

Hazard and Risk Identification



UNIVERSITY OF
TORONTO



MINERVA
Safety Management Education

Concept Definitions

Hazard – An intrinsic chemical, physical, societal, economic or political *condition that has the potential for causing damage* to a risk receptor (people, property or the environment).

Examples of intrinsic hazards:

- *Toxicity and flammability* – H₂S in sour natural gas
- *High pressure and temperature* – steam drum
- *Potential energy* – walking a tight rope

Hazards: Industrial Examples

- Mechanical motion
- Fall-related
- Lifting-related
- Pressure
- Sound, noise and vibration
- Heat, cold and temperature
- Fire
- Human and psychosocial factors
- Explosion
- Electrical
- Chemical
- Biological
- Toxic and carcinogenic
- Radiation
- Automation
- Ergonomic

Concept Definitions

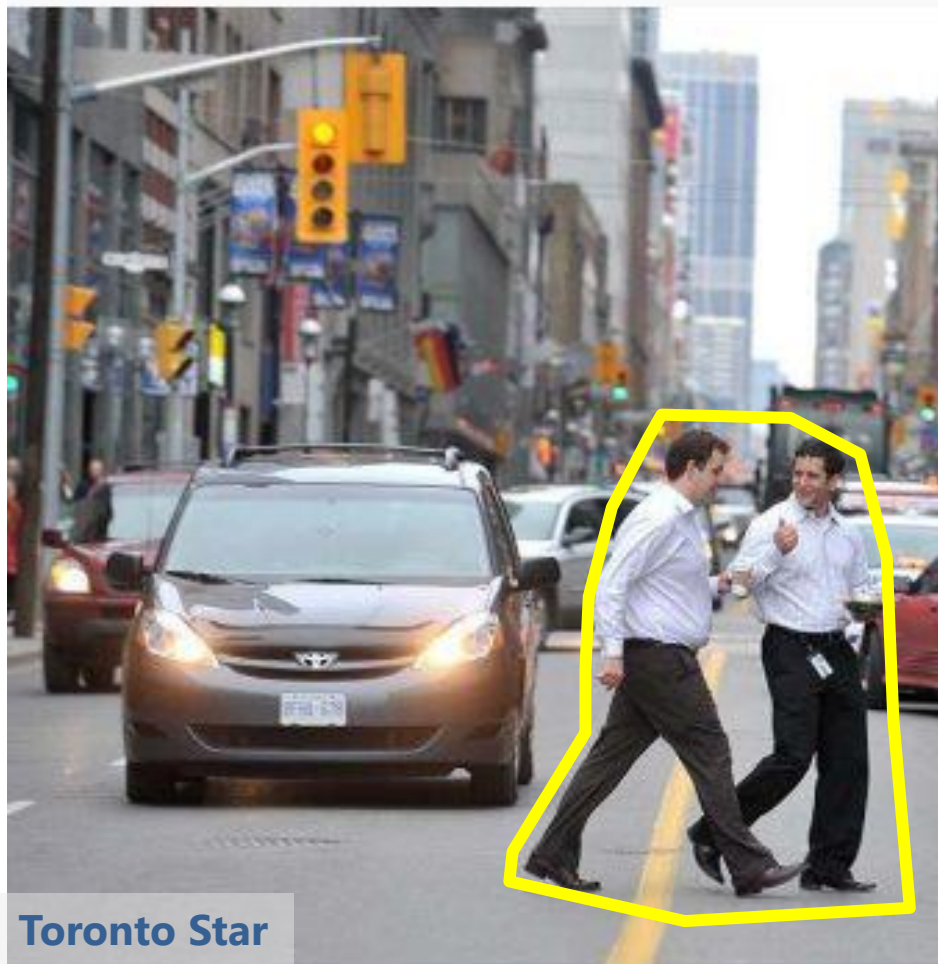
Risk – A *measure* of human injury, environmental damage or economic loss in terms of both the *likelihood* and the *magnitude* of the loss or injury.

$$\text{Risk} = \text{Consequence} \times \text{Likelihood}$$

Risk: Jaywalking



Risk: Jaywalking – Consequences and Frequency



Toronto Star

Consequences

1. Death
2. Severe Injury
3. Broken Bones
4. Fractured Bones
5. Scratches
6. No Injury

Frequency

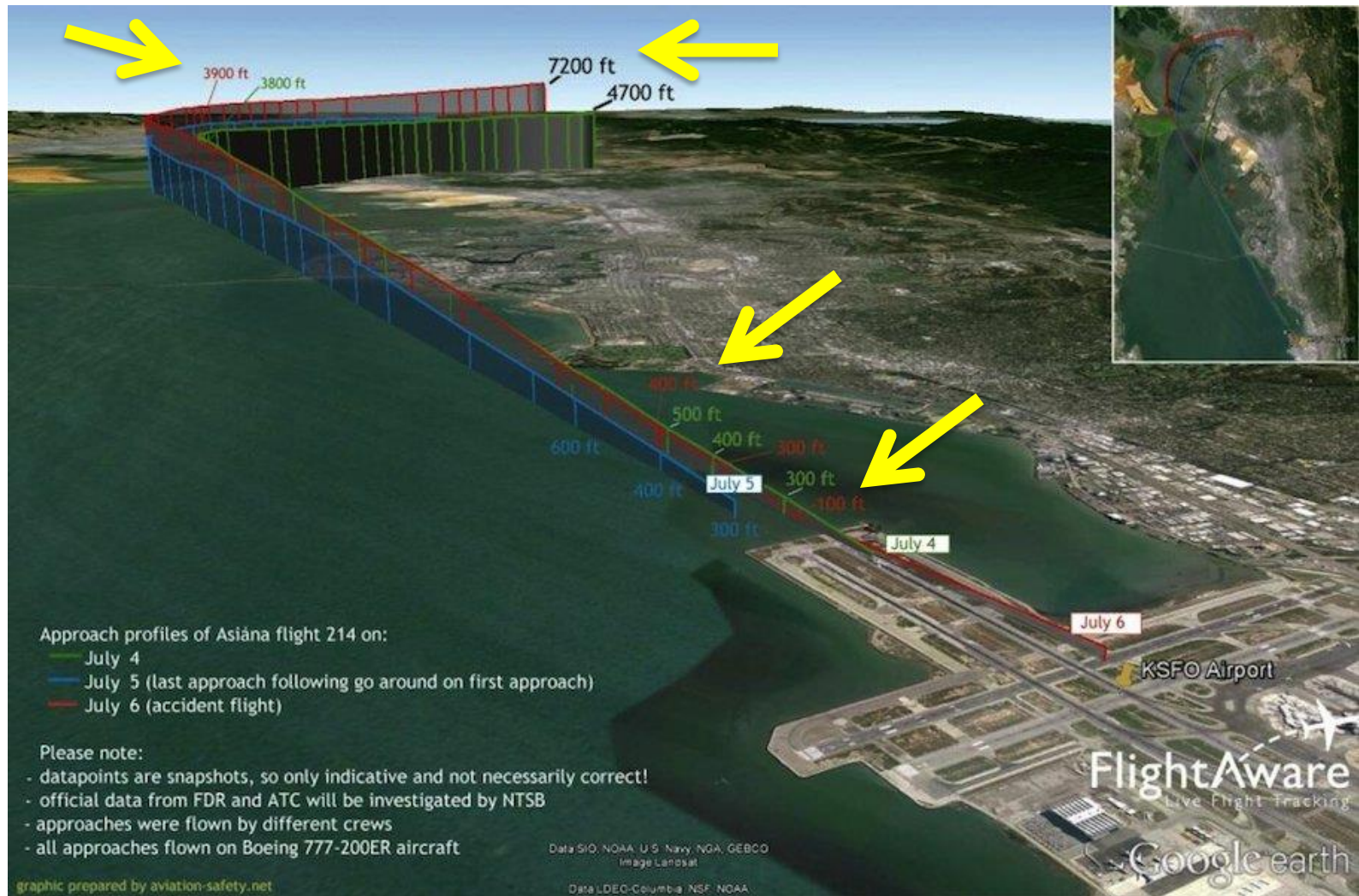
1. Every Day
2. Once a week
3. Once a month
4. Once a year
5. Never

Risk: Plane Landing



- Asiana Airlines Boeing 777 crash on July 6, 2013 at San Francisco International Airport
- 8 deaths and 180 injuries

Risk: Plane Landing – Human Error?

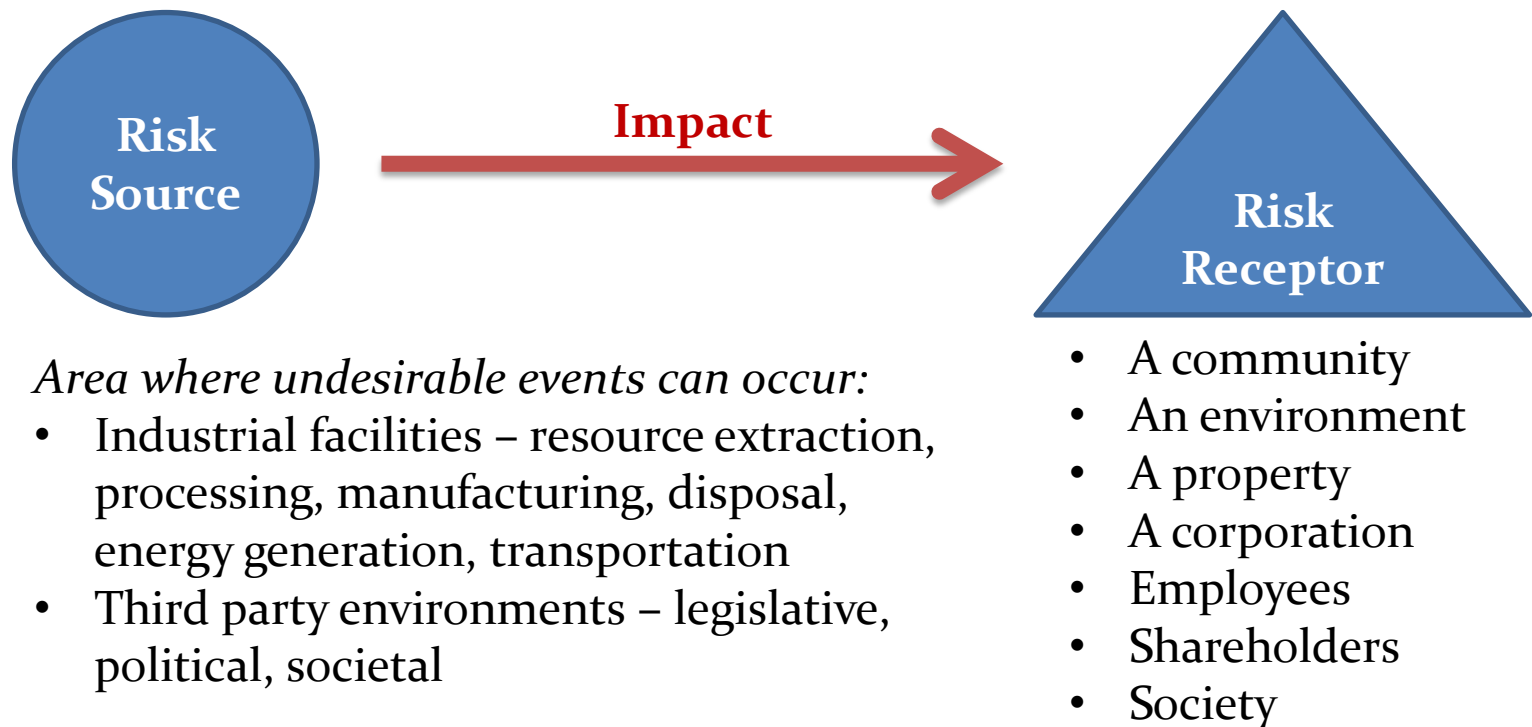


Risk: Plane Landing – Multiple Hazards

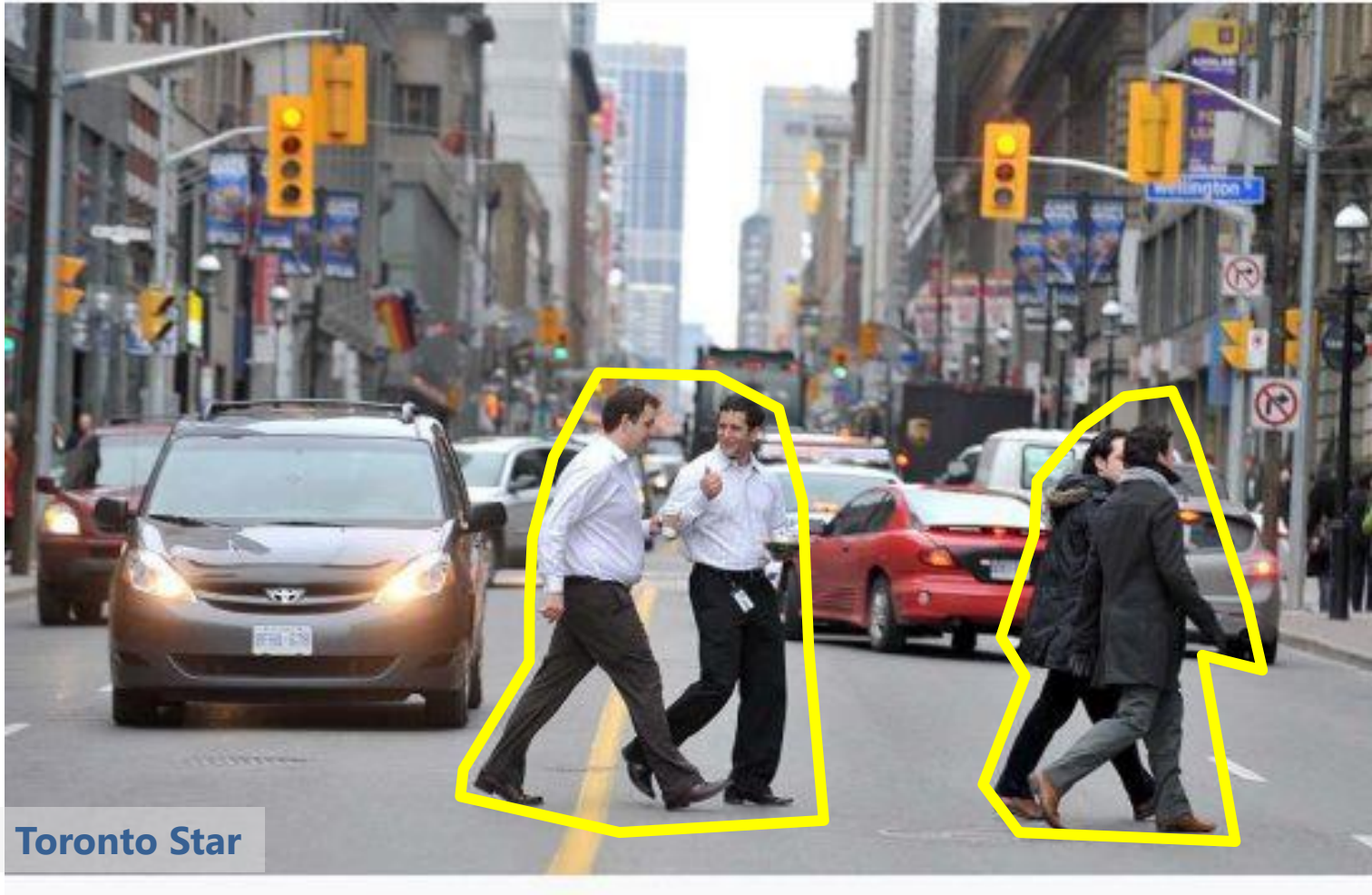


Concept Definitions

Risk – A *measure* of human injury, environmental damage or economic loss in terms of both the *likelihood* and the *magnitude* of the loss or injury.



Risk: Jaywalking – Individual vs. Decision Maker



Concerns about Hazards - Points of View

Individual Receptor

- *Consequence* – What can happen to me as a result of an undesirable event?
 - Could I die? Could I get injured? Could I be inconvenienced?
 - Could my property be damaged? What would be level and type of problem damage, income loss and cost of the repairs?
- *Likelihood* – What are the chances?
 - That I could die? That I could get injured? That I could be inconvenienced?
 - That my property could be damaged?
- *Risk* – Measurement of the combined importance of the consequences and likelihood of those consequences.
 - This will be used to make judgements of about the acceptability of the **individual** risk.

Concerns about Hazards - Points of View

Safety Decision Maker - Societal or Aggregate View

- *Consequence* – What can happen to the individual receptors exposed to the risk source?
 - Could anyone die, get injured, be inconvenienced? How many?
 - Could there be any property damage or production loss?
 - Could there be any environmental damage? How much?
- *Likelihood* – What are the chances?
 - That anyone could die, get injured, be inconvenienced?
 - That any property could be damaged?
 - That there will be any environmental damage?
- *Risk* – Measurement of the combined importance of the consequences and likelihood of those consequences.
 - This will be used to make judgements of about the acceptability of the **societal** risk.

Concept Definitions

Risk Analysis– The development of a quantitative risk estimate based on an engineering evaluation of incident *consequences* and *frequency*.

