EMPLOYEE SCHEDULING FOR MAINTENANCE OF AUTOMATED SAFETY SYSTEMS FOR REMOTELY LOCATED OIL AND GAS FACILITIES

Yury Redutskiy
Associate Professor
Faculty of Logistics
Molde University College
e-mail: Yury.Redutskiy@HiMolde.no
Oil and gas industry is facing a shift towards the operations in nonconventional environments and remote locations.
Structure of an automated safety system:

- Technology
- Process Value Transmitter
- Logic Solver
- Final Control Element

The set of safety measures to be optimized:

- Safety system’s specification:
  - device models
  - redundancy
  - common-cause failure mitigation
- Safety system’s maintenance planning:
  - test interval
  - testing policy
  - workforce plan
ISSUES RELATED TO SAFETY SYSTEMS DESIGN

- **Safety standards:**
  - international standards IEC 61508 and IEC 61511

<table>
<thead>
<tr>
<th>SIL</th>
<th>Risk reduction requirements</th>
<th>Minimum hardware fault tolerance requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Target PFD&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>SFF &lt; 60%</td>
</tr>
<tr>
<td>1</td>
<td>[10&lt;sup&gt;-2&lt;/sup&gt;, 10&lt;sup&gt;-1&lt;/sup&gt;]</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>[10&lt;sup&gt;-3&lt;/sup&gt;, 10&lt;sup&gt;-2&lt;/sup&gt;]</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>[10&lt;sup&gt;-4&lt;/sup&gt;, 10&lt;sup&gt;-3&lt;/sup&gt;]</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>[10&lt;sup&gt;-5&lt;/sup&gt;, 10&lt;sup&gt;-4&lt;/sup&gt;]</td>
<td>spec. req.</td>
</tr>
</tbody>
</table>

- **ALARP principle of risk reduction:** find a trade-off between the investments into the safety measures and the achieved risk reduction

- **Issues relevant for facility operating companies:**
  - costs
  - smooth operations
  - requirements specification
**MODELLING AND OPTIMIZATION**

**BLACK BOX OPTIMIZATION ALGORITHM**

- **Function in Matlab**
  Lifecycle evaluation of a SIS design, maintenance approach and workforce planning

- **Markov model**
  Subsystem evaluation
  - Subsystems' reliability characteristics

- **Markov model**
  SIS life cycle
  - Average probability of failure on demand
  - Expected facility downtime
  - Life cycle cost of the solution

- **Staffing size evaluation**
  Requirements for personnel

- **Integer programming model**
  Workforce scheduling (trips and shifts)
  - Workforce costs

- **Life cycle cost evaluation**

- **Device models for the subsystems**
- **Subsystems' MoOn architectures**
- **Additional separation for the subsystems**
- **Test interval (TI) for proof testing**
- **Maintenance (proof testing) policies for the subsystems**
- **Target SIL**
Set-covering formulation

\[
\begin{align*}
\min \sum_{s \in S^{TRIP}} \sum_{c \in S^{DS}} c_s^{trip} \cdot x_s^{WFT} \cdot \beta_{c}^{shift} \cdot x_{sc}^{WFT} \\
\text{s.t.} \quad \sum_{p \in S^{TRIP}} \sigma_{wp} \cdot x_p^{WFT} & \geq x_w^{\text{required}}, \quad \forall w, \\
\sum_{c \in S^{DS}} x_{pc}^{WFS} & = 1, \quad \forall p.
\end{align*}
\]
Three main components of lifecycle costs

\[ C_{lifecycle} = C_{procurement} + \sum_{\tau=1}^{LC} \left( C_{\tau}^{operations} + C_{\tau}^{risk} \right) \cdot \frac{1}{(1 + \delta)^{\tau-1}} \]

- **Procurement:**
  - Purchasing components
  - System design
- **Operations:**
  - Electricity consumption
  - Tests
  - Production losses
  - Spare parts
  - Workforce
- **Risk costs:**
  - Spurious trips
  - Incidents
**COMPUTATIONAL EXPERIMENT**

**Data for the example:**

- **Critical process parameters:**

<table>
<thead>
<tr>
<th>#</th>
<th>Process parameter</th>
<th>Event</th>
<th>Frequency, [y⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Temperature of the air</td>
<td>HH</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>Flame detected on main burner</td>
<td>No flame detected</td>
<td>0.01</td>
</tr>
</tbody>
</table>

- **Shutdown actions:**

<table>
<thead>
<tr>
<th>#</th>
<th>Final control element</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Valve for discharging the gas</td>
<td>open</td>
</tr>
<tr>
<td>2</td>
<td>Valve on the input line</td>
<td>close</td>
</tr>
<tr>
<td>3</td>
<td>Valve on the output line</td>
<td>close</td>
</tr>
</tbody>
</table>
# EXPERIMENT RESULTS

