</tr>
<tr>
<td>6:04:48</td>
<td>Owensboro</td>
<td>Sampler Pot 1</td>
<td>Uncommanded change to state INACTIVE</td>
</tr>
<tr>
<td>6:04:48</td>
<td>Owensboro</td>
<td>Sampler Pot 2</td>
<td>Uncommanded change to state ACTIVE</td>
</tr>
<tr>
<td>6:05:48</td>
<td>Owensboro</td>
<td>Incoming Gravity</td>
<td>Modified analog OWENGRIGRV.hilow.lolim from &quot;34.000000&quot; to &quot;28.900000&quot; b</td>
</tr>
<tr>
<td>6:05:51</td>
<td>Owensboro</td>
<td>Meter 5 Total Flow Rate</td>
<td>Value=567.602 BPH - analog dev-low</td>
</tr>
<tr>
<td>6:05:51</td>
<td>Owensboro</td>
<td>Meter 5 Total Flow Rate</td>
<td>Value=567.602 BPH - analog LOW</td>
</tr>
<tr>
<td>6:05:52</td>
<td>Owensboro</td>
<td>Incoming Gravity</td>
<td>Modified analog OWENGRIGRV.hilow.hilim from &quot;42.000000&quot; to &quot;36.900002&quot; b</td>
</tr>
<tr>
<td>6:05:55</td>
<td>Owensboro</td>
<td>Incoming Gravity</td>
<td>Value=32.88 API - analog NORMAL</td>
</tr>
<tr>
<td>6:05:56</td>
<td>Owensboro</td>
<td>Meter 5 Total Flow Rate</td>
<td>Value=10281.2 BPH - analog deviation return to normal</td>
</tr>
<tr>
<td>6:05:56</td>
<td>Owensboro</td>
<td>Meter 5 Total Flow Rate</td>
<td>Value=10281.2 BPH - analog NORMAL</td>
</tr>
<tr>
<td>6:06:43</td>
<td>Patoka, PAO</td>
<td>Patoka - Owensboro</td>
<td>Modified status BPMATPOWEN cnp, time high from &quot;048090606&quot; to &quot;048074&quot;</td>
</tr>
</tbody>
</table>
Previous Alarm Accidents

• Gramercy
  – P-98-22
  – Board recommended an audit of alarms
  – Company reported an alarm decrease from 200 to 60 leak alarms per day
Companies Conduct Alarm Audits

1 of 3 companies do not audit alarms
Number of Alarm Priorities

Companies

Not Prioritized | Two | Three | Four or more

Not Prioritized: 0
Two: 5
Three: 10
Four or more: 15

Ideal
Alarms Summary

• Alarms are the most important safety feature of SCADA systems
• Controllers believe they are receiving too many alarms
• Alarm audits can reduce the number of alarms
• Alarm priorities can improve the salience of important alarms.
SCADA Related Issues

- Graphic Design
- Alarm Management
- Leak Detection
CPM Systems

• Computational pipeline monitoring is a computerized decision aid to help controllers identify leaks
• Many methods of CPM
  – Line balance
  – Volume balance
  – Model based
  – Statistical
CPM Detection Times

- CPM systems detected leaks in
  - Cohasset (3 minutes)
  - Gramercy (3 minutes)
  - Winchester (1 minute)
  - Bellingham (13 minutes)
### CPM Graphics

#### Balance Signature

<table>
<thead>
<tr>
<th>Yellow</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Now - 20 minutes</td>
<td>20 - 40 minutes</td>
<td>40 - 60 minutes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unpack</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak</td>
<td>Pack</td>
</tr>
</tbody>
</table>

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*Image*
CPM System Screen
CPM Summary

- CPM systems are effective in indicating leaks
- CPM systems not on 40 percent of companies systems
Controller Issues

- Fatigue
- Training
Controller Schedules

- All companies visited monitored the pipeline 24 hours
- 11 of 12 companies visited used a 12-hour shift
- No hours of service in pipeline regulations
Schedule Limits in Similar Jobs

- **Air traffic control**
  - 40 hours/wk, max: 10 hours
  - 30-minute lunch break
  - 2 hours on sector before break

- **Nuclear power**
  - 48 hours/wk, max: 16 hours,
  - Mandatory breaks for shifts > 10 hrs

- **Rail dispatch**
  - Max 9 hrs (multiple shifts)
Controller Fatigue

- 8 of 18 controllers least liked their schedules
- 10 controllers noted concerns about getting enough sleep, working nights, or switching shifts
- Controllers like their schedules because of the time off
Fatigue Effects

- Degraded judgment/decision-making
- Reduced vigilance
- Reduced short-term memory
- Lack of concentration
- Visual/mental fixation
Previous Board Recommendations

• Issue bulletin on 12-hour shift scheduling
  – Fork Shoals accident (1996)
  – P-98-30
  – Currently Open—Acceptable Action

• Issue hours of service rules
  – Fatigue Safety Report
  – P-99-12
  – Currently Open—Acceptable Action
PHMSA response

- Advisory Bulletin, *Pipeline Safety: Countermeasures to Prevent Human Fatigue in the Control Room*
  - Shift rotation practices
  - 12-hour shifts
  - 10 hours of rest between shifts
  - Guidelines for scheduling controllers
Fatigue Issue Summary

- No hours of service regulations
- Controller fatigue
- PHMSA bulletin on fatigue
- Bulletin not mandatory
- No fatigue data collected in OPS accident database
Controller Related Issues

– Fatigue
– Training
Previous Accidents and Training

- Inadequate controller training in 7 of the 10 accidents
- Four companies chose to purchase or enhance simulators to improve training
Electricity SCADA Training

• 2003 power outage in the Northeast
• North American Electrical Reliability Council findings:
  – Controllers not adequately prepared
  – Controllers trained on the job
Power Outage Recommendations

• Improved training for abnormal operations
• Simulations of abnormal operation either on computer or as tabletop drills
Typical Controller Training

• Average training for controllers
  – 6 month average
  – 3 months to several years
  – Six companies had simulators
    • Three companies were using them
    • 6 of 18 controllers had simulator training
Majority of Training On-the-Job

Time

Majority of training is done through on-the-job training (OJT). Classroom training and other methods are used less frequently.
Simulator Training

1 of 4 companies have simulators

- Yes: 28%
- No: 72%
SCADA Trend Screen
Training Issue Summary

- SCADA-related accidents include training issues
- Most training is on the job
- Most companies do not have simulators
- Simulation of abnormal events would better prepare controllers for these rare events