Units: fatalities per year or
cost per year

Risk Analysis: Plane Crash



Risk = *Number of fatalities* per incidents x Number of incidents per year

Risk = *Cost* per incidents x Number of incidents per year

Concept Definitions

Safety – Relative protection from the exposure to hazards that lead to *severe and sudden outcomes*. Safety is a measure and is achieved if risk is judged to be acceptable.

People are not completely logical when it comes to analysing risk versus the cost of safety.

As human beings we tend to under estimate the likelihood of adverse scenarios. This is why we use quantitative mathematical models.

Concept Definitions

Health – Relative protection from the exposure to hazards that lead to illness or disease. This measure deals with adverse reactions to *exposure over prolonged periods to hazards* that are usually less severe but still dangerous.

Types of Acceptable Risk

Voluntary Risk

vs.

- Mountain Climber
- Driving

Individual Risk

vs.

- Motorcycle Crash

Involuntary Risk

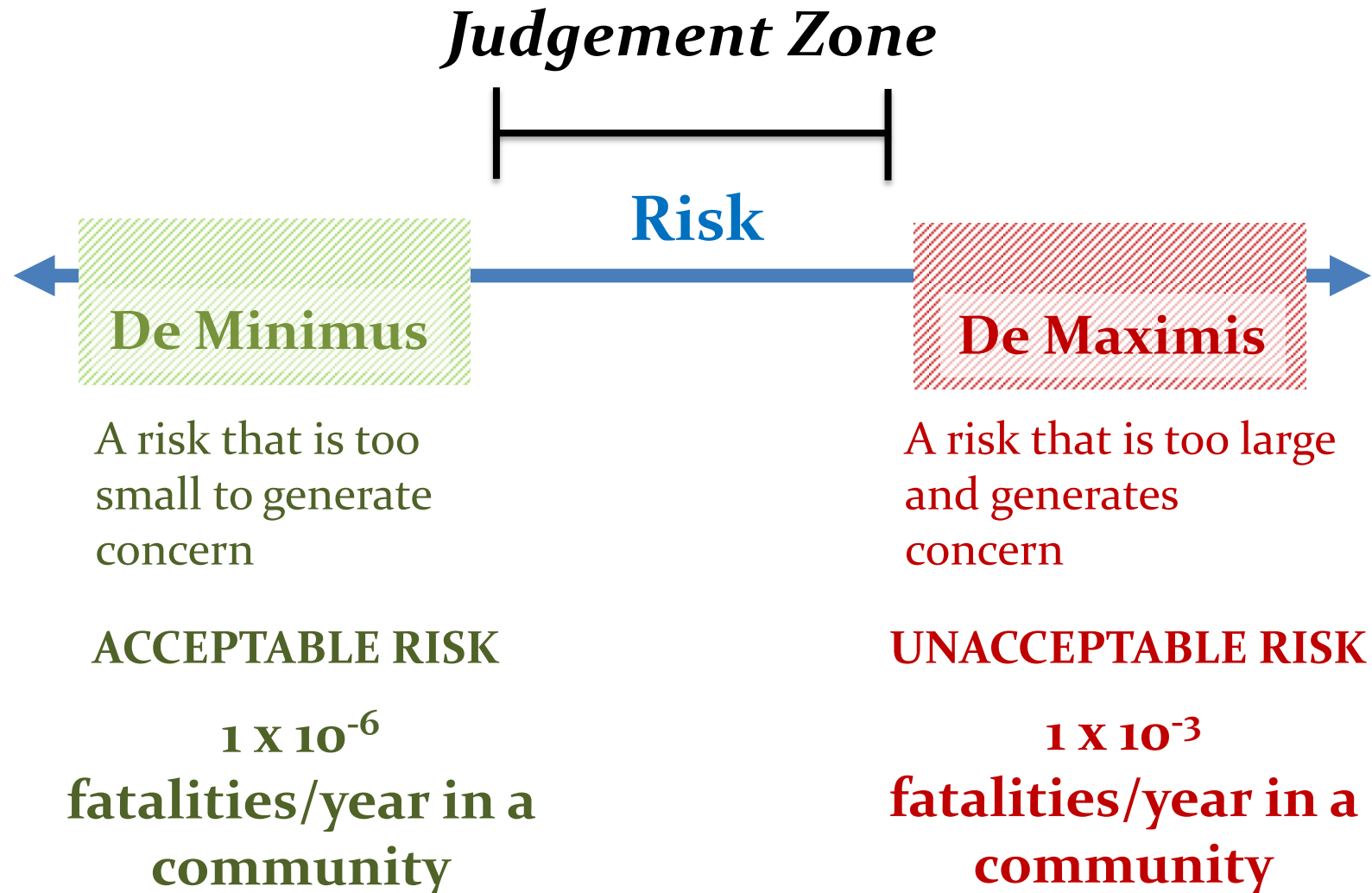
- Assembly Line Worker
- Commercial Flight

Societal Risk

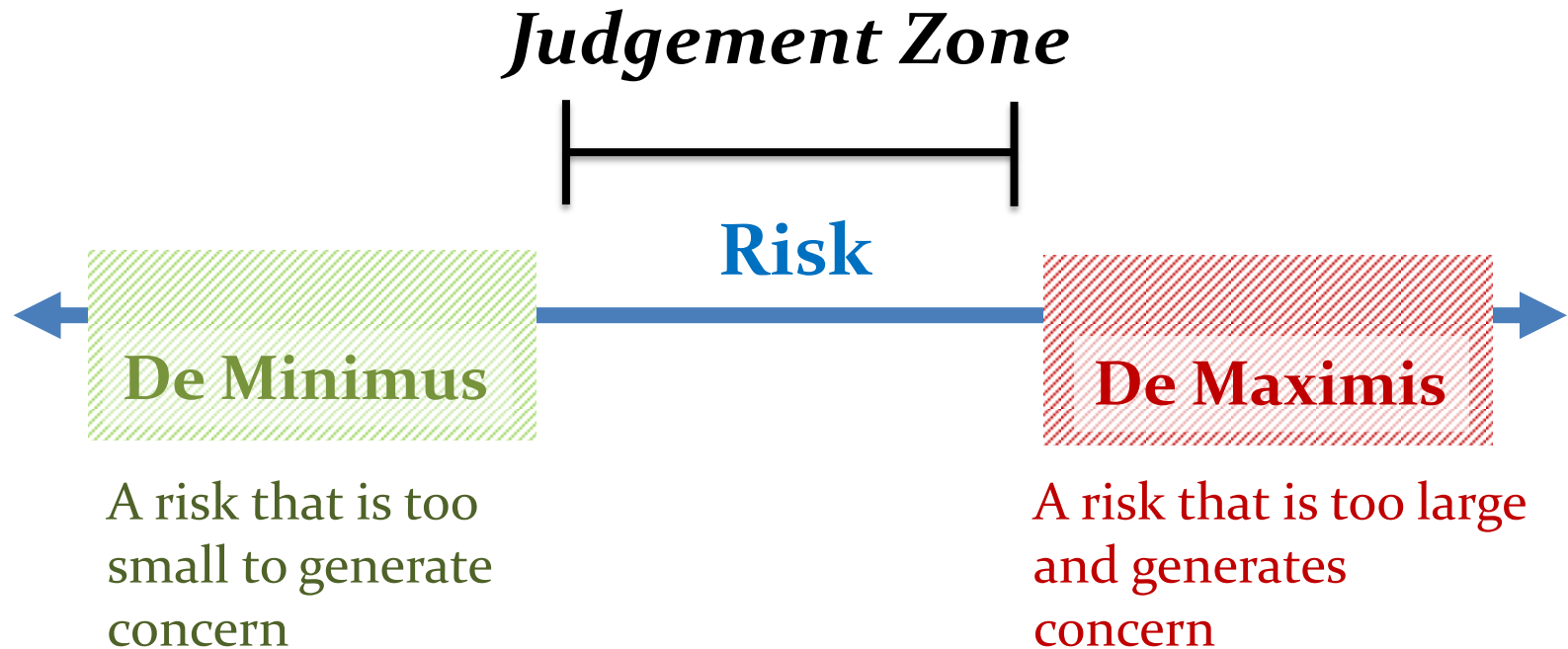
- Plane Crash

Each person has a level of individual and voluntary risk they will tolerate for their own safety. However, when considering involuntary and societal risk, we must accept a standardised level of risk.

What is Acceptable Risk?



What is Acceptable Risk?



Toronto's Population = 3 million

Deaths per
year

<3
Acceptable

>3000
Unacceptable

Acceptable Risk: Car Accidents

In 2010, there were 2,000 car accidents with 2227 victims.

The Canada-wide risk can be determined by accounting for the population of the nation (34 million)

$$\text{Canada – wide Risk} = \frac{2227 \text{ fatalities per year}}{34 \text{ million population}}$$

$$= 65 \times 10^{-6} \text{ fatalities per year}$$

JUDGEMENT ZONE

Acceptable Risk: Ontario Workplace Injuries

In 2010, there were 184,099 people injured such that they could not go to work the next day.

There were 6.82 million workers in Ontario in 2010.

Ontario Injury Risk = 3 injures per year per 100 workers

Is this acceptable?

Who is responsible for risk?

The stakeholders responsible for identifying and managing risk include:

- *Employers*
- *Employees*
- *Government and other regulatory authorities*
- *Compensation and insurance providers*
- *The public*

In an organization, occupational health and safety involves everyone, from the chief executive officer to the worker. Employees and employers often are jointly responsible for occupational health and safety and employers are accountable for non-compliance.

Why bother with identifying hazards and risks?

- *Economics*
- *Legality*
- *Morality*
- Corporate image
- Employee and employer well-being
- Liability
- Insurance
- Professional Ethics
- Good corporate moral
- Employee recruitment

Why bother with identifying hazards and risks?

Morality

It is generally accepted that employers have moral responsibility their employees in providing a safe working environment

Economics

The indirect and direct economic costs of workplace accidents and illnesses are significant. Costs can be associated with the time lost from work, human pain and suffering, and the subsequent loss of moral and decline in worker efficiency and productivity.

Why bother with identifying hazards and risks?

Legality

Governmental legislation on occupation health and safety provides workers with the right to a safe work environment. In protecting workers, employers must exercise due diligence. For example, employers must take reasonable precautions appropriate for the circumstances. There are significant legal penalties for violating health and safety legislation; they can civil lawsuits and criminal prosecutions.

Checkpoint

This is a condition:

- A. Health
- B. Safety
- C. Risk
- D. Hazard

Answer: D

Checkpoint

This is considered to be an acceptable level of risk for societal or voluntary activities:

- A. 1 in 10,000 fatalities
- B. 1 in 100,000 fatalities
- C. 1 in 1,000,000 fatalities
- D. 1 in 10,000,000 fatalities

Answer: C

Checkpoint

This is the unit of risk analysis:

- A. Cost per event
- B. Fatalities per event
- C. Fatalities per year
- D. Extent of Injury per event

Answer: C

Checkpoint

Which of the following is a reason for a company to be interested in workplace safety?

- A. Employee and employer well-being
- B. Insurance
- C. Corporate Image
- D. Economics
- E. All of the above

Answer: E

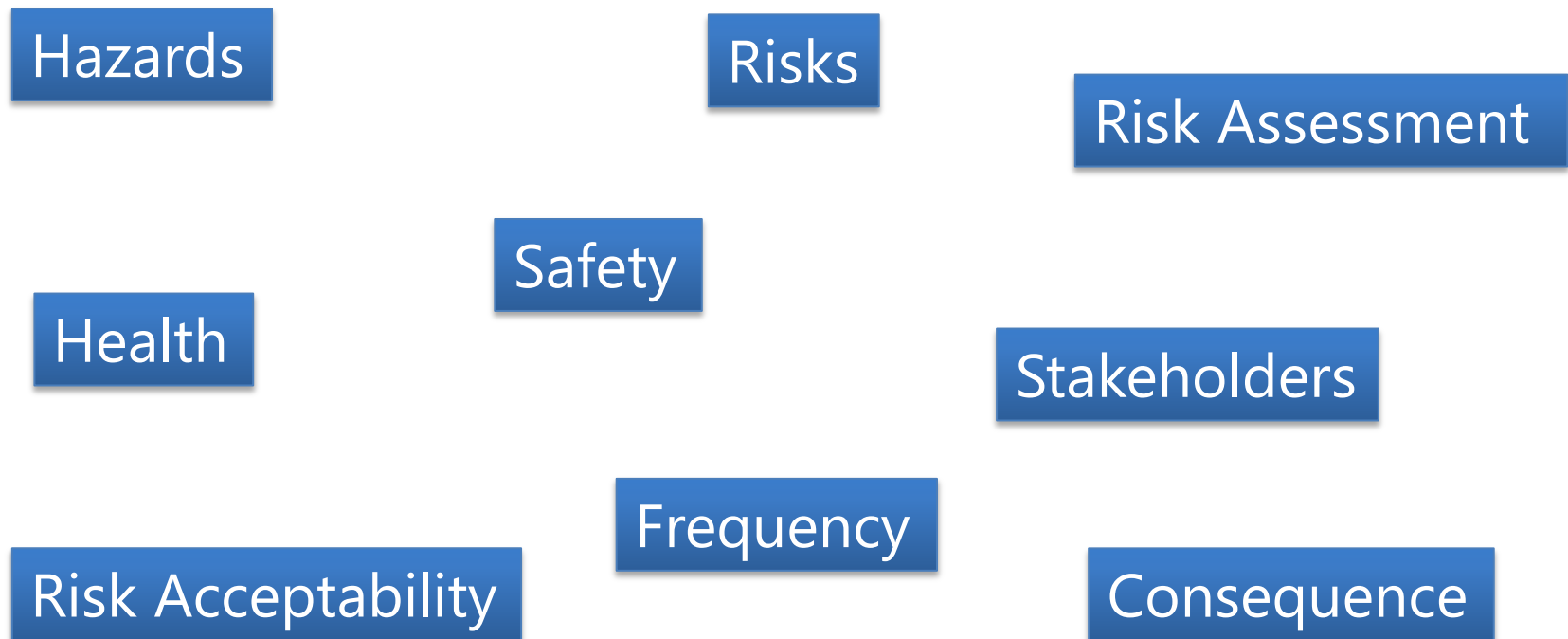
Checkpoint

Which of the following is a reason for a company to be interested in workplace safety?

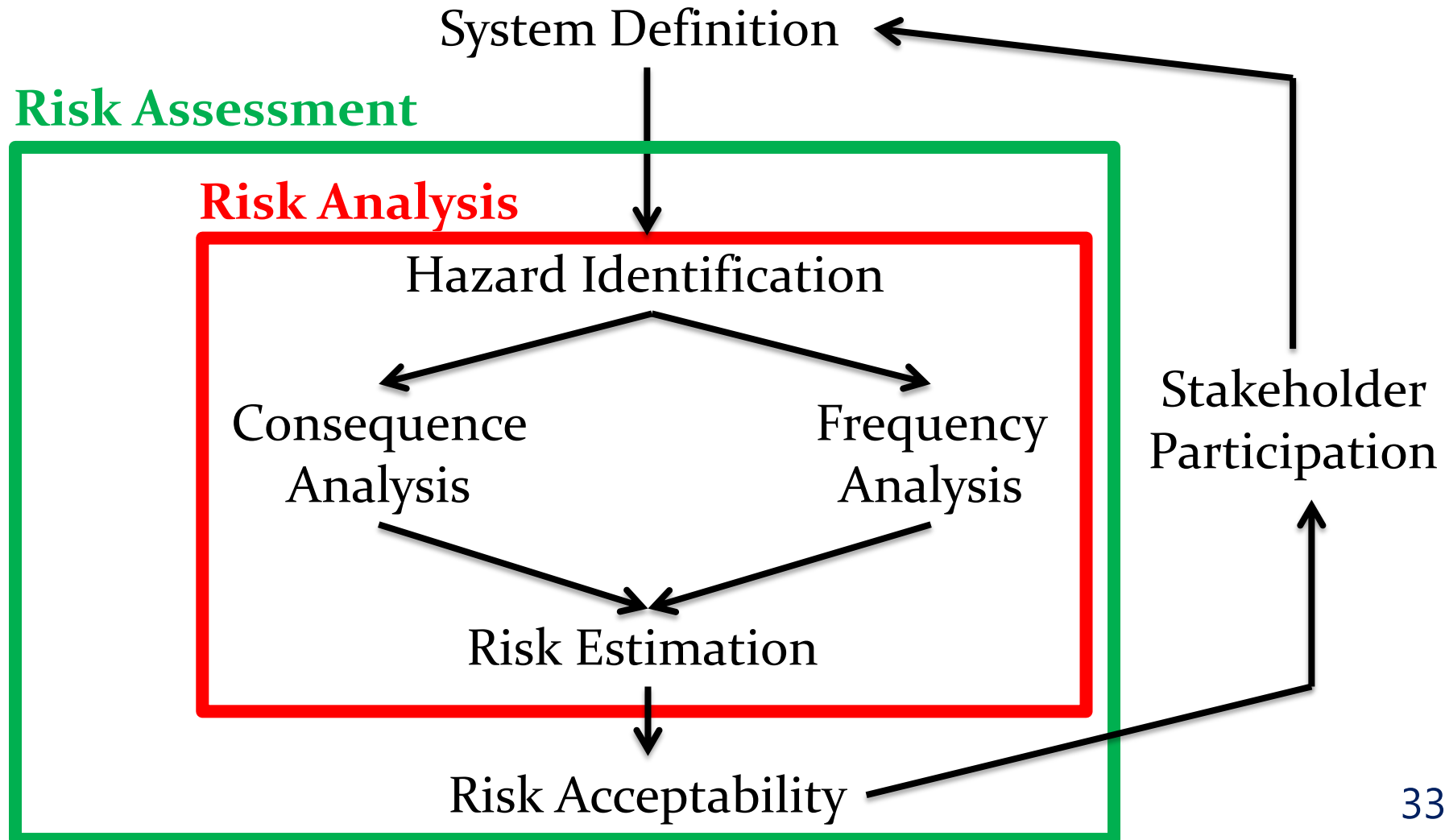
- A. Employee and employer well-being
- B. Insurance
- C. Corporate Image
- D. Economics
- E. All of the above