<table>
<thead>
<tr>
<th>#</th>
<th>TT</th>
<th>FD</th>
<th>LS</th>
<th>SV</th>
<th>SV</th>
<th>SV</th>
<th>Ti, [w]</th>
<th>PFD_{avg}</th>
<th>DT, [h]</th>
<th>Lifecycle cost, [CU]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TT4/1oo2e/seq</td>
<td>FD4/1oo3e/seq</td>
<td>PLC2/1oo3e/par</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/par</td>
<td>12</td>
<td>1.509 \cdot 10^{-7}</td>
<td>1245</td>
<td>14 141 224.90</td>
</tr>
<tr>
<td>2</td>
<td>TT4/1oo2e/seq</td>
<td>FD4/1oo3e/seq</td>
<td>PLC1/1oo2e/par</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/seq</td>
<td>16</td>
<td>2.917 \cdot 10^{-7}</td>
<td>705</td>
<td>12 478 522.65</td>
</tr>
<tr>
<td>3</td>
<td>TT4/1oo2e/seq</td>
<td>FD4/1oo3e/seq</td>
<td>PLC2/1oo3e/par</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/seq</td>
<td>16</td>
<td>2.720 \cdot 10^{-7}</td>
<td>705</td>
<td>12 809 454.25</td>
</tr>
<tr>
<td>4</td>
<td>TT5/1oo3e/par</td>
<td>FD4/1oo3e/seq</td>
<td>PLC2/1oo3e/par</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/seq</td>
<td>16</td>
<td>2.649 \cdot 10^{-7}</td>
<td>933</td>
<td>14 144 003.47</td>
</tr>
<tr>
<td>5</td>
<td>TT5/1oo3e/par</td>
<td>FD4/1oo3e/seq</td>
<td>PLC2/1oo3e/par</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo3e/seq</td>
<td>16</td>
<td>2.673 \cdot 10^{-7}</td>
<td>629</td>
<td>15 148 724.01</td>
</tr>
<tr>
<td>6</td>
<td>TT4/1oo2e/seq</td>
<td>FD4/1oo3e/seq</td>
<td>PLC1/1oo2e/par</td>
<td>SV2/1oo3e/seq</td>
<td>SV2/1oo4e/par</td>
<td>SV2/1oo3e/par</td>
<td>24</td>
<td>5.014 \cdot 10^{-7}</td>
<td>518</td>
<td>12 783 512.95</td>
</tr>
<tr>
<td>7</td>
<td>TT5/1oo3e/seq</td>
<td>FD4/1oo3e/seq</td>
<td>PLC2/1oo3e/par</td>
<td>SV2/1oo4e/par</td>
<td>SV2/1oo3e/par</td>
<td>SV2/1oo3e/par</td>
<td>24</td>
<td>4.364 \cdot 10^{-7}</td>
<td>580</td>
<td>12 366 906.19</td>
</tr>
<tr>
<td>8</td>
<td>TT5/1oo5e/par</td>
<td>FD4/1oo3e/seq</td>
<td>PLC2/1oo3e/par</td>
<td>SV2/1oo4e/par</td>
<td>SV2/1oo3e/par</td>
<td>SV2/1oo4e/seq</td>
<td>24</td>
<td>4.290 \cdot 10^{-7}</td>
<td>518</td>
<td>13 712 005.72</td>
</tr>
</tbody>
</table>
# TRIPS AND SHIFTS ALTERNATIVES WITH ASSOCIATED COSTS

## DAILY SHIFT ALTERNATIVES:

<table>
<thead>
<tr>
<th>Work/rest hours alternatives</th>
<th># of workers for continuous service</th>
<th>Pay rate, CU/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 8 hours of work + 16 hours of rest</td>
<td>3</td>
<td>125</td>
</tr>
<tr>
<td>2 12 hours of work + 12 hours of rest</td>
<td>2</td>
<td>250</td>
</tr>
</tbody>
</table>

## TRIP ALTERNATIVES:

<table>
<thead>
<tr>
<th>Trip alternative</th>
<th>Pay rate cost modifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 week trip</td>
<td>1</td>
</tr>
<tr>
<td>2 2 weeks trip</td>
<td>1.25</td>
</tr>
<tr>
<td>3 4 weeks trip</td>
<td>1.5</td>
</tr>
<tr>
<td>4 6 weeks trip</td>
<td>2</td>
</tr>
</tbody>
</table>

- Personnel constantly present at the facility
- Additional personnel for overhauls
Further research

The presented research is a “pilot research” combining the problems of:

- engineering design of safety instrumented systems for hazardous industrial processes
- maintenance planning and workforce scheduling to support these safety systems for the remotely located facilities

The research will be continued and the following aspects will be incorporated into the decision-making framework:

- incorporating **diverse redundancy**
- incorporating elaborate **maintenance policies**, such as partial testing and staggered testing
- engineering **contractor’s** perspective on the workforce scheduling decisions.
Thank you!