LAYERS OF PROTECTION ANALYSIS FOR HUMAN FACTORS (LOPA-HF)

Paul Baybutt, Primatech Inc.
ASSE Symposium on Human Error In Occupational Safety,
March 13 – 14, 2003, Atlanta, Georgia
PREMISE

- Plethora of human error classification schemes and human factors models
- Importance of human error contributions to accidents in process plants is well recognized
- Large body of knowledge on human errors/factors
- Few companies have applied it to their existing plants
  - or designs for new ones
WHY NOT?
CONTRIBUTING REASONS

- Language of human factors not understood
- Potential benefits not recognized
- Cost of studies
- Acceptance of a culture of blame
  - i.e. fix people, not the process
- Discomfort with a field that sounds “touchy-feely”

“A most human beings have an almost infinite capacity for taking things for granted.”

Aldous Huxley
CONTRIBUTING REASONS (CONT'D.)

- Absence of
  - human factors framework to which plants can relate
  - simple and straightforward methods
  - how to fix human factors problems
CONTRIBUTING REASONS (CONTD.)

- Field seems so broad it appears overwhelming
- Existing safety programs viewed as adequate
- Perceived to benefit only safety
  - not productivity, operability, quality, etc.
- Value not convincingly demonstrated

“Minds are like parachutes; they work best when open.”

Lord Thomas Dewar
Plants do not have the time or resources
  ➤ overwhelmed with other programs
  ➤ thinly staffed
  ➤ operating in a highly competitive environment

No imperatives, or motivating factors
  ➤ contributions to financial performance
  ➤ regulations
PATH FORWARD

- Many companies covered by PSM/RMP
- Process hazard analysis (PHA) required
- “The PHA shall address human factors”
- Present approaches only pay lip service
- Find a better way to mount HF on this horse
  - LOPA-HF

“To err is human; to forgive, infrequent.”
Franklin P. Adams
OVERVIEW

- Causes of process accidents
- Human factors in PHA
- Human factors models
- LOPA-HF
- Example
PROCESS ACCIDENTS

- Equipment Failures
- Human Failures
- External Events
Generally believed that 50 – 90% of all accidents are caused by human failures.
HUMAN FACTORS IN PHA

- Account for human failure as a cause of hazard scenarios
  - “Human errors”
- Consider factors that impact human performance
  - “Human Factors”
OSHA PHA CITATIONS
May 26, 1992 – September 30, 2002

(e)(1) Initial PHA 680
(e)(2) Methodology 32
(e)(3) PHA shall address (general) 60
   (e)(3)(i) Hazards of process 77
   (e)(3)(ii) Previous incidents 36
   (e)(3)(iii) E&A controls 72
   (e)(3)(iv) Consequences of failure of E&A controls 57
   (e)(3)(v) Facility siting 95
   (e)(3)(vi) Human factors 80
   (e)(3)(vii) Qualitative evaluation 33
(e)(4) Qualified team 41
(e)(5) System to address findings 238
(e)(6) Revalidate PHA 39
(e)(7) Retain for life of process 19
Total 1559
HUMAN FAILURES

- Acts of omission (something not done)
  - E.g. failure to execute a step in a procedure

- Acts of commission (something done incorrectly)
  - E.g. mechanic closes block valves in both the main line and the bypass
HUMAN FACTORS

- Don’t confuse human factors in PSM/PHA with OSHA’s ergonomic standard
EXAMPLES OF HUMAN FACTORS FOR PROCESSES

- Operator/process and operator/equipment interface
- Number of tasks operators must perform and their frequency
- Extended or unusual work schedules and shift rotations
- Clarity and simplicity of control displays
- Automatic instrumentation versus manual procedures
- Operator feedback
- Clarity of signs and codes
- Etc.
CLASSICAL HUMAN-MACHINE MODEL
WHAT IS A FACILITY?