Answer: E

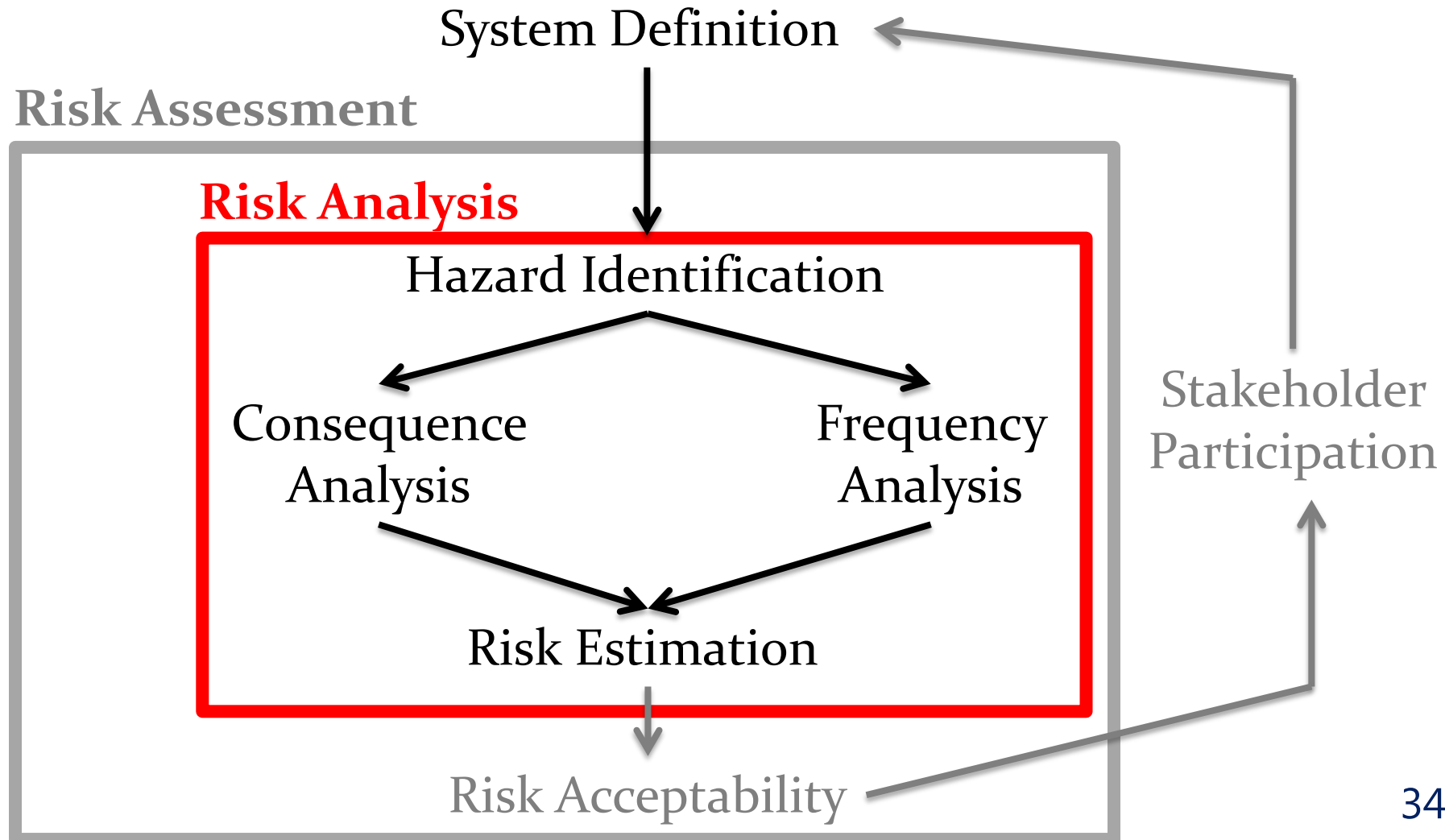
How do all these concepts fit together?



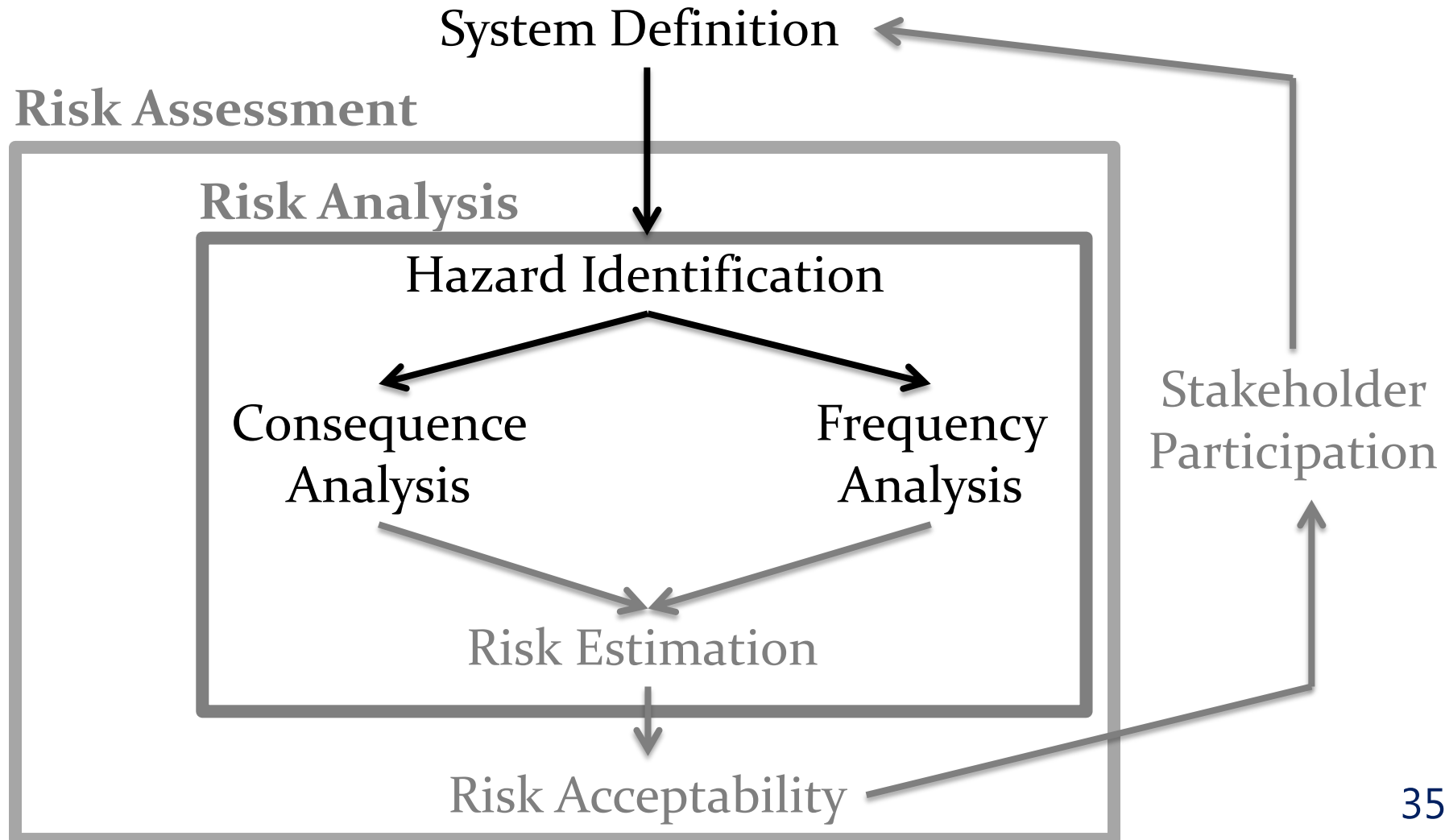
Hazard and Risk Framework



Hazard and Risk Framework



Hazard and Risk Framework



Hazard Identification

Hazard identification is conducted with a aim of understanding the intrinsic hazards associated with any given situation and their potential to cause damage.

Identify *hazards*



Think through hazard *event scenarios*



Recognise the *consequences* of these hazard event scenarios and their *severity*

Where do we find hazards?

Here are some broad examples of hazardous events related to process safety management:

Identified Hazard	Hazardous Event
Fires	Thermal radiation exposure
Explosions	Overpressure and possibility shrapnel
Moving Machinery	Kinetic energy, pinch points
Gasoline	Highly flammable
Hydrogen Sulphide	Toxic by inhalation

Where do we find hazards?

Hazards are often related to *energy*, most often potential energies.

- **Kinetic Energy**

- Involved with *moving* equipment
- Momentum is proportional to velocity squared. Equipment moving with higher speeds pose greater consequence. A car moving collision at a high speed will cause more damage.
- *Machine guards* are good safeguards to keep people away from equipment with moving parts.

- **Potential Energy**

- Associated with changes in elevation (a box placed on a high shelf) or pressure (a vacuum system).
- Pipeline are typically elevated in chemical facilities which places liquids in tanks and vessels 5 – 20 m above ground.

Where do we find hazards?

Hazards are often related to *energy*, which can also include:

- **Heat**
 - Released from chemical reactions – unreacted molecules are a source of potential energy, when reacted heat is released.
 - Hot surfaces can initiate fires and explosions which can cause severe burn.
- **Electricity**
 - Hazards can result from electric shock, arcing incidents or electrical fires
 - Shocks are the most common and may occur through direct contact of an energised conductor or contacting two points at different electrical potentials. Shock can cause fatalities.

Hazards on different scales



Hazards on different scales



Community

University Lab Injuries

Injuries that can involve you



- Michele Dufault, a final year Yale undergrad student, died when her hair got caught in a lathe when working alone in the Chemistry workshop at 2:30am.

Hazards on different scales



Individual



Workers



Facility



Community

Health Care Industry

Worker Injuries



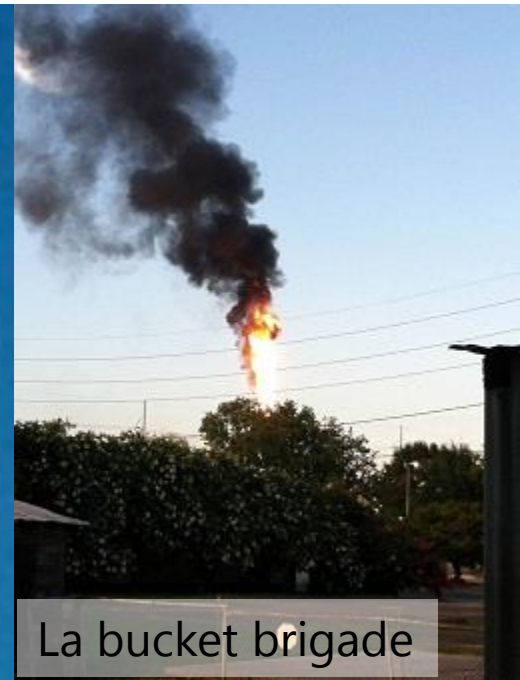
- Healthcare workers have the greatest risk of workplace injuries and mental health problems than any other occupational group.
- Back injuries are the biggest worker injury issue
- 3.7 injuries per 100 full time employees

Hazards on different scales



Norco, Louisiana

1988 – Shell Oil Refinery Explosion



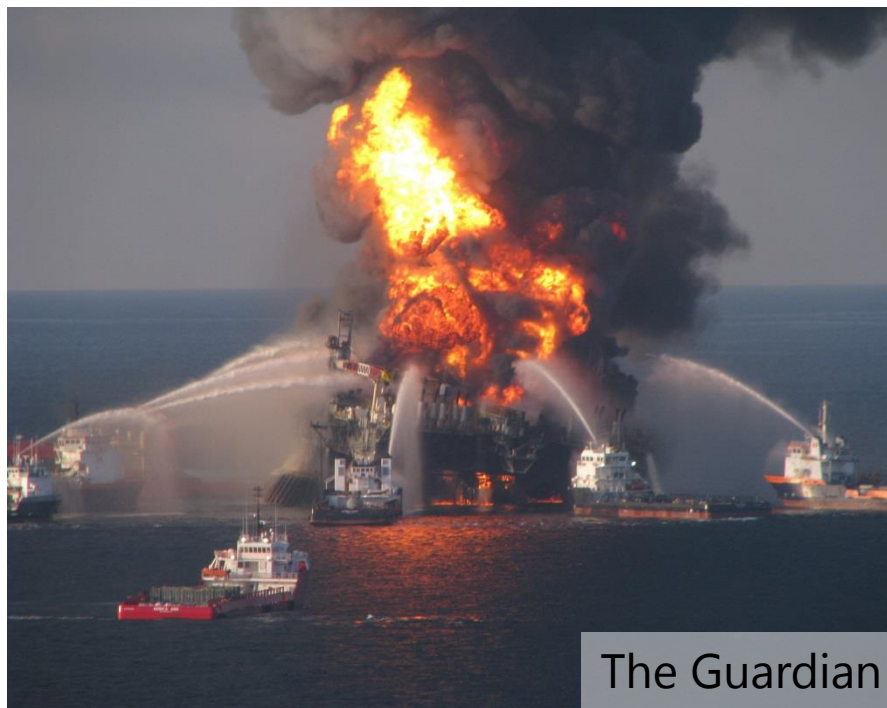
- Resulted from an equipment failure
- Large releases of benzene, hydrogen sulphide, butadiene
- 7 deaths, 42 injuries and \$400 million in damages

Hazards on different scales



Gulf of Mexico, US

2010 – BP Deepwater Horizon Oil Rig Spill



- High pressure methane gas explosion
- 4.9 millions of barrels of oil spilled in gulf (780,000 m³)
- 11 deaths, significant injury and deaths in wildlife population

Hazard Identification

Start to looking for energy sources or release mechanisms.

Energy Sources

- Leak from a flammable gas vessel into the air can create an ignitable mixture.
- This hazard can be minimised by using proper construction materials, regular leak testing and installing explosion proof electrical connections.
- These safeguards reduce the risk the likelihood of the hazard but cannot eliminate it.

Release Mechanisms

- Large reactors and vessels can be major problems given the volume of material stored.
- As tank size increases, surface area to volume ratios decrease. The ability for tanks to release heat is proportional to the surface area (d^2) and the energy content is proportional to the volume (d^3).

Hazard Identification – Primary Tools

- Common Sense
- Open mind
- Good understanding of physics, chemistry and thermodynamics
- Experience – first hand or access to historical data
- **Process Hazard Analysis**
 - Screening Level
 - Checklist
 - What-if
 - Failure Modes and Effects Analysis (FMEA)
 - Hazard and Operability Study (HAZOP)

**Qualitative
Techniques**

All techniques seek to understand the physical components of the system, the operation and the factors influencing failure frequency.

*Process Hazard Analysis techniques present a **pro-active** and **systematic** approach for the identification, mitigation or prevention of hazards from a process, materials, equipment or human error.*

The **purpose** of Process Hazard Analysis :

- Determine the location of the potential safety problem
- Prevent or mitigate the improvement of safety measures of a problem
- Pre-plan emergency actions that should be taken if the safety controls fail

Process Hazard Analysis **methods address**:

- Any hazards in an process
- Previous incidents which could have resulted in catastrophic outcomes
- Engineering controls that can be used to prevent or mitigate hazards
- Consequences of hazards
- Human factors that could cause hazards

Process Hazard Analysis can miss some hazards...

- No method is capable of identifying all hazards in a system
- It is feasible for a hazard to be excluded from the scope if the engineering team is unaware of a hazard event scenario
- It is essential that the team seriously consider all hazard event scenarios

Hazard Identification – So many techniques, which one to choose?

Selecting a hazard identification technique is typically influenced by the following factors:

- Motivation
- Type of result needed
- Type of information available to perform the study
- Characteristic of the analysis problem
- Perceived risk associated with the subject process or activity
- Resource availability and preference of the analyst

Hazard Identification – Common Technique Application

	Screening Level	Checklist	What-if	FMEA	HAZOP
Research & Development	✓		✓		
Conceptual Design	✓	✓	✓		
Pilot Plant Operation	✓	✓	✓	✓	✓
Detailed Engineering	✓	✓	✓	✓	✓
Construction	✓	✓	✓		
Routine Operation	✓	✓	✓	✓	✓
Plant Expansion or Modification	✓	✓	✓	✓	✓
Incident Investigation	✓		✓	✓	✓
Decommissioning	✓	✓	✓		

Hazard Identification – Qualitative Techniques

- *Screening Level* is the recommended starting point to through evaluation of all significant hazards
- This screening level technique should be immediately followed by more detailed analysis for *identified hazards* that warrant further examination.
- When all significant potential undesirable events are identified then their *consequence and frequency* will be investigated.
- Risk evaluation then produces a *risk ranking list* which allows management to set priorities and define alternative *risk control* measures.

Hazard Identification – Moving beyond Screening Level

- Once a Screen Level is complete then other more detailed methods can be applied
- Hazard and Operability Study (HAZOP) is recommended as the second analysis stage of **process systems**
- Failure Modes and Effects Analysis (FMEA) is recommended for the second, more detailed qualitative analysis complex **equipment or machinery**.

Let's now discuss each of the qualitative hazard identification methods in more detail.

Screening Level For Hazard and Risks Identification

- Focus on *identifying major hazards that could lead to severe consequences*.
- This technique can be applied to:
 - Existing permanent and temporary processes, equipment and machinery during the implementation phase of a Process Safety/ Risk Management Programme
 - New facilities during their conceptual design and detailed engineering phases
 - Major modification to existing facilities

Screening Level**Checklist****What-if****FMEA****HAZOP**

This PHA technique...

- Uses a *process-focused protocol* to identify potential undesirable events
- Relies on participation of *front-line personnel* through physical inspections

We'll now walk through the individual steps of performing screen level.

Overview of the Procedure

1. Collect and review **information** about the facility
2. Divide the facility into **process sections**
3. Compile a list of **intrinsic hazards** for each process section (ie. chemical, equipment and external events).
4. Identify **hazardous events** in each process section
5. Evaluate the potential **causes**.

STEP 1

Collect *general information* about the engineering facility:

- Facility plan, equipment layout, map, transportation routes
- Equipment and process descriptions
- Chemicals handled
- Spill containment and emergency response systems
- Environmental, occupational health and safety, process safety, loss control quality management systems
- Incident history

STEP 2

Divide the facility into *process sections*. This will enable consideration of the all process areas, auxiliary services including transportation and distribution facilities.

Let's consider an example of process sections at a product distribution business:

At the company site

- Storage
- Loading
- Electrical supply
- Wastewater treatment system
- Firewater protection system
- Shops building
- Fuel depot

External to the company site

- Rail transport
- Truck transport
- Marine transport
- Distribution terminals
- Customer sites

STEP 3

List potential the inherently hazardous items for each process section.

Ask yourself what can go wrong?

- Equipment
- Chemicals
- Electrical systems
- Facility's building structure

This information can be collected by interviewing operators and engineer designers, reviewing previous hazard studies and by inspecting each of the process sections.

Screening Level**Checklist****What-if****FMEA****HAZOP**

Hazard identification in a screening level involves consideration of:

- The hazards of each process section
- Previous hazardous incidents
- Engineering and administrative controls
- The consequences of engineering and administrative control failure
- Human failure
- Maintenance programmes
- Process safety, safety and loss control programmes

Screening Level**Checklist****What-if****FMEA****HAZOP**

There are some helpful tools for identifying hazards associated with each process section:

- **HazMat checklist** – properties of the chemical and material hazards
- **Compatibility matrix** – consequences of interaction between chemical or materials
- **Equipment Hazard checklist** – overview of potential operating failures
- **External Initiating Factors checklist** – events induced by adjacent facilities or natural causes

Screening Level**Checklist****What-if****FMEA****HAZOP**

A ***HazMat checklist*** is a useful tool for rigorously understanding the ***hazards and potential consequences of materials***.

Company:		Participants:		By:												
Location:																
Date:																
Hazard Review Section:																
Materials, Chemicals or Components	Physical State (Liquid, solid, powders)	Quantity (Throughput or inventory)	Operating Pressure	Operating Temperature	Compressed or Liquefied Gas	Fire	Explosion	Oxidiser	Corrosive	Reactive	Radiation	Air or Water Pollutants	Smells/Fumes	Toxic – Acute /Chronic	Detonation	Ground Contaminant

Screening Level**Checklist****What-if****FMEA****HAZOP**

It is also useful to consider how materials in each process section will interact. A **compatibility matrix** is a useful tool.

	Chemical 1	Chemical 2	Chemical 3	Chemical 4	Chemical 5	Chemical 6	Chemical 7	Chemical 8	Chemical 9	Chemical 10
Chemical 1										
Chemical 2										
Chemical 3										
Chemical 4										
Chemical 5										
Chemical 6										
Chemical 7										
Chemical 8										
Chemical 9										
Chemical 10										

Screening Level**Checklist****What-if****FMEA****HAZOP**

An ***Equipment Hazard checklist*** is a useful tool for rigorously understanding the ***hazards and significant losses associated with equipment*** in each section.

Company:

Participants:

By:

Date:

Location:

Hazard Review Section:

Equipment or Workspace	Stationary or Mobile	Operating Pressure	Mechanical Energy	Pressurised Systems	Heat	Extreme Cold	Electrical Energy	Impact/ Collision	Falling/ Flying Objects	Radioactive	Confined Space	Noise	Sharps	Seismic	Rock/ Mud Flow	Capital Value >\$500k	Production Value >25%

Screening Level**Checklist****What-if****FMEA****HAZOP**

An **External Initiating Factors checklist** is a useful for understanding hazards from adjacent facilities or environments in addition to natural events.

Company:
Location:

Participants:
Hazard Review Section:

By:

Date:

Process Area	Geotechnical Events							Other External Events							Operating Events						
	Seismic Activity	Avalanche/ Landslide	Soil Shrinkage/ Consolidation	Erosion	Waves	Flows and Drainage	Containment (normal, surge)	Drought	Flooding/ Rain/ Snow Melt	Extreme Cold/ Ice Cover	Extreme Heat	Extreme Winds	Fog	Forest Fire	Hail	Internal Flooding	Maintenance Activity	Construction	Sabotage/ Vandalism	Night Work	Power Failure

STEP 4

Pair each inherent hazard (chemical, material, equipment, initiating factor) with an action to develop a list of *hazardous events*.

- Release
- Fire
- Exposure
- Failure

Screening Level**Checklist****What-if****FMEA****HAZOP**

Here is an example of a selection of hazardous event list for a chemical plant:

Process Section	Hazardous Event
Natural Gas Supply	Jet Flame
Process Steam Supply	Boiler Explosion
Feed Gas Preparation	Spent Catalyst Bed
Reformer Unit	Firebox Explosion
Shops Building	Drum Spillage
Fuel Depot	Gasoline Leak from Tanks
Carbon Dioxide Injection System	Liquid Spill
Methanol Separator	Gas Release and Fire
Distillation Section	Pool Fire
Electrical Supply	Pool Fire
Cooling Tower	Carryover Emission

STEP 5

List all major *potential causes* of identified hazardous events.

Use **checklists to organise the causes** into 5 categories:

- *Open-ended loss of containment* – drains, vents, relief valves, etc.
- *Internal agency* – disintegration of rotating machinery, blockage, etc.
- *External agency* – collision, weather, seismic, etc.
- *Equipment failure while operating* within design conditions due to deterioration, faulty maintenance or improper replacement of materials.
- *Equipment failure by exceeding design limits* on pressure, temperature and composition

Finishing up a Screening Level

- Develop a scope for a more detailed hazard identification analysis (i.e. HAZOP).
- Identify opportunities for improvement:
 - Physical plant (design, maintenance, technology)
 - Employee training
 - Management systems/ integration
 - Emergency response
- Assign priorities to improvement opportunities based on the priority of the risk they are designed to address
- Assign responsibility
- Follow up

Checklists

- A checklist is a detailed **lists of known intrinsic hazards or hazardous events** compiled based on past experience facility design and operation.
- Questions are answered with a ‘Yes’ or ‘No’
- Hazards are identified through compliance with established standards

It is essential that checklists be validated for system before use.

Checklists

Purpose

- Identify hazards
- Check compliance with a set of standard procedures

Reviews

- Existing systems – tours, inspections, interview
- New process – team member review of process drawings

Results

- Responses to standard checklist questions
- List of hazards and suggested corrective action

Categories and Questions

- **Causes of Accidents**

Process equipment, human error, external events

- Is the process equipment properly supported?
- Is equipment properly identified?
- Is the system designed to withstand a tsunami?

- **Facility Functions**

Documentation and training, instrumentation, construction materials, piping, pumps, vessels, control systems, alarms, etc.

- Is it possible to distinguish between different alarms?
- Is pressure relief provided?
- Is the vessel free from external corrosion?
- Are sources of ignition controlled?

Screening Level**Checklist****What-if****FMEA****HAZOP**

Advantages

- Can be used by non-system experts
- Capture a wide range of historical experience and knowledge
- Ensures common or obvious problems are not overlooked

Disadvantages

- Limited application to new systems
- Inhibits creative thinking about new hazard identification
- Overview hazards that have not been previously identified

Final details of the Checklist procedure

- The simplest process hazard analysis techniques
- Provides quick results and communicates information well
- Good way to account for learned lessons
- NOT a good method for identifying new or unrecognised hazards
- Application requires good knowledge of the system and standard operating procedures
- Requires regular updating and auditing

What-if analysis

- Experienced personnel brainstorm a series of ‘What if’ questions.
- Each question represents a potential failure or hazard in the facility
- If it is possible for a hazard to occur then the safeguards must be evaluated for the severity of the consequence

Examples

Equipment failures – *What if ... a pump fails?*

Human error – *What if ... an operator fails to clean up a chemical spill?*

External events – *What if ... there is a rapid snow melt?*

What-if analysis

Purpose

- Identify hazards and consequence to develop risk mitigation strategies

Requirements

- Process descriptions, drawings and operating procedure
- Preliminary list of what-if questions

Analysis Procedure

- Go through the system process, starting with the introduction of the feed until the end of the process
- Ask ‘what-if’ at each process stage

Results

- Recommendations on the effects of removing hazards

Overview of the procedure

1. Collect and review information about the facility
2. Divide the facility into process sections
3. Select a question and identify:
 - Hazards
 - Consequences
 - Severity
 - Likelihood
 - Recommendations
4. Repeat Steps 4 – 6 until process is complete

Here is an example of **what-if questions** for a plant:

Area	What-if	Hazard and Consequence	Previously Addressed	Safeguard	Recommendations?
Chemical 1	Connects to the wrong line when loading off truck?	1) Released into the air - an explosion is possible 2) Gets wet - bacteria will grow and become useless.	No	1) Lines are sized differently 2) Labelled 3) Colour coded 4) Use a reliable vendor	1) Vacuum system to remove dust 2) Perform a moisture test
	Truck's ignition is on while unloading?	Exhaust fumes – adverse health effects	No	None	1) Turn engine off 2) Local ventilation system
	The dust collector fails?	Dust accumulation – adverse health effects	No	None	1) Place an alarm with lights and horns in the truck unloading area.

Final details of the What-if procedure

- One of the most commonly used process hazard analysis techniques
- One of the least structured techniques
 - Applicable to a large range of systems
 - The experience of the analyst determines if the technique will be successful
- Useful when making a change to a process section
- Can be applied to a system at any point in its life cycle

Failure Modes and Effect Analysis

- Lists ways equipment can fail and the effect on the system.
- Bottom-up analysis
- Uses a spreadsheet to detail each hazard, cause, frequency, consequence and proposed safeguard

Failure Modes and Effect Analysis

Purpose

- Assess component failures and the hazards caused
- Develop recommendations for better equipment reliability

Requirements

- Process descriptions, drawings and operating procedure

Analysis Procedure

- Go through the system process, starting with the introduction of the feed until the end of the process
- Complete the FMEA table

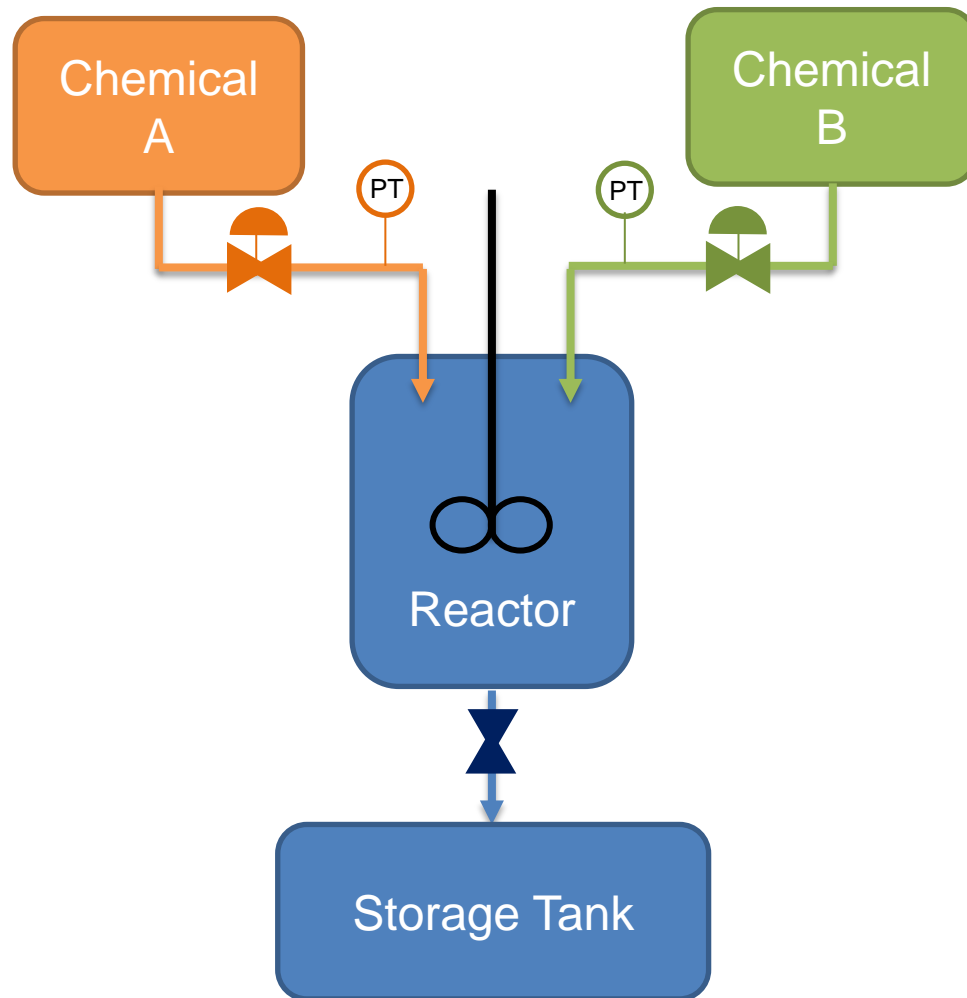
Results

- Recommendations on safeguards to avoid hazards associated with equipment failures

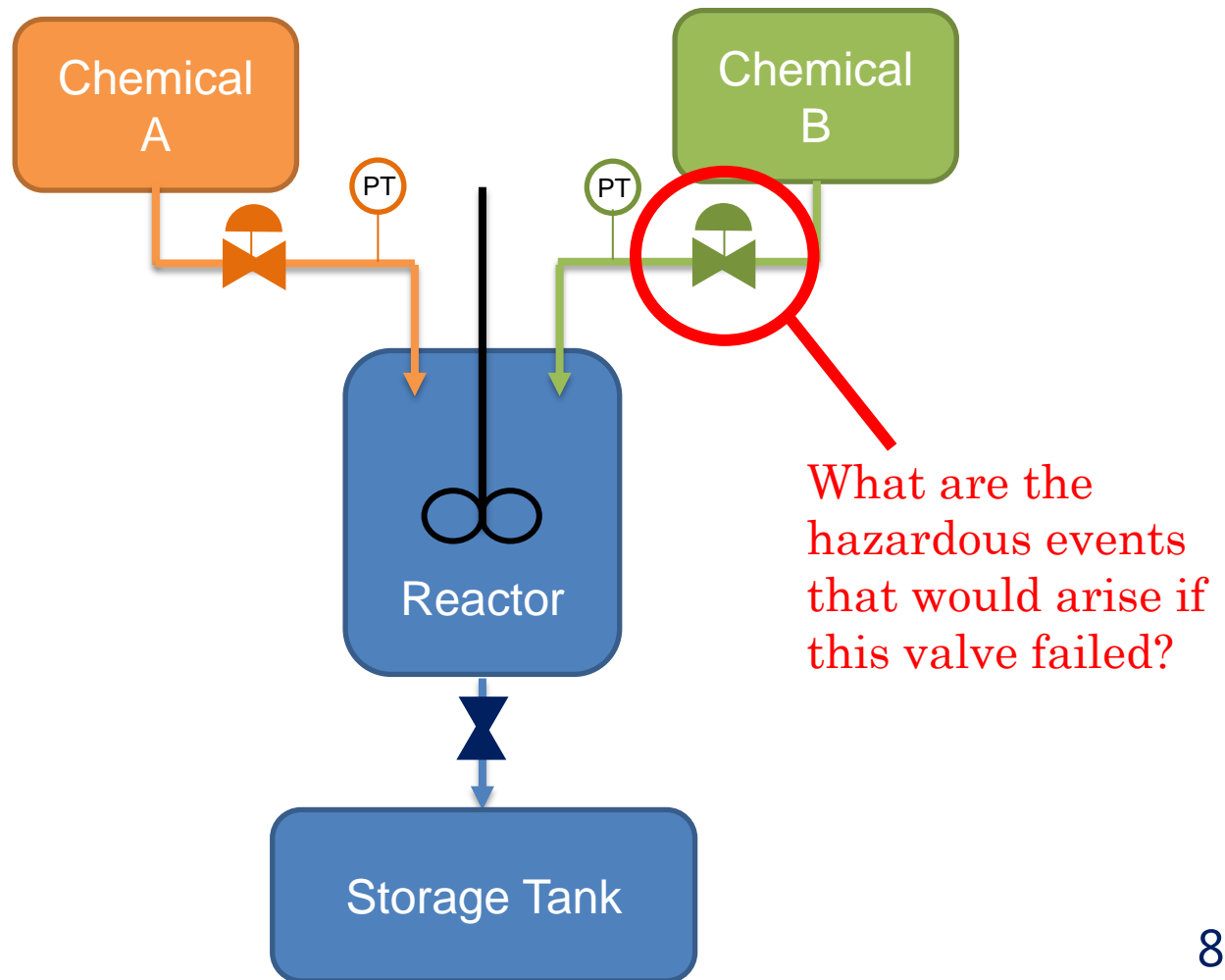
Keywords for FMEA analysis

- Crack
- Rupture
- Plugged
- Leak
- False start or stop
- Loss of function
- High or low pressure
- High or low temperature
- Overfilling
- Failure to open or close
- Failure to start or stop

What are some point of failures in this chemical system?