- Organization
- Environment
- Workplace
- Jobs & Tasks
  - People
  - Equipment
  - Procedures/ Rules
  - Computers
WHAT IS A HUMAN?

- Anthropometry
- Gender
- Motor
- Culture
- Senses
- Qualifications
- Verbal
- Health
- Cognition
- Psychology
- Physiology
IMPROVED HUMAN FACTORS MODEL
# PERSON-PROCESS MATRIX MODEL

## Human Attributes
- Skills
- Senses
- Strength
- Etc.

## Process Attributes
- Equipment
- Procedures
- Environment
- People
- Etc.

<table>
<thead>
<tr>
<th></th>
<th>Equipment</th>
<th>Procedures</th>
<th>Environment</th>
<th>People</th>
<th>Etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skills</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senses</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Etc.</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
SYSTEMS VIEW OF HUMAN ERROR

Vulnerability (unforgiving conditions)

Error-inducing environment

Human limitations

Errors with likelihood of significant consequences
TREATMENT OF HUMAN FACTORS IN PROCESS SAFETY

HUMAN FACTORS STUDY → HUMAN FAILURES STUDY → PROCESS HAZARD ANALYSIS

HUMAN FAILURES

HUMAN FACTORS

RECOMMENDED  DESIRABLE  REQUIRED  REQUIRED
APPROACHES FOR TREATMENT OF HUMAN FAILURES IN PHA

- Simple brainstorming
- Checklists
- Structured brainstorming

“There are many ways of going forward, but only one way of standing still.”

Franklin D. Roosevelt
APPROACHES FOR TREATMENT OF HUMAN FACTORS IN A PHA

- Checklists
- LOPA-HF

“The only real mistake is the one from which we learn nothing.”

John Powell
HUMAN FACTORS CHECKLISTS

- Disadvantages
  - Lengthy checklists are cumbersome to use and quickly become repetitive and tiresome
  - If the checklists are kept simple, human factors may be missed
  - Do not provide much structure or guidance
  - Produces only a simplistic analysis
LOPA-HF

- Uses the framework of Layers of Protection Analysis (LOPA)
  - Simplified risk assessment method
  - Provides scenario risk estimate
    - objective, rational and reproducible
  - Compares it with risk tolerance criteria to decide if existing safeguards are adequate
  - Studies high risk scenarios from PHA
  - Can be viewed as an extension of PHA
LOPA-HF (CONTD.)

- Human factors are addressed by determining their impact on each individual element of a hazard scenario

“To the man who only has a hammer in the toolkit, every problem looks like a nail.”

Abraham Maslow
CONSTITUENT ELEMENTS OF A HAZARD SCENARIO

Initiating event

Operator actions
Automated responses

Intermediate Events

Enabling events

Equipment failure
Human failure
External events

Human factors, e.g. an error-inducing environment
Human failures, e.g. mis-calibrated instruments

Consequences

Effects on:
People
Property
Process
Environment
Etc.
LOPA-HF (CONT'D.)

- Dominant human factors that influence each part of the hazard scenario are identified using simple Issues Lists.
- Information is recorded in a worksheet.

"The mind is not a vessel to be filled but a fire to be kindled."

Plutarch
ISSUES LISTS

- Each represents part of the body of knowledge on human factors
- Prepared in advance
- Tailored for each situation
  - short
- Provide structure, guidance and completeness
- Allow analysts to focus quickly on the principal human factors issues
  - without the need to wade through a PHA human factors checklist
EXAMPLE OF LOPA-HF APPLIED TO HEXANE UNLOADING
EXAMPLE – KEY POINTS

- Unload hexane from a tank truck into a storage tank using a pump
- Tank surrounded by a dike
  - Equipped with a level indicator and a high level alarm that annunciates in the control room
EXAMPLE – KEY POINTS (CONTD.)

- Two operators involved in the unloading operation
  - Field operator initiates the transfer with the truck driver
  - Control room operator monitors and operates various process functions from a computer console
- Truck driver required to supervise the transfer
EXAMPLE (CONTD.)