What are some point of failures in this chemical system?



Screening Level**Checklist****What-if****FMEA****HAZOP**

Here is a FMEA example for valve failure on chemical B:

Date: October 15, 2013
Plant: Chemical Toronto
System: Reaction System

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By: Minerva

Item	Identification	Description	Failure Modes	Effects	Safeguards	Actions
3.1	Valve on the chemical B solution line	Motor-operated and normally open for chemical B service	Fails closed	No flow of chemical B Carryover of chemical A to the storage and released in the enclosed work area	Flow indicator on chemical B line Chemical A detector and alarm	Consider alarm/shutdown of system for low chemical B flow Consider using a closed storage tank or ensure adequate ventilation of enclosed work area

Final details of the FMEA procedure

- Very structured process hazard analysis technique that is reliable for evaluating systems
- Easy to learn and apply the technique
- Can be time-consuming and expensive as the technique doesn't directly identify process sections where multiple faults could occur
- The technique may not identify areas of human error in process sections
- Procedural review is not easy

Hazard and Operability Study

Structured brainstorm using guide words to identify *hazards* (health, safety and environmental) and *operations* in a system.

Purpose

- Systematic identification of hazards

Requirements

- Process descriptions, drawings and operating procedure

Analysis Procedure

- Evaluate deviations from normal operation as potential hazards

Results

- Understand hazards and consequences for process sections
- Recommendations of safeguards as a protection against the hazards

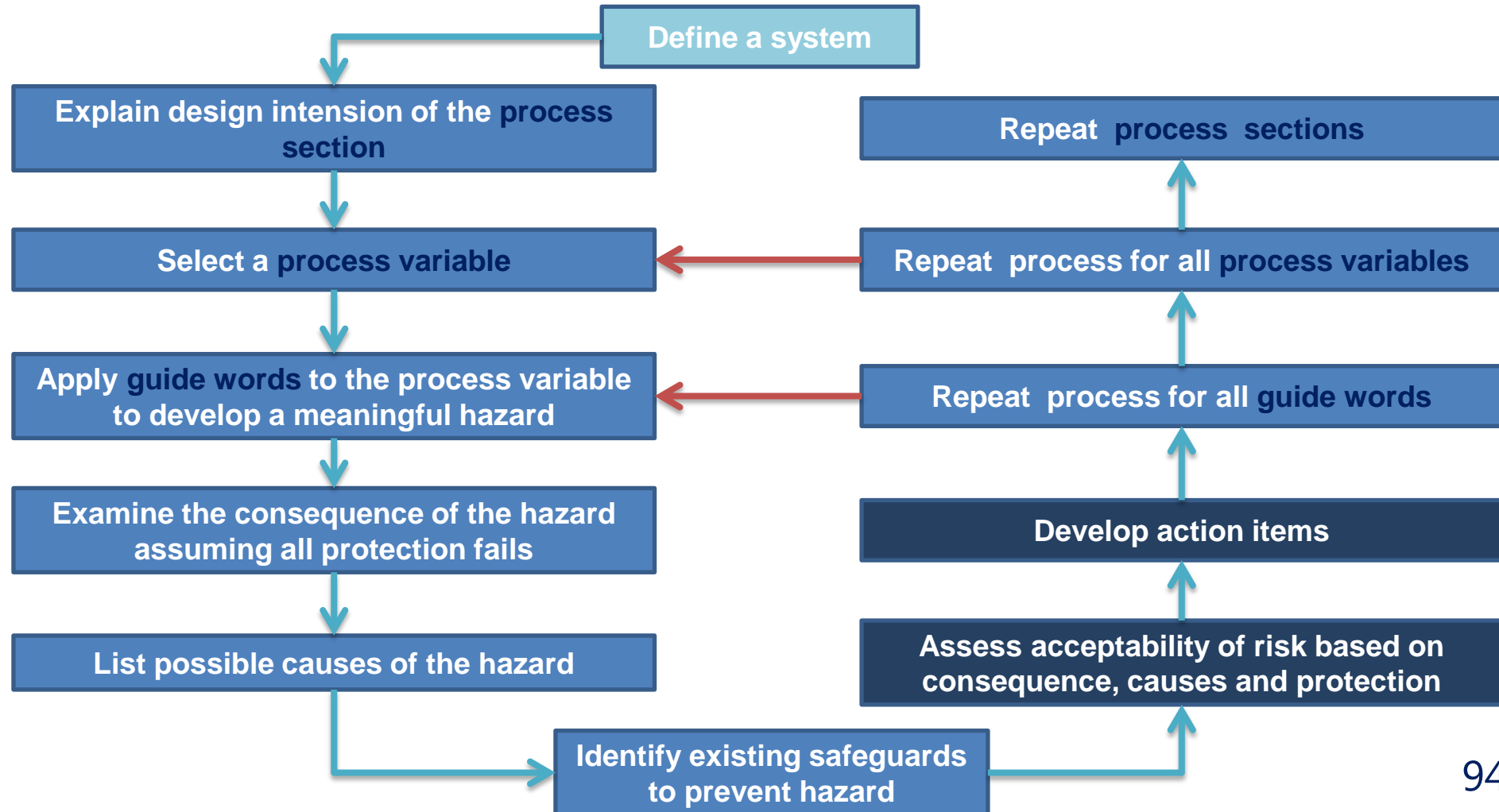
Before going through details of the HAZOP procedure, let's review some *relevant terminology*:

Intentions	How the process operations are expected to occur
Hazard	Departures from the design intentions
Causes	Ways the hazard might occur
Consequences	Results of the hazard
Safeguards	Provisions for reducing the frequency or decrease the severity of the consequence of the hazard
Actions	Suggestions for the procedural changes, design changes or further study

When performing a HAZOP there are *several general hazard types* of you should focus on:

- Leak
- Rupture
- Reaction
- Static
- Corrosion or Erosion
- Relief
- Sampling
- Testing
- Maintenance
- Start-up
- Shutdown
- Service Failure

Over view of the Procedure



What is meant by *process variables*?

- Flow
- Pressure
- Temperature
- Level
- Time
- Composition
- pH
- Speed
- Frequency
- Viscosity
- Voltage
- Mixing
- Addition
- Separation
- Reaction

Be aware not all combinations make sense!

HAZOP uses guide words to identify process deviations which could lead to hazards:

Guide Words	Meaning
No, not	Not doing what was intended
More (high, long, ...) Less (low, short, ...)	Doing more, or less, of what is intended, quantitative increase or decrease
Part of, As well as	Doing it differently; qualitative decrease or increase
Reverse	Doing something else; logical opposite of the intent
Other Than	Doing something else; complete substitution

Guide Word + Process Parameter = Process Deviation

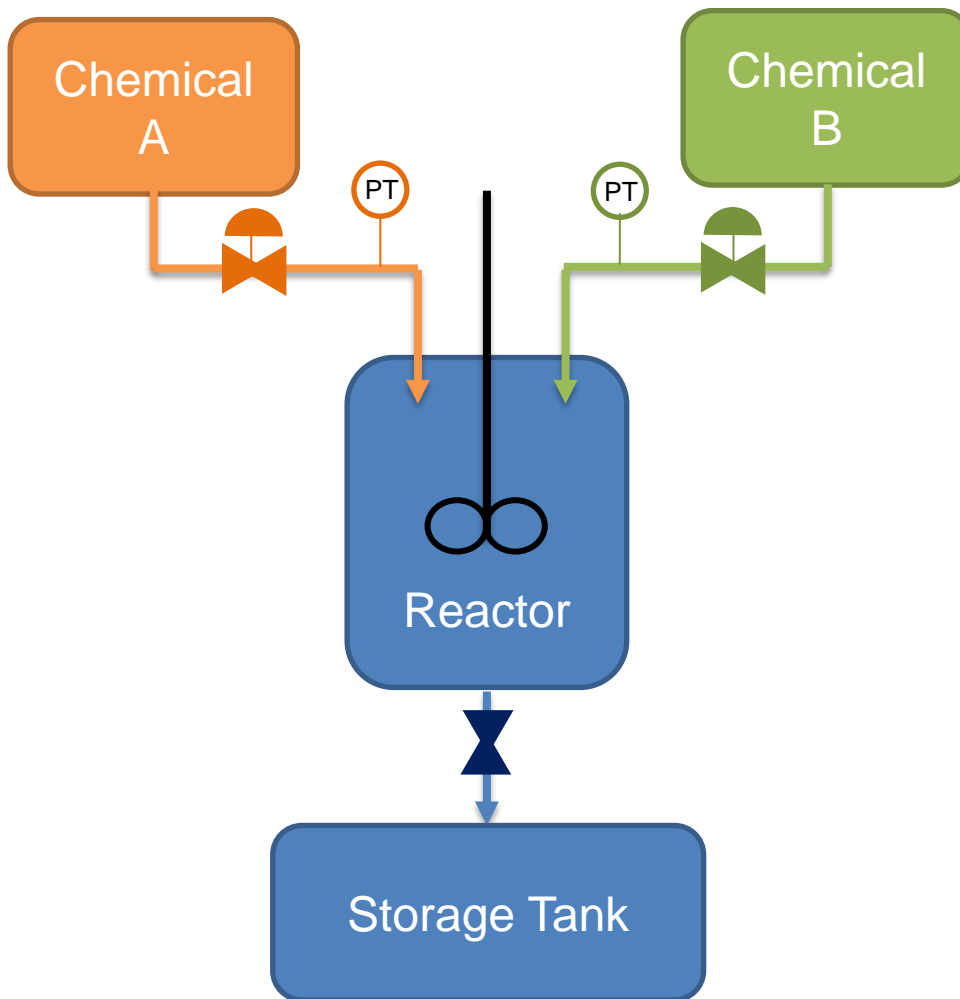
Example:

Less

Flow

No reaction

Example of hazards resulting from process deviations



Process Variables

Flow, Temperature, Pressure

Guideword + Process Variable Combinations

- *No Flow* of Chemical A
= No reaction
- *High Temperature* in reactor
= degradation of product
- *Low pressure* in storage tank
= flow out of reactor accelerated

This technique makes some inherent assumptions...

- Hazards are detectable with careful review
- Engineering facilities are designed and operated to appropriate standards
- Hazards can be controlled by a combination of equipment, procedures
- This technique is conducted with openness and good faith by competent analysts

This identification procedure has *limitations:*

- Requires a well-defined system
- It is time consuming
- Provides no numeric ranking of hazards
- Requires trained personnel to conduct
- Focuses on one-event failures

Screening Level

Checklist

What-if

FMEA

HAZOP

Advantages

- Creative and open-ended
- Rigorous and structured procedure
- Very versatile
- Identifies **both** safety and operational hazards

Disadvantages

- Can be time-consuming
- Critical that experienced analysts are involved in the process
- No distinction between low and high probability and consequence hazards

Summary of Hazard Identification Techniques

What are the end products?

- A list of intrinsic hazards
- A list of hazardous events and existing/ potential prevent/mitigation strategies:
 - Event scenarios
 - Their potential causes
 - Existing safeguards
 - Possible additional safeguards
- A list of potential consequences and their frequency
 - Low chance of burn injuries or death,
 - Moderate change of damage to process equipment,
 - Low change of injury or death from toxic gas inhalation

Checkpoint

Process Hazard Analysis presents techniques what purpose:

- A. Identification of hazards
- B. Mitigation of hazards
- C. Prevention of hazards
- D. A , B and C
- E. A and C

Answer: D

Checkpoint

Process Hazard Analysis should be conducted in parallel with:

- A. Common sense
- B. An open mind
- C. A good understanding of physics, chemistry and thermodynamics
- D. All of the above
- E. None of the above

Answer: D

Checkpoint

For routine plant operation, which of Process Hazard Analysis is the best to use?

- A. Screening Level followed by FMEA
- B. Checklist followed by HAZOP
- C. Checklist and What-if
- D. Screening Level, What-if or HAZOP
- E. Screening Level, Checklist, What-if, FMEA or HAZOP

Answer: E

Checkpoint

Which of the follow is false about checklists as a hazard identification technique?

- A. The method is applicable to new systems
- B. It is possible to capture a range of historical system knowledge
- C. Ensures that common problems are not overlooked
- D. New users are able to use the approach

Answer: A

Checkpoint

Which best describes a failure modes and effect analysis approach?

- A. Bottom-up analysis
- B. Top-down analysis

Answer: A

Hazards caused by Human Error

Materials, equipment and electrical components in a process can be attributed to hazards. However, human factors can also cause errors which lead to hazardous events.

What causes workplace injuries?

- *4% are due to unsafe work conditions*
- *96% result from unsafe worker actions*

Unsafe behaviours are often repeated when observed as being “safe” (ie not injured).

The Safety Iceberg



What lies below the water?

Major Facility Accidents (BP Oil Spill)

Medical treatment
First aid care
Near miss incidents

Most errors happen below the water, they are small and often go unnoticed by upper management. It is essential to focus on this level of hazards as they commonly propagate into larger hazards over time.

Understanding Human Limitations

Human error can be best prevent by understanding the main factors which mediate the limitations of human behaviour:

- Attention
- Perception
- Memory
- Logical Reasoning

Understanding Human Limitations

Attention

- Huge amounts of information overloads humans in the workplace and attention on a task can only be sustained for short time, about 20 minutes.
- Workers are prone to fatigue and errors when their attention is not focused.
 - *Information Bottleneck* – attention can only be focused on a small number of tasks.
 - *Habit Forming* – If a task is repeated often then we tend to complete it without any conscious supervision. Regular, repetitive behaviours can cause mistakes.

Are you still focused on hazard identification?
Take a quick stretch.

Understanding Human Limitations

Perception

- Safe interaction in the workplace requires correct perception of hazards – information can be easily misinterpreted.
 - *Interpreting the senses* – we interpret information we sense rather than perceiving it directly. Errors can be minimised by making information more visual.
 - *Signal Detection* – More intense stimuli cause more powerful responses. Danger signs in the workplace are purposely designed to provoked a response.



Traffic lights signal to stop with a red light (most dangerous) then yellow and finally green to go (no danger).

Understanding Human Limitations

Memory

- The amount of information expected that workers remember can cause great stress.
 - *Capacity* – Short-term memory has very limited capacity.
 - *Accessibility* – It can be difficult to access details stored in our memory.
 - *Levels of processing* – Learning material at great depth helps us more reliably remember information.

Understanding Human Limitations

Memory

Take a look at these risk related terms.

Quantitative Analysis

Effect Modelling

Risk Management

Bow-tie

Probit

Continual Improvement

Layers of Protection

Fixed Limit

Stakeholders

ALPHA

Toxicity

Learning Loop

Understanding Human Limitations

Memory

How many of those risk terms can you remember?

Understanding Human Limitations

Memory

On average, people can remember no more than **7** individual items at one time.

If you were told these terms were grouped into three topics, it is likely your retention of this information would have been improved:

Quantitative Analysis

Bow-tie

Layers of Protection

ALPHA

Effect Modelling

Probit

Fixed Limit

Toxicity

Risk Management

Continual Improvement

Stakeholders

Learning Loop

Understanding Human Limitations

Logical Reasoning

- Not all people are good at logical thinking but technical situations require logical procedures.
- Severe implications can result from failures in reasoning and decision making in engineering facilities.

Design Principles for a Good System

To prevent hazards caused by human error, it is essential that a system inhibit people from making mistakes easily.

There are 6 design principles for creating a good system:

- User-centred Design
- Managing Information
- Reducing Complexity
- Visibility
- Constraining Behaviour
- Design for Errors

Design Principles for a Good System

User-centred Design

- There is often a difference in how the user thinks about the system and the system itself. This discrepancy happens because the system designer rarely becomes the system user.
- The design needs to think about the expectations and intentions of the user.

Design Principles for a Good System

Managing Information

- We are easily distracted which cause us to forget essential tasks.
- Maintenance tasks are an example of easily omitted tasks:
 - *At home* – How large is your pile of laundry or dishes by the sink?
 - *At an engineering facility* the same issues arise. When workers are under time pressure, replacing worn gaskets can be overlooked.
 - A simple solution to both examples would be to include these maintenance items on a daily checklist or put them into your calendar.

Design Principles for a Good System

Reducing Complexity

- The more complicated a task, the more likely there will be human error.
- By structuring tasks to be as simple as possible, our ability to manage information is improved.
- For example, this online module was organised into 6 sections that were placed in a logical sequence. This was done to reduce complexity of the material and facilitate the learning process.

Design Principles for a Good System

Constraining Behaviour

- If it were possible for a system to inhibit a user from performing any dangerous actions then there would be no accidents. This is impossible as the real world is too complicated!
- ‘Forcing functions’ is a concept that is useful when trying to push users to follow a series of steps.



An example of constrained behaviour is a cash machine.

- Before you can walk away with your cash, the machine prompts you with lights and a sound to first remove your cash card. This prevents the user from walking away without their card.

Design Principles for a Good System

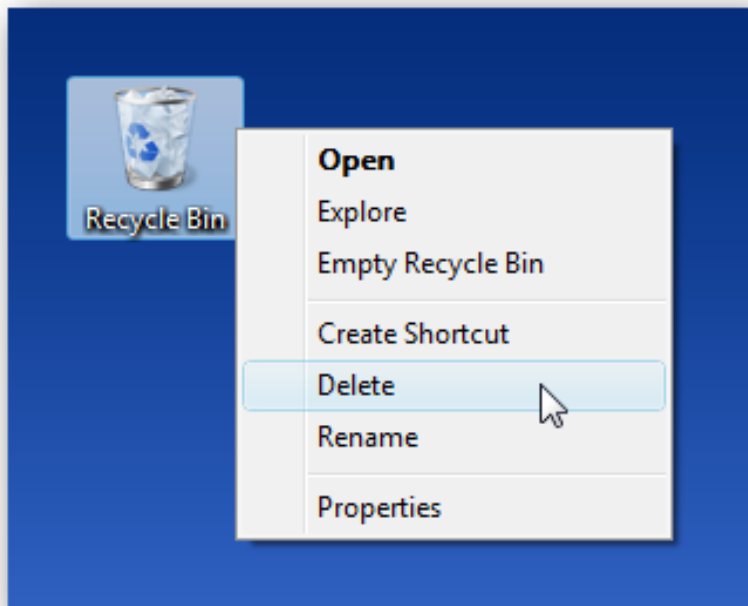
Design for Errors

- When a system is designed, you must assume that mistakes will happen. When these mistakes happen, it is necessary that essential systems be designed to recovery from these human errors.
- It should be difficult for the user to proceed with actions that are non-reversible.

Design Principles for a Good System

Design for Errors

Before permanently deleting files from your computer, you are prompted asking if you are sure you want proceed.



Design Principles for a Good System

Visibility

- When the user is able to perceive how their actions will influence the system, there are fewer human errors.



*Prior to the nuclear incident at Three Mile Island, an example of **poor user visibility** was reported. Experienced operators were not able to comprehend the implications of elevated reactor temperatures. Their inability to perceive the negative feedback that reactors elevated temperatures would have on the plant lead them to underestimate the situation's severity.*

A Culture of Safety

- Human error cannot be blamed solely on the worker.
- The management team in an organisation play an important role in the overall safety at the facility. Decisions at this level are key to fostering a culture of safety – this thinking lays the foundation for accident prevention.
- A safety culture represents the values, attitudes, competencies and behaviour patterns of the workers and management team. This actions and beliefs drive quality of the organisation's health and safety programmes.

A Culture of Safety

A shared perspective about the importance of safety and preventative measurements at all levels of an organisation is central to a positive safety culture.

Factors that contribute to a positive safety culture:

- **Felt Leadership**
 - Commitment from the CEO and management
- **Policies and principles of safety**
 - All illnesses and injuries can be prevented – the goal is zero
 - Management is responsible for safety
 - Adherence to safety is a condition of employment
 - Employee involvement is essential

A Culture of Safety

Factors that contribute to a positive safety culture:

- Follow safe procedures – be seen doing it – believe it

This thinking influences employee through:

- Strong personal involvement
- Setting an example
- Building commitment to urgency, accountability, willingness
- Setting high standards and expecting no less from others



Stop Programme

Behaviour based safety through peer observation

- Hi!
- I see that you have your proper personal protection equipment for the job you are doing; that's good.
- I am however concerned about how you are lifting the equipment, you could hurt yourself. May I suggest an alternative approach to lifting.

A Culture of Safety

Factors that contribute to a positive safety culture:

- Tools to get the job done
 - Expertise in safety resources
 - Procedures and development
 - Communication and motivation
 - Audits and investigations
 - Rituals

A Culture of Safety

Factors that contribute to a positive safety culture:

- Good communication and shared goals that extend beyond the workplace
 - Instilled values and beliefs will be practiced by workers irrespective of what work they are doing, where they are doing it or who is watching.
 - Practicing safe practices at home is important as off-the-job injuries cause personal suffering to the injured person and their family.

Summary

Hazards generated by human error can be understood through the factors governing the **limitations of human behaviour**: attention, perception, memory, logical reasoning.

Designing a good system to prevent human error can be achieved following key principles: user-centred design, managing information, reducing complexity, visibility, constraining behaviour, and designing for errors.

Once a good system is designed, instilling a **culture of safety** is essential to developing an organisation. In this culture, each employee exhibits a mindset and behaviour that ensures that their well-being leaving the workplace is the same or better than when they arrived – *a commitment to zero injuries*.

Checkpoint

What is the percentage of occurrences that unsafe worker actions the cause of workplace injuries?

- A. <5% of occurrences
- B. >15% of occurrences
- C. >50% of occurrences
- D. >75 of occurrences
- E. >95% of occurrences

Answer: E

Checkpoint

Human error can be blamed solely on the worker:

- A. True
- B. False

Answer: B

Checkpoint

What are factors that contribute to limitations of human memory?

- A. Capacity, processing levels and accessibility
- B. Capacity, aptitude and processing level
- C. Capacity and interest level

Answer: A

Checkpoint

Designing a system for errors is defined as:

- A. Inclusion of safeguards to prevent hazardous events caused by human error
- B. Inclusion of safeguards to mitigate hazardous events caused by human error
- C. It should be difficult for the user to proceed with actions that are non-reversible
- D. Essential systems affected by inevitable mistakes from human error should be designed to recover

Answer: C

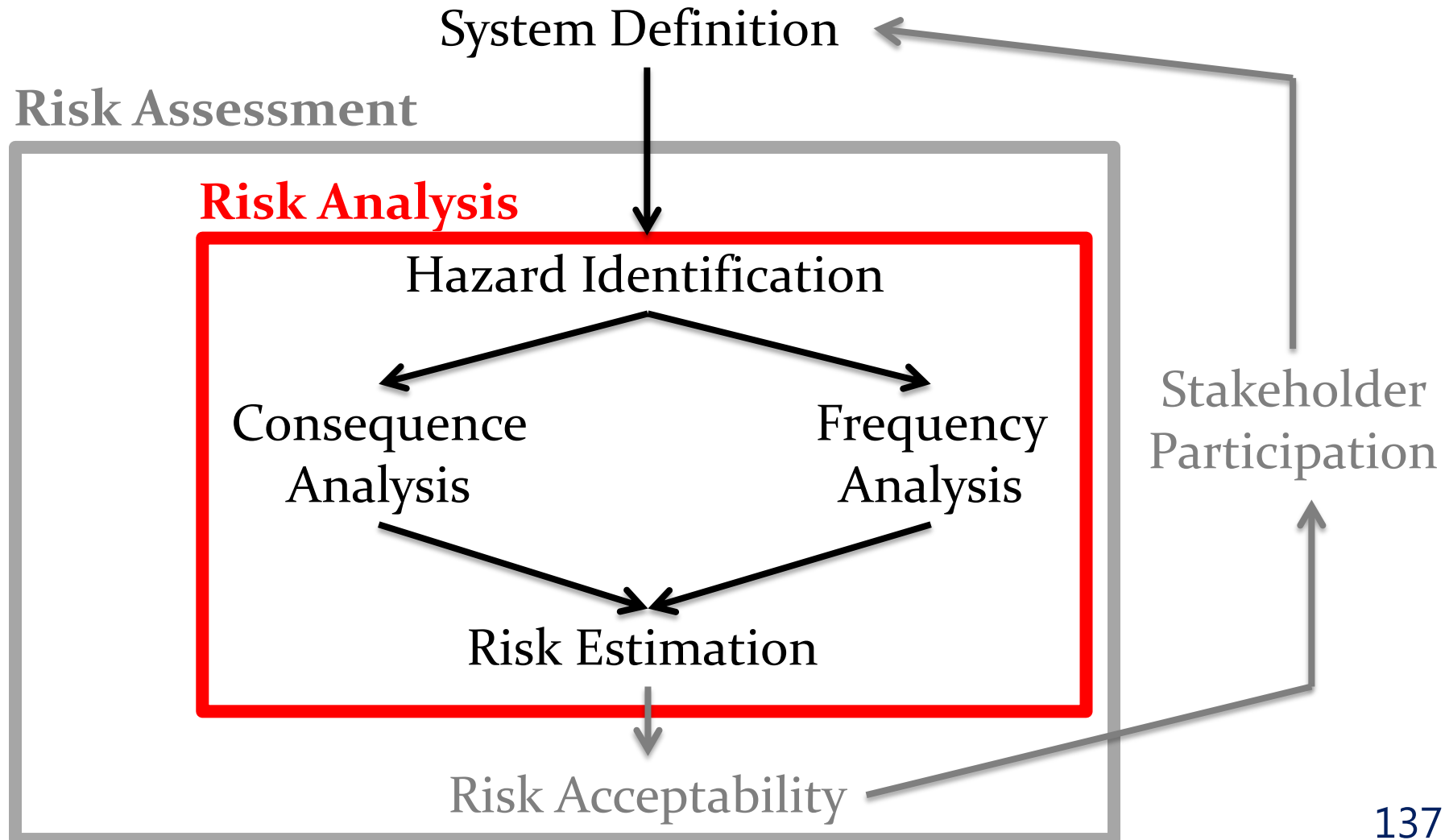
Checkpoint

What is meant by a “commitment-to-zero”?

- A. Zero worker sick days
- B. Zero worker accidents
- C. Zero workplace hazards

Answer: B

Hazard and Risk Framework



Review of the end product from Process Hazard Analysis

- A list of intrinsic hazards
- A list of hazardous events and existing/ potential prevent/mitigation strategies:
 - Event scenarios
 - Their potential causes
 - Existing safeguards
 - Possible additional safeguards
- Some analysis techniques may also generate a list of potential consequences and their frequency
 - Low chance of burn injuries or death,
 - Moderate change of damage to process equipment,
 - Low change of injury or death from toxic gas inhalation

Overview of the Procedure

1. Identify the **consequence** of each hazard
2. Categorise each consequence
3. Evaluate the **frequency** of each consequence
4. Categorise these frequencies
5. Prioritise hazards based on categorised consequences and frequencies using a **risk matrix**
6. Use the risk matrix to **rank risks** from each hazard
7. Develop **action plans** for high-risk events

STEP 1

Identify consequences of each hazardous event and classify each with respect to relevant risk receptors:

- Employee safety and health
- Public safety and health
- The environment
- Production
- Equipment and machinery
- Company reputation and market share

STEP 2

Categorise consequences according the level of event severity.

Categorise *hazard consequences* with these tables:

Category	Consequences to the Public	Consequence to Employees
1	No injury or health effects	No injury or occupational safety impact
2	Minor injury or health effects	Minor injury or occupational safety impact
3	Injury or moderate health effects	Injury or moderate occupational illness
4	Death or severe health effects	Death or severe occupational illness

Category	Consequences to Capital Loss, Facility/Equipment Damage
1	< \$100,000
2	\$100,000 - \$1,000,000
3	\$1,000,000 - \$10,000,000
4	> \$10,000,000

Category	Environment Consequences	Consequence to Production Loss	Consequence to Market Share Loss
1	< \$1,000	< 1 week	< 1 week
2	\$1,000 - \$10,000	1 week – 1 month	1 week – 1 month
3	\$10,000 - \$100,000	1 – 6 months	1 – 6 months
4	> \$100,000	> 6 months	> 6 months

STEP 3

Estimate the frequency range of each consequence.

How many times per year will this hazard consequence happen?

STEP 4

Categorise consequences according the level of event severity.

Three levels of severity can be selected:

- Least stringent
- More stringent
- Most stringent

Categorise the *frequency of hazard consequences* with these tables – pick least, more and most stringent cases:

Least Stringent

Category	Frequency Range	Description
1	< 0.02 / year	Not expected to occur during the facility's lifetime (about 50 years), but possible
2	0.02 – 0.05 / year	Expected to occur no more than once during the facility's lifetime
3	0.05 – 1 / year	Expected to occur several times during the facility's lifetime
4	> 1 / year	Expected to occur more than once a year

Categorise the *frequency of hazard consequences* with these tables – pick least, more and most stringent cases:

More Stringent

Category	Frequency Range	Description
1	< 0.001 / year	Remote – A series of failures, with a low probability of occurring within the facility's lifetime
2	0.001 – 0.01 / year	Unlikely – A failure with a low probability of occurring within the facility's lifetime
3	0.01 – 0.1 / year	Probable – A failure which can reasonably be expected to occur once within the expected lifetime of the plant.
4	> 0.1 / year	Frequent – A failure which can reasonably be expected to occur more than once within the facility's lifetime.

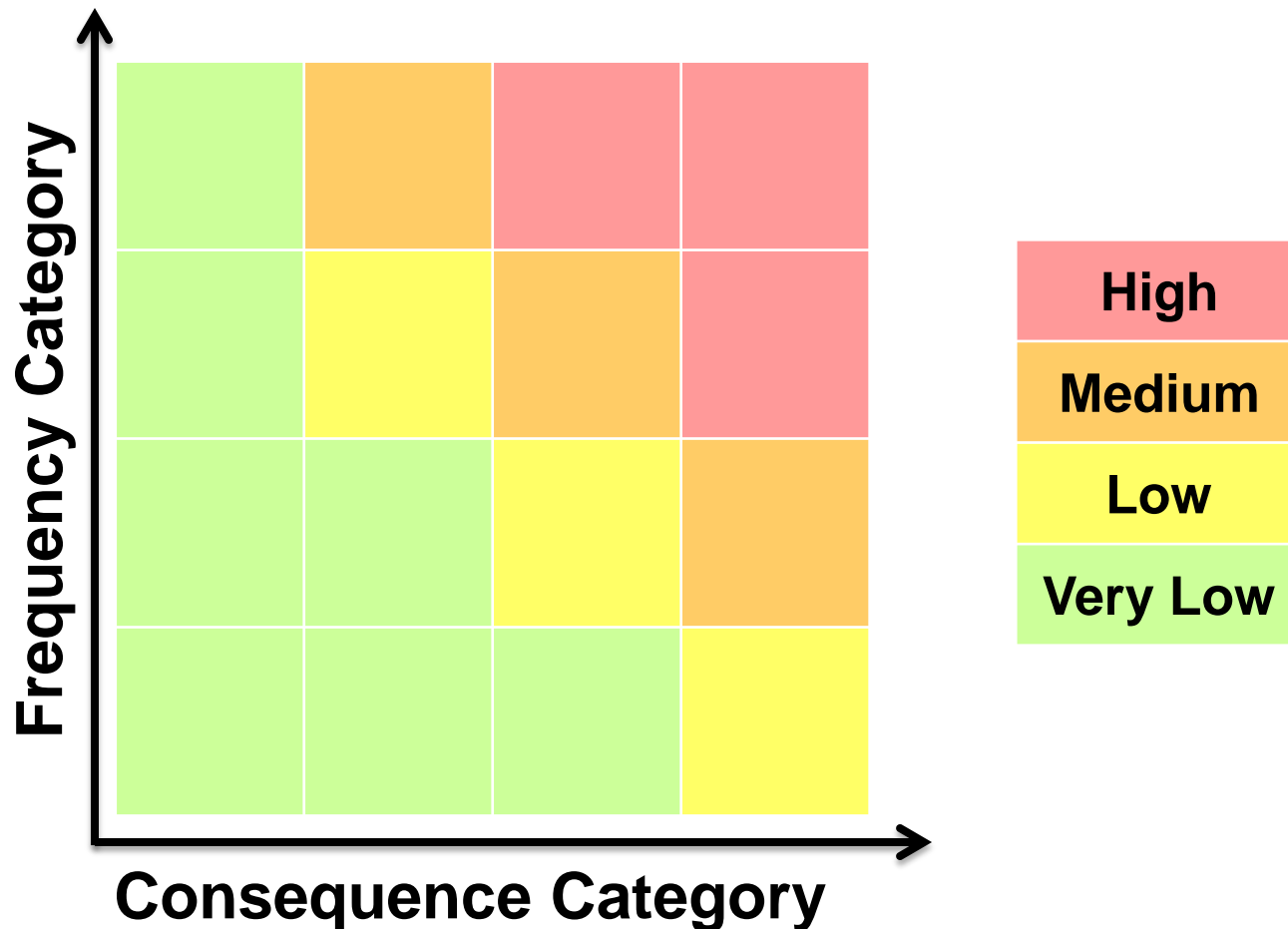
Categorise the *frequency of hazard consequences* with these tables – pick least, more and most stringent cases:

Most Stringent

Category	Frequency Range	Description
1	$< 10^{-6}$ / year	Remote – A series of failures, with a low probability of occurring within the facility's lifetime
2	$10^{-6} - 10^{-4}$ / year	Unlikely – A failure with a low probability of occurring within the facility's lifetime
3	$10^{-4} - 0.01$ / year	Probable – A failure which can reasonably be expected to occur once within the expected lifetime of the plant.
4	> 0.01 / year	Frequent – A failure which can reasonably be expected to occur more than once within the facility's lifetime.