Scenario considered:

- Overfilling the hexane storage tank with the spill not contained by the dike
ELEMENTS OF A HAZARD SCENARIO

- Initiating event
- Intermediate Events
- Consequences
- Enabling events
INITIATING EVENT

- “Delivery of hexane when there is insufficient room in the storage tank due to a failure in the inventory control system”
- Issues Lists used to identify
  - dominant human factors contributors to the failure rate
  - existing protective measures
  - recommendations for additional protective measures
HUMAN FACTORS ISSUES LIST – INCORRECT ACTION BY PERSON

- Work overload/underload
- Insufficient training
- Inadequate skills
- Inadequate resources
- Inadequate procedures
- Inadequate labeling
- Equipment not easily operable
- Displays/controls not visible/heard
- Displays/controls confusing
- Displays/controls not accessible/usable
- Inadequate communications
- Environmental issues (temperature, humidity, light, noise, distractions)
- Error (wrong action, no specific reason)
- Mistake (wrong action, misunderstood)
- Other?
PROTECTIVE MEASURES ISSUES LIST – INCORRECT ACTION BY PERSON

- Training
- Procedures
- Equipment labeled
- Check
- Other?
<table>
<thead>
<tr>
<th><strong>Scenario Description:</strong></th>
<th>Overfilling the hexane storage tank with the spill not contained by the dike.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initiating event:</strong></td>
<td>Delivery of hexane when there is insufficient room in the storage tank due to a failure in the inventory control system.</td>
</tr>
<tr>
<td><strong>Human Factors:</strong></td>
<td>Mistake in ordering due to work overload. Mistake in gaging the tank contents due to inadequate training.</td>
</tr>
<tr>
<td><strong>Protective Measures:</strong></td>
<td>Unloading procedures. Level indicator. High level alarm.</td>
</tr>
<tr>
<td><strong>Recommendations:</strong></td>
<td>Improve training of the operators and the truck driver. Consider installing a high level trip for the feed pump and an inlet shutdown valve to help prevent overfilling accidents.</td>
</tr>
</tbody>
</table>
ELEMENTS OF A HAZARD SCENARIO

- Initiating event
- Intermediate Events
- Consequences
- Enabling events
INTERMEDIATE EVENTS

- Include:
  - operator actions
  - automated responses of the process control and safety systems
- Many intermediate events are safeguards that can prevent, detect, or mitigate accidents
<table>
<thead>
<tr>
<th><strong>IPL1</strong>: Dike</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Human Factors</strong>: None</td>
</tr>
<tr>
<td><strong>Protective Measures</strong>: N/A</td>
</tr>
<tr>
<td><strong>Recommendations</strong>: N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>IPL2</strong>: Operator response to alarms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Human Factors</strong>: Inadequately designed computer control interface.</td>
</tr>
<tr>
<td><strong>Protective Measures</strong>: Level indicator (weak)</td>
</tr>
<tr>
<td><strong>Recommendations</strong>: Consider installing a high level trip for the feed pump and an inlet shutdown valve to help prevent overfilling accidents.</td>
</tr>
</tbody>
</table>
ELEMENTS OF A HAZARD SCENARIO

- Initiating event
- Intermediate Events
- Consequences
- Enabling events
ENABLING EVENTS/CONDITIONS

- Do not directly cause the hazard scenario
  - Make possible another event in the scenario

“I hear and I forget. I see and I remember. I do and I understand.”

Confucius
ENABLING EVENTS/CONDITIONS (CONTD.)

- Frequently influenced by human factors, e.g.
  - An error-inducing environment, e.g. work overload
  - Deliberate actions, e.g. disabled alarms
  - Human failures, e.g.
    - Mis-calibrated instruments
    - Incorrect maintenance that leaves the process in an undetected unsafe state
ENABLING EVENTS / CONDITIONS

ISSUES LIST

- Installation of incorrect seals, gaskets, etc.
- Process left in incorrect state after turnaround, maintenance, sampling, or other operation
- Disabled alarms
- Overrides
- LOTO not effected
- Startup/shutdown/operating/emergency mode, etc.
- Other?
<table>
<thead>
<tr>
<th>LOPA - HF WORKSHEET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Enabling event/condition:</strong> High temperature alarm overridden</td>
</tr>
<tr>
<td><strong>Human Factors:</strong> Alarm left inoperable after process adjustments owing to the lack of a check.</td>
</tr>
<tr>
<td><strong>Protective Measures:</strong> None.</td>
</tr>
<tr>
<td><strong>Recommendations:</strong> Revise the process optimization procedure to confirm operation of the alarm after completion of adjustments.</td>
</tr>
</tbody>
</table>
ELEMENTS OF A HAZARD SCENARIO

Initiating event → Intermediate Events → Consequences

Enabling events
CONSEQUENCE

- Effect of the scenario on:
  - People (on-site or off-site)
  - Property (on-site or off-site)
  - Process (downtime, product quality, etc.)
  - Environment
  - Etc.
**Consequence:** Hexane release outside the dike that could result in fire and/or injury.

| Human Factors:                      | Lack of awareness of this hazard by the process personnel.  
|                                  | Lack of a smoking prohibition outside the area of the tank farm where the spill could reach. |
| Protective Measures:               | None.                                                      |
| Recommendations:                   | Address this hazard in the initial and refresher training for all affected personnel.   
|                                  | Restrict smoking to designated locations.                   |
DECIDING ON CORRECTIVE ACTIONS
- HF CREDITS

- Credits assigned for each type of human factors improvement
  - According to its effectiveness
- When aggregated, each 10 credits of improvements contributes an order of magnitude reduction in the scenario likelihood
- Target risk level can be met by accumulating sufficient credits
  - Analysts decide which of various possible combinations are preferred
<table>
<thead>
<tr>
<th>SCENARIO ELEMENT</th>
<th>EVENT</th>
<th>RECOMMENDATIONS</th>
<th>CREDITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiating event</td>
<td>Delivery of hexane when there is insufficient room in the storage tank due to a failure in the inventory control system.</td>
<td>Improve training of the operators and the truck driver. Consider installing a high level trip for the feed pump and an inlet shutdown valve to help prevent overfilling accidents.</td>
<td>2 4 + 4</td>
</tr>
<tr>
<td>IPL1</td>
<td>Dike</td>
<td>None</td>
<td>-</td>
</tr>
<tr>
<td>IPL2</td>
<td>Operator response to alarms</td>
<td>Consider installing a high level trip for the feed pump and an inlet shutdown valve to help prevent overfilling accidents.</td>
<td>4 + 4</td>
</tr>
<tr>
<td>Enabling condition</td>
<td>High temperature alarm overridden</td>
<td>Revise the process optimization procedure to confirm operation of the alarm after completion of adjustments.</td>
<td>3</td>
</tr>
<tr>
<td>Consequence</td>
<td>Hexane release outside the dike that could result in fire and/or injury.</td>
<td>Address this hazard in the initial and refresher training for all affected personnel. Restrict smoking to designated locations.</td>
<td>2 1</td>
</tr>
</tbody>
</table>
CONCLUSIONS – ADVANTAGES OF LOPA-HF

- Considers a wide range of human factors issues but in an organized and manageable way
  - using Issues Lists
- Focuses on the specific human factors issues that contribute to the risk
- Provides a structured analysis
CONCLUSIONS – ADVANTAGES OF LOPA-HF

- Builds on PHA
- Can be performed using qualitative methods
  - can be refined using quantitative analysis
- Easily used by people experienced with PHA or LOPA
CONTACT INFO

paulb@primatech.com

www.primatech.com - papers on human factors

“There are no shortcuts to any place worth going.”
Anon