STEP 5

Rank each hazardous event with a *risk matrix*.



Hazardous event categories in the risk ranking matrix.

High (H)	Should be mitigated with engineering and/or administrative controls to a risk ranking of LOW or VERY LOW within a specified time frame (i.e. 6 months).
Medium (M)	Should be mitigated with engineering and/or administrative controls to a risk ranking of LOW or VERY LOW within a specified time frame (i.e. 12 months).
Low (L)	Should be verified on a continuous basis to ensure procedures or controls are in place.
Very Low (VL)	No mitigation required.

STEP 6 - Rank the risk association with each hazard

Process Area	Hazardous Event	Potential Cause	Existing Safeguards to Prevent Event	Expected Future Frequency (#/year)	Risk Receptors						Maximum Event Risk Score	Comments	Recommended Actions
					Public			Employee					
					Consequence Score	Frequency Score	Risk Score	Consequence Score	Frequency Score	Risk Score			
Natural Gas Supply	Fireball and jet flame from transmission line	Above ground pipeline rupture from impact of heavy machinery	None	1/20	4	1	L	4	3	H	H	No physical impact protection where pipe comes out of the ground	Install collision protection at main inlet to plant process area; Improve line labelling and develop unique colour coding for piping.
Natural Gas Supply	Gas release with H ₂ S traces	Upstream failure to treat gas at source	None	1	2	1	VL	2	1	VL	VL	None	Check H ₂ S in gas supply.

Note: This risk matrix is simplified. A complete matrix includes risk score for all risk receptors (public, environment, employees, production, capital equipment and market share).

STEP 7

For each hazardous event, develop *safeguards*, including action plans for any interactions between adjacent units and the emergency response on site.

Summary

Risk analysis estimates the risk from hazards to individuals, populations, property or the environment.

This analysis follows the two steps:

- **Hazard identification**
 - Definition of undesirable events and the type of potential damage
- **Risk estimation**
 - Measure of the level of health, property or environmental risks
 - Consequence and frequency analyses

It is important that **no value judgements** be included from risk analysis.

Checkpoint

Risk Analysis is best described as:

- A. Consequence and frequency analyses
- B. Hazard identification and risk estimation
- C. Hazard identification and risk acceptability
- D. Hazard identification, risk estimation and risk acceptability

Answer: B

Checkpoint

Once hazards are identified, how is risk analysed?

- A. Consequences and frequencies are identified and evaluated through a risk matrix
- B. Consequences and frequencies are identified and evaluated through a risk matrix followed by a ranking procedure
- C. Consequences and frequencies are identified and evaluated through a risk matrix followed by a ranking procedure and development of action plans

Answer: C

Checkpoint

Hazard consequences are categorised with tables. Which of the following is not a standard table?

- A. Consequences to the public
- B. Consequences to the worker
- C. Consequences to management
- D. Consequences to capital loss
- E. Consequences to market share

Answer: C

Checkpoint

Hazardous events classed as medium risks should be managed in the following manner:

- A. No mitigation required, redesign system to ensure hazard prevention
- B. Should be verified on a continuous basis to ensure that procedures and controls are in place
- C. Should be mitigated with engineering and/ or administrative controls to achieve a lower risk ranking with 12 months
- D. Should be mitigated with engineering and/ or administrative controls to achieve a lower risk ranking with 6 months

Answer: C

Checkpoint

Value judgements are a key component to the risk estimation procedure?

- A. True
- B. False

Answer: B

Automotive Case Study – Health Hazards

In a Canadian manufacturing plant of a global automotive company, many engineering activities are conducted in design, part production, assembly, testing and quality assurance areas. The plant produces and assembles vehicle parts including engines, pumps, fans and electronics.

The manufacturing processes by 400 plant employees and some are performed using automated technologies and equipment. Use of people or machines to perform tasks is dependent on cost, time, quality and worker health and safety.

The plant operates 3 shifts per day. There are production lines including machining equipment, conveyers and overhead cranes, punch presses and paint-spray booths.

Automotive Case Study – Health Hazards

Workers at the plant have reported several different health problems. The following information has been received by the head engineer:

1. In a recently installed assembly area, workers have to bend to the ground throughout the day to attach several small parts onto a vehicle chassis. Some workers developed lower back pain, likely due to repetitive bending. For one of the workers, the problem is so severe that he was advised by his doctor to stay off work for two weeks so his back can recover.

The manufacturing engineers who designed the assembly operation had wanted to use an automated system but this option was not deemed to be economic. A manual operation was used but industrial ergonomics was not taken into account because of a lack of expertise.

Automotive Case Study – Health Hazards

Workers at the plant have reported several different health problems. The following information has been received by the head engineer:

2. An increased incidence of respiratory illness has been reported over past month by workers operating near the paint-spray booths. Many of the paints and solvents used in the booths are known to be the cause of respiratory illnesses. Works are not supposed to be exposed to these substances because the paint-spray booths were designed to be ensured all materials exit the paint through a high-capacity ventilation system. No tests have been carried out on the ventilation system or the plant air quality so it is uncertain whether or not there have been any paint-spray booth leaks.

Automotive Case Study – Health Hazards

Workers at the plant have reported several different health problems. The following information has been received by the head engineer:

3. In an area of the plant where metal cutting occurs, works are required to wear protective eyewear. However, workers operating in this area have started to report minor eye injuries. It is common knowledge that workers do not routinely use the protective equipment; the eyewear is frequently observed to be hanging on nearby hooks or loosely hanging around workers' necks. Workers complain that they find the protective eyewear to be uncomfortable and do not think it is needed or important. The plant manager knows of this behaviour but overlooks it since enforcing the eyewear use seems to make workers unhappy and less productive.

Challenge Questions

1. How would you go about investigating the causes of the observed health problems? List two options.

Answer:

- *Talk to stakeholders, employees, engineers,*
- *Bring in an ergonomics specialist,*
- *Check paint-spray booth ventilation,*
- *Check plant air quality*

Challenge Questions

2. What are 3 unsafe conditions and acts in the plant?

Answer:

- *Ergonomics of the assembly line*
- *Solvent and paint fumes from the paint-spray booth,*
- *Potential paint-spray booth leakage*
- *No protective eyewear equipment*

Challenge Questions

3. Human behaviour or management are contributing to unsafe conditions and acts in the plant?

- a. True
- b. False

Answer: A

Challenge Questions

4. What are 3 steps that can be taken to rectify the health problems observed?

Answer:

- *Talk to stakeholders,*
- *Educate employees and employers,*
- *Bring in an ergonomics specialist,*
- *Check paint-spray booth ventilation*
- *Check plant air quality,*
- *Identify new eyewear protection that is more comfortable,*
- *Enforce use of protective eyewear protection*

Challenge Questions

5. Should the head engineer endeavour to rectify the health problems or her/his own, or should she/he report the problems to the plant manager beforehand?

- A. Seek support from the plant manager
- B. Correct identified problems

Answer: A

Challenge Questions

6. The head engineer is not sure if she/he will receive support from the plant manager in rectifying the problem; what should she/he do if support is not provided?

- A. Contact other stakeholders
- B. Do nothing further, an attempt was made
- C. Wait until a serious accident or illness is reported to justify the expense of changing plant procedures.
- D. Educate workers about available protective equipment in plant

Answer: D

Challenge Questions

7. Were some of the reported health problems due to worker health and safety being unduly compromised to allow the plant to be more productive or profitable?

- A. True
- B. False

Answer: A

Automotive Case Study – Safety

Let's consider the same automotive facility again but this time we'll look at a safety related concerns.

Automotive Case Study – Safety

The head engineer wants to ensure that plant provides a safe and healthy environment. An engineering health and safety consulting company was hired to do a health and safety audit of the plant. The consulting companies report included the following issues:

1. An expert on fires and explosions notes the extensive use of natural gas in the plant could lead to an explosion in some circumstances. The potential for an explosion could develop if a sufficient natural gas leak. Which could lead to severe worker injuries or deaths. Detection of natural gas concentrations in the plant is monitored by sensors. Only one sensor is installed in the plant but not in the main area where accumulation of natural gas would be likely to occur. In addition to the concern for the only having the single sensor installed, the expert noted the sensor was not connected to an automated natural gas shut-off system. Without a shut-off feature, the severity of an incident would increase.

Automotive Case Study – Safety

The head engineer wants to ensure that plant provides a safe and healthy environment. An engineering health and safety consulting company was hired to do a health and safety audit of the plant. The consulting companies report included the following issues:

2. Gas line maintenance is required every quarter; no evidence of maintenance had been found since the gas lines were installed four years ago. This maintenance procedure involves checking for and fixing gas leaks. Workers also require training on procedures to prevent an explosion; this training had not been conducted and workers were not aware of the potential explosion hazard. No written procedure relating to explosions were found within the plant.

Automotive Case Study – Safety

The head engineer wants to ensure that plant provides a safe and healthy environment. An engineering health and safety consulting company was hired to do a health and safety audit of the plant. The consulting companies report included the following issues:

3. The plant was found to contain toxic materials that can harm the health of people and animals. The storage area for these hazardous substances was not found to be sufficient in containing the chemicals in the event of an explosion. Release of these substances could lead to illness or deaths among members of the public and could also harm the environment.

Challenge Questions

1. List 2 unsafe conditions in the plant?

Answer:

- Natural gas line
- Toxic materials

Challenge Questions

2. What are 3 steps that can be taken to rectify the noted safety concerns?

Answer:

- Install sensors,
- Perform regular maintenance,
- Provide worker training,
- Educate workers on explosion potential,
- Prepare written procedures on explosions within the plant,
- Change storage area of toxic materials/chemicals to prevent environmental release in the event of an explosion

Challenge Questions

3. With regards to toxic material release due to unsafe chemical storage, it is clear that this problem affects not only work safety but also the safety of the public and environment. Should the difference in who or what is affected cause the head engineer to modify her/his actions in address the problem?

A. Yes

B. No

Answer: B

Challenge Questions

4. Can the head engineer choose to ignore or not act fully on the safety concerns raised by the consulting company?

A. Yes

B. No

Answer: B

Challenge Questions

5. Do any of the problems cited demonstrate that it is best to address health and safety comprehensively in the early stages of an engineering activity, preferably within the design process and not as an afterthought?

A. Yes

B. No

Answer: A

Hazard and Risk identification answers the following questions:

What can go wrong? How? Why?

What are the consequences?

How likely are these consequences?

What is the risk?

Finding Hazards

Hazards are commonly related to energy:

- Human error
- Kinetic energy
- Potential energy
- Heat
- Electricity

In addition to energy sources, human error can be attributed to most workplace accidents.

96% of workplace injuries are caused by unsafe worker actions

Human Error as a Hazard

As engineers designing a facility, we must be aware of the **limitation of human behaviour**. This includes a workers or operator's attention span, perception, memory and logical reasoning abilities.

When human error is identified as a hazard in a process, we must acknowledge that the worker cannot be solely blamed. An organisation's management team plays a key part in overall safety.

Instilling a **safety culture** in an organisation is essential to reducing the number of worker caused accidents to zero.

Hazards, Risk, Sources and Receptors

A **hazard connects risk sources with risk receptors**. These system components include:

- *Risk sources*
 - Industrial facilities
 - Roadways
 - University laboratories
- *Risk receptors*
 - Plant Operators and workers
 - Students at a University
 - Shareholders
 - Community
 - Environment
 - Regulators

Hazard Identification Methods

Process Hazard Analysis techniques are used to identify hazards. **Qualitative methods** we discussed include:

- *Screening Level analysis*
- *Checklists*
- *What-if analysis*
- *Failure Modes and Effects Analysis (FMEA)*
- *Hazard and Operability Study (HAZOP)*

These techniques present a **pro-active** and **systematic** approach for the identification, mitigation or prevention of hazards from a process, materials, equipment or human error.

Generalised Process Hazard Analysis Procedure

1. Break down the system into process sections
2. Identify the intrinsic hazards in each section (chemical, material, equipment, human)
3. Evaluate the cause of each hazard to develop a hazardous event

Additional steps for What-if, FMEA and HAZOPs

4. Determine the consequence of each hazardous event
5. Estimate the frequency of each hazard consequence

Estimating Risk

We can use hazard-related frequency and consequence information to determine the associated risk.

Consequences and their frequency can be ranked in a **matrix** to estimate risk.

*Risk = Estimated consequences of a hazardous event x
Frequency of the event's occurrence*

Risks are ranked as **very low**, **low**, **medium** and **high**

Risk analysis

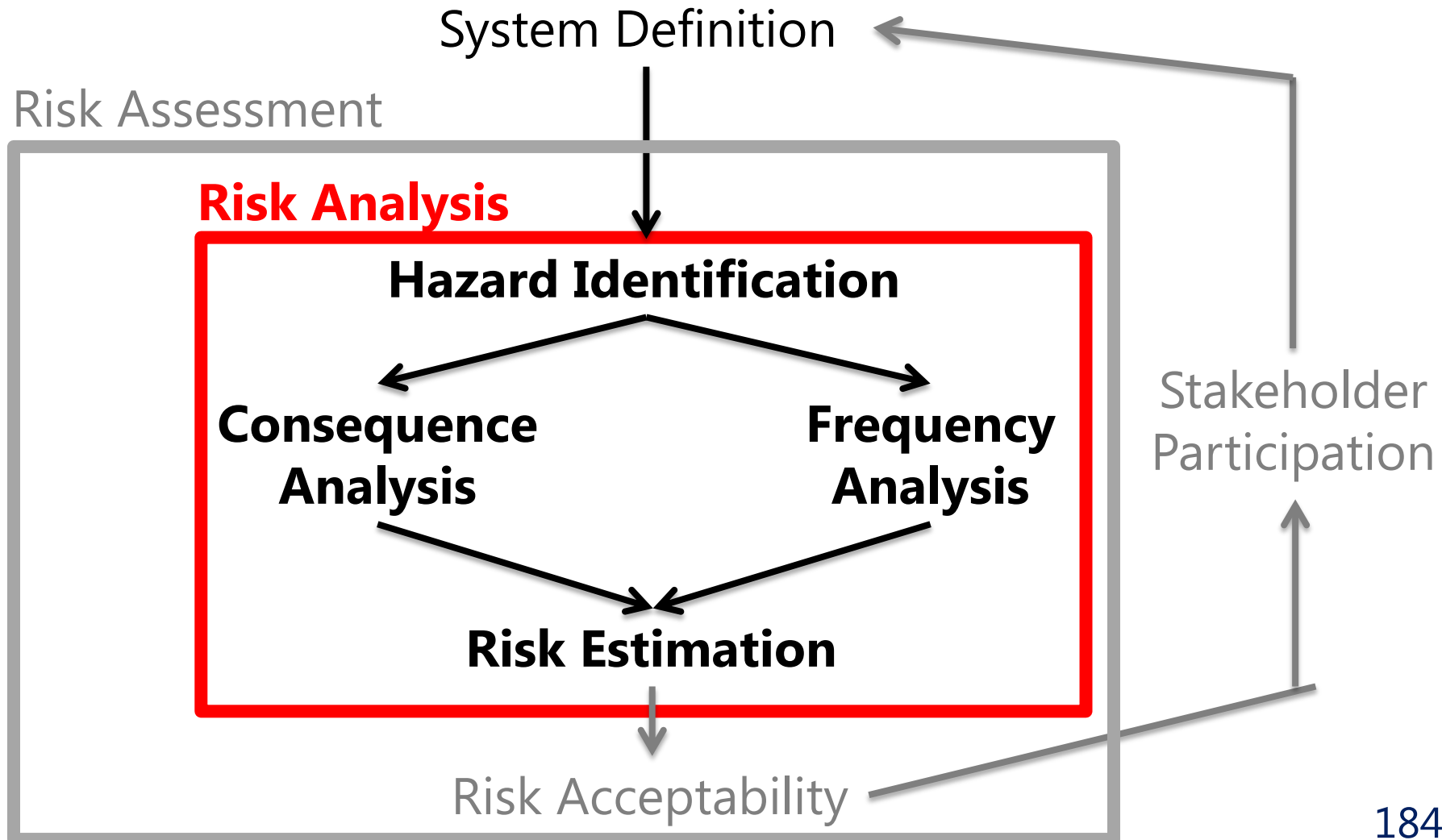
Provides an objective basis for **comparing hazards**, alternatives and risk control measurements

This analysis procedure is also of great importance for **response planning for emergencies**

There many types of risks that may be identified:

- *Event Risk*
- *Facility Risk*
- *Individual Risk*
- *Societal Risk*
- *Voluntary Risk*
- *Imposed Risk*
- *Safety Risk Environmental Risk*
- *Equipment Risk*
- *Shareholder Risk*

Hazard and Risk Framework



Hazard and Risk Identification Test

This considered to be an unacceptable level of risk for societal or voluntary activities:

- A. 1 in 10 fatalities
- B. 1 in 1,000 fatalities
- C. 1 in 100 fatalities
- D. 1 in 10,000 fatalities

Answer: C

Hazard and Risk Identification Test

This is considered to be an acceptable level of risk for societal or voluntary activities:

- A. 1 in 10,000 fatalities
- B. 1 in 100,000 fatalities
- C. 1 in 1,000,000 fatalities
- D. 1 in 10,000,000 fatalities

Answer: C

Hazard and Risk Identification Test

What is level of risk is considered to be in the judgement zone for societal or voluntary activities?

- A. Between 10^{-6} and 10^{-3} fatalities
- B. Between 10^{-7} and 10^{-3} fatalities
- C. Between 10^{-7} and 10^{-4} fatalities
- D. d. Between 10^{-6} and 10^{-2} fatalities

Answer: A

Hazard and Risk Identification Test

This parameter can be measured:

- A. Hazard
- B. Safety
- C. Risk
- D. Safety and Risk

Answer: C

Hazard and Risk Identification Test

This is a condition:

- A. Health
- B. Safety
- C. Risk
- D. Hazard

Answer: D

Hazard and Risk Identification Test

Which of the following are considered to be hazard conditions?

- A. Chemical, physical, societal, economic or political
- B. Chemical, physical, societal or economic
- C. Chemical, physical or societal
- D. Chemical and physical

Answer: A

Hazard and Risk Identification Test

A standardised level of risk must be considered when evaluating the hazards encountered as:

- A. Voluntary Activities
- B. Societal Activities
- C. Involuntary Activities
- D. Societal and Involuntary Activities

Answer: D

Hazard and Risk Identification Test

This is the unit of risk analysis:

- A. Cost per event
- B. Fatalities per event
- C. Fatalities per year
- D. Extent of Injury per event

Answer: C

Hazard and Risk Identification Test

Risk can be calculated as the product of these parameters of a hazard:

- A. Health and Safety
- B. Fatalities and likelihood
- C. Consequence and probability
- D. Safety and probability

Answer: C

Hazard and Risk Identification Test

Which of the following is a reason for a company to be interested in workplace safety?

- A. Employee and employer well-being
- B. Insurance
- C. Corporate Image
- D. Economics
- E. All of the above

Answer: E

Hazard and Risk Identification Test

Non-human derived hazards are most often related to:

- A. Energy
- B. Electricity
- C. Equipment

Answer: A

Hazard and Risk Identification Test

Hazards from energy sources can be minimised with the following:

- A. Proper construction materials
- B. Regular leak testing
- C. Installation of explosion proof electrical connections
- D. All of the above
- E. None of the above

Answer: D

Hazard and Risk Identification Test

Hazards from energy sources can be eliminated with the following:

- A. Proper construction materials
- B. Regular leak testing
- C. Installation of explosion proof electrical connections
- D. All of the above
- E. None of the above

Answer: E

Hazard and Risk Identification Test

This is the most simple qualitative process hazard analysis technique discussed:

- A. Screening level
- B. Checklist
- C. What-if analysis
- D. Failure Modes and Effects Analysis
- E. Hazard and Operability Study

Answer: B

Hazard and Risk Identification Test

This is the most commonly used qualitative process hazard analysis technique discussed:

- A. Screening level
- B. Checklist
- C. What-if analysis
- D. Failure Modes and Effects Analysis
- E. Hazard and Operability Study

Answer: C

Hazard and Risk Identification Test

This is the most structured qualitative process hazard analysis technique of those discussed:

- A. Screening level
- B. Checklist
- C. What-if analysis
- D. Failure Modes and Effects Analysis
- E. Hazard and Operability Study

Answer: D

Hazard and Risk Identification Test

Process Hazard Analysis should be conducted in parallel with:

- A. Common sense
- B. An open mind
- C. A good understanding of physics, chemistry and thermodynamics
- D. All of the above
- E. None of the above

Answer: D

Hazard and Risk Identification Test

Process Hazard Analysis presents techniques what purpose:

- A. Identification of hazards
- B. Mitigation of hazards
- C. Prevention of hazards
- D. A , B and C
- E. A and C

Answer: D

Hazard and Risk Identification Test

Process Hazard Analysis is capable of missing some hazards?

- A. True
- B. False

Answer: A

Hazard and Risk Identification Test

For routine plant operation, which of Process Hazard Analysis is the best to use?

- A. Screening Level followed by FMEA
- B. Checklist followed by HAZOP
- C. Checklist and What-if
- D. Screening Level, What-if or HAZOP
- E. Screening Level, Checklist, What-if, FMEA or HAZOP

Answer: E

Hazard and Risk Identification Test

This process hazard analysis technique is best used to evaluate equipment or machinery?

- A. Screening level
- B. Checklist
- C. What-if analysis
- D. Failure Modes and Effects Analysis
- E. Hazard and Operability Study

Answer: D

Hazard and Risk Identification Test

When conducting a process hazard analysis it is useful to talk with workers on the engineering facility site?

- A. True
- B. False

Answer: A

Hazard and Risk Identification Test

A HazMat checklist is used to identify hazards associated with:

- A. Chemicals
- B. Materials
- C. Equipment
- D. Chemicals and Materials
- E. Materials and Equipment

Answer: D

Hazard and Risk Identification Test

An equipment hazard checklist requires analysts to evaluate equipment according to:

- A. Hazards and significant losses
- B. Various action guide words
- C. Potential for hazard results from human error
- D. Potential for hazard from external factors

Answer: A

Hazard and Risk Identification Test

The External Initiating Factors checklist evaluates hazards originating from

- A. Geotechnical events
- B. Operating Events
- C. Other External Events
- D. A and B
- E. A, B and C

Answer: E

Hazard and Risk Identification Test

The potential cause of hazard events can be categorised by the following:

- A. Internal agency
- B. External agency
- C. Equipment failure while operating
- D. Open-ended loss of containment
- E. Equipment failure by exceeding design limits
- F. A, b, and C
- G. A, B, and D
- H. All of the above
- I. None of the above

Answer: H

Hazard and Risk Identification Test

Checklists are answered with Yes or No questions:

A. Yes

B. No

Answer: A

Hazard and Risk Identification Test

A checklist can be created by the analyst prior to the start of analysis if the checklist method?

- A. Yes
- B. No

Answer: B

Hazard and Risk Identification Test

It is possible for non-experts to conduct hazard identification using the checklist approach:

- A. Yes
- B. No

Answer: A

Hazard and Risk Identification Test

Which of the follow is false about checklists as a hazard identification technique?

- A. The method is applicable to new systems
- B. It is possible to capture a range of historical system knowledge
- C. Ensures that common problems are not overlooked
- D. New users are able to use the approach

Answer: A

Hazard and Risk Identification Test

The What-if analysis for hazard identification requires experienced personnel?

- A. True
- B. False

Answer: A

Hazard and Risk Identification Test

The result of the What-if analysis is:

- A. Identify causes for identified hazards
- B. Identify the effects of removing hazards
- C. Identify recommendations on the effects of removing hazards
- D. Identify hazards, consequences and risk mitigation strategies

Answer: C

Hazard and Risk Identification Test

A What-if analysis will identify

- A. Hazards, cause and consequences
- B. Hazards, consequence and frequency
- C. Hazard, consequence, severity and frequency
- D. Hazard, consequence, severity, frequency and recommendations

Answer: D

Hazard and Risk Identification Test

What-if analysis incorporates recommendation for safeguards against the identified hazards?

- A. True
- B. False

Answer: A

Hazard and Risk Identification Test

This process hazard analysis is the least structured technique discussed?

- A. Screening level
- B. Checklist
- C. What-if analysis
- D. Failure Modes and Effects Analysis
- E. Hazard and Operability Study

Answer: C

Hazard and Risk Identification Test

Which best describes a failure modes and effect analysis approach?

- A. Bottom-up analysis
- B. Top-down analysis

Answer: A

Hazard and Risk Identification Test

The FMEA analysis will identify:

- A. Hazards, cause and consequences
- B. Hazards, consequence and frequency
- C. Hazard, cause, consequence, frequency and safeguard
- D. Hazard, consequence, severity, frequency and safeguard

Answer: C

Hazard and Risk Identification Test

FMEA incorporates identification of human error?

- A. True
- B. False

Answer: B

Hazard and Risk Identification Test

Guide words are used to identify hazardous events in this Process Hazard Analysis technique:

- A. Screening level
- B. Checklist
- C. What-if analysis
- D. Failure Modes and Effects Analysis
- E. Hazard and Operability Study

Answer: E

Hazard and Risk Identification Test

What is the best definition of a safeguard?

- A. Provisions for eliminating the frequency or preventing the severity of the hazard's consequence
- B. Provisions for decreasing the frequency or reducing the severity of the hazard's consequence

Answer: B

Hazard and Risk Identification Test

This is the procedure for conducting a HAZOP study:

- A. Obtain process descriptions, drawings and operating procedures, identify failure points as potential hazards
- B. Identify the system's process sections, evaluate deviations as hazards, recommend safeguards
- C. Review process descriptions and use a checklist to identify hazardous materials and operations
- D. Examine the process system, break the system into process sections, use of list of predefined hazards to evaluate if present in the system, recommend prevention measures

Answer: B

Hazard and Risk Identification Test

HAZOP analysis identify hazards in addition to their causes, consequences and frequency?

- A. True
- B. False

Answer: B

Hazard and Risk Identification Test

What is the desired outcome of HAZOP analysis?

- A. Understand the hazards and consequences of these hazards in each process section
- B. Develop a list of recommended safeguards to present workers and the operation from hazards
- C. Develop recommendations for better equipment reliability
- D. A and B
- E. A and C

Answer: D

Hazard and Risk Identification Test

Which hazard type should be evaluated for HAZOP analysis?

- A. Leaks
- B. Corrosion or erosion
- C. Maintenance
- D. Service failures
- E. Reactions
- F. All of the above

Answer: E

Hazard and Risk Identification Test

Which of the following are process variables?

- A. Separation
- B. Frequency
- C. Time
- D. Composition
- E. All of the above

Answer: E

Hazard and Risk Identification Test

Guidewords are used in the HAZOP analysis process to identify hazards?

- A. True
- B. False

Answer: A

Hazard and Risk Identification Test

A HAZOP analysis produces a numerical ranking of hazards?

- A. True
- B. False

Answer: B

Hazard and Risk Identification Test

These hazard identification techniques should be carried out by experienced personnel:

- A. HAZOP
- B. Checklists
- C. FMEA

Answer: A

Hazard and Risk Identification Test

Which of the discussed process hazard analysis techniques identify and evaluate consequence and frequency?

- A. Checklists
- B. What-if analysis
- C. A and B
- D. Neither A or B

Answer: B

Hazard and Risk Identification Test

These are the end products from process hazard analysis

- A. Intrinsic hazard list, associated hazardous events with safety strategies
- B. Intrinsic hazard list, associated hazardous events with prevention strategies
- C. Intrinsic hazard list, associated hazardous events with mitigation strategies
- D. Intrinsic hazard list, associated hazardous events with prevention and mitigation strategies

Answer: D

Hazard and Risk Identification Test

What is the percentage of occurrences that unsafe worker actions the cause of workplace injuries?

- A. <5% of occurrences
- B. >15% of occurrences
- C. >50% of occurrences
- D. >75 of occurrences
- E. >95% of occurrences

Answer: E

Hazard and Risk Identification Test

Which factors can be used to best prevent human error?

- A. Attention, Perception, Training Level
- B. Perception, Logistical Reasoning, Memory
- C. Memory, Complexity of Process, Perception

Answer: A

Hazard and Risk Identification Test

What is the length of time that an individual can typically sustain attention?

- A. 20 minutes
- B. 40 minutes
- C. 60 minutes

Answer: A

Hazard and Risk Identification Test

What are factors that contribute to limitations of human memory?

- A. Capacity, processing levels and accessibility
- B. Capacity, aptitude and processing level
- C. Capacity and interest level

Answer: A

Hazard and Risk Identification Test

Which of the design principles can be applied to creating a system that inhibits people from making mistakes easily?

- A. Information management
- B. Behaviour constraint
- C. User Education
- D. A and B
- E. A and C
- F. A, B and C

Answer: D

Hazard and Risk Identification Test

Designing a system for errors is defined as:

- A. Inclusion of safeguards to prevent hazardous events caused by human error
- B. Inclusion of safeguards to mitigate hazardous events caused by human error
- C. It should be difficult for the user to proceed with actions that are non-reversible
- D. Essential systems affected by inevitable mistakes from human error should be designed to recover

Answer: C

Hazard and Risk Identification Test

Ensuring good visibility in a system is defined as:

- A. Allowing the user to perceive how their actions will influence the system
- B. Educating system users about common sources of human error
- C. Displaying notifications to users about potential hazards

Answer: A

Hazard and Risk Identification Test

Human error can be blamed solely on the worker:

- A. True
- B. False

Answer: B

Hazard and Risk Identification Test

What is the role of the management team in an organisation with respect to safety?

- A. Taking responsibility for decisions about health and safety to foster a culture of safety
- B. Instilling values, attitudes, competencies and behaviour patterns at all levels of the organisation
- C. Establish health and safety programmes
- D. A and B
- E. A, B and C

Answer: D

Hazard and Risk Identification Test

A culture of safety at an organisation is important for

- A. Decreasing severance payments
- B. Increase worker productivity
- C. Company profitability
- D. Worker moral
- E. All of the above

Answer: E

Hazard and Risk Identification Test

Members of a company that involved in the organisation's safety culture

- A. Workers
- B. Workers, operators
- C. Workers, operators, management team
- D. Workers, operators, management team including the CEO

Answer: D

Hazard and Risk Identification Test

These are tools required to building a culture of safety:

- A. Safety resources
- B. Communications
- C. Audits and Investigations
- D. Rituals
- E. A and B
- F. A, B and C
- G. A, B, C and D

Answer: G

Hazard and Risk Identification Test

A culture of safety applies to:

- A. The workplace
- B. The workplace for tasks related to system operation
- C. The workplace when supervisors are watching
- D. The workplace and off-the-job

Answer: D

Hazard and Risk Identification Test

What is meant by a “commitment-to-zero”?

- A. Zero worker sick days
- B. Zero worker accidents
- C. Zero workplace hazards

Answer: B

Hazard and Risk Identification Test

Risk Analysis is best described as:

- A. Consequence and frequency analyses
- B. Hazard identification and risk estimation
- C. Hazard identification and risk acceptability
- D. Hazard identification, risk estimation and risk acceptability

Answer: B

Hazard and Risk Identification Test

Once hazards are identified, how is risk analysed?

- A. Consequences and frequencies are identified and evaluated through a risk matrix
- B. Consequences and frequencies are identified and evaluated through a risk matrix followed by a ranking procedure
- C. Consequences and frequencies are identified and evaluated through a risk matrix followed by a ranking procedure and development of action plans

Answer: C

Hazard and Risk Identification Test

Hazard consequences are categorised with tables. Which of the following is not a standard table?

- A. Consequences to the public
- B. Consequences to the worker
- C. Consequences to management
- D. Consequences to capital loss
- E. Consequences to market share

Answer: C

Hazard and Risk Identification Test

How many levels of event severity can the frequency of hazard consequences be categorised?

- A. 2
- B. 3
- C. 4
- D. 5

Answer: B

Hazard and Risk Identification Test

What are the axes of a risk matrix?

- A. Consequence Category and Frequency Category
- B. Consequence Category and Severity Category
- C. Consequence Category and Likelihood of Consequence

Answer: A

Hazard and Risk Identification Test

Hazardous events classed as medium risks should be managed in the following manner:

- A. No mitigation required, redesign system to ensure hazard prevention
- B. Should be verified on a continuous basis to ensure that procedures and controls are in place
- C. Should be mitigated with engineering and/ or administrative controls to achieve a lower risk ranking with 12 months
- D. Should be mitigated with engineering and/ or administrative controls to achieve a lower risk ranking with 6 months

Answer: C

Hazard and Risk Identification Test

Value judgements are a key component to the risk estimation procedure?

- A. True
- B. False

Answer: B