Applications of System Safety in Utility Industries

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www.hkarms.org

Existing Underground Utilities are the Veins and Arteries of our Cities and Roads

Communication
Gas / Propane
Petroleum
Sewerage
Drainage
Power
Steam
Water
…

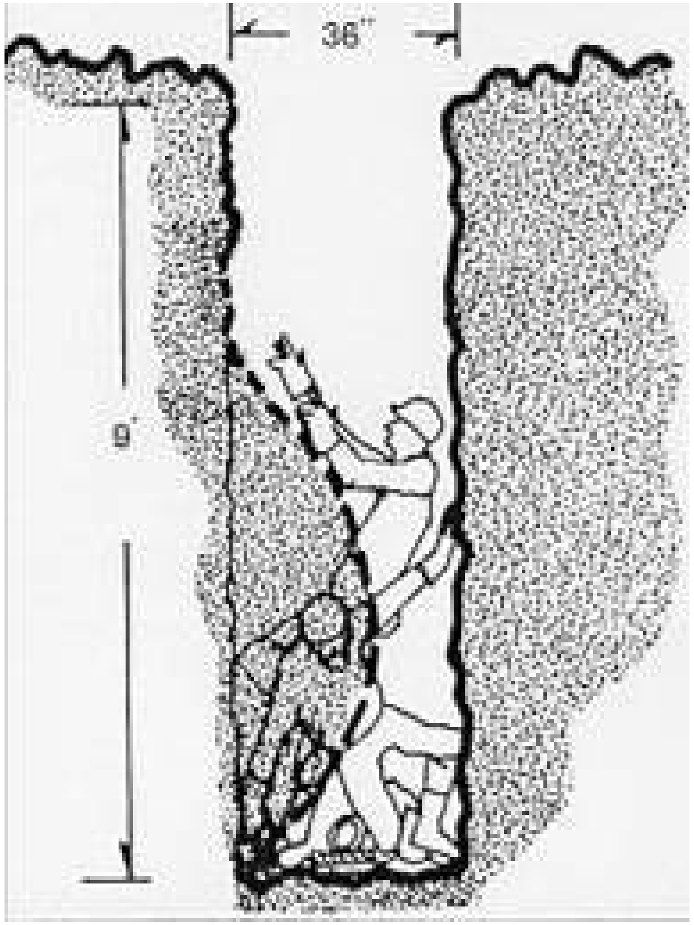
Many risks associated with underground utilities

What are these Risks?

- Utility damages affecting
  - Utility services to public
  - Safety of construction crews, or the public

Injury and Death

- Excavating is one of the most hazardous construction operations
- Most accidents occur in trenches 5-15 feet deep
- There is usually no warning before a cave-in



Serious Accident Happens

The Aftermath

The Little Pipe That Started it all

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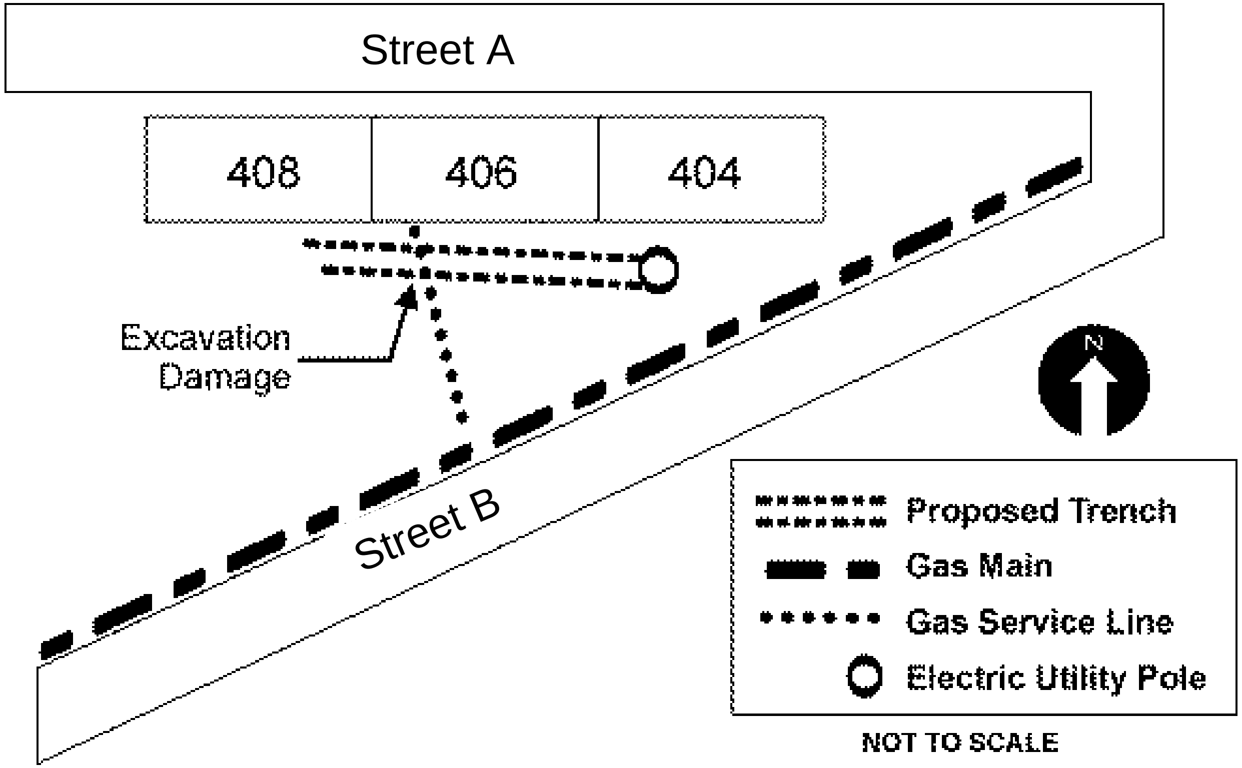
Typical Root Cause



The contractor did not plan ahead before digging the trench

There are a Lot of Other Risks Too

- Redesign costs
- Higher construction bids
- Change orders
- Extra work orders
- Construction Claims
- Higher insurance costs
- Higher financing costs
- Bad publicity
- Project delays
- Detours, traffic delays
- Intangibles

Recognizing Risk

- You have to recognize risk before you can understand risk
- You have to understand risk before you can assess it
- You have to assess risk before you can manage or control it

Recognizing Risk

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Let’s Focus on Safety Risks…

DID YOU KNOW?
THE FATALITY RATE FOR EXCAVATION WORK IS 112% HIGHER THAN THE RATE FOR GENERAL CONSTRUCTION.

Using System Safety Tools and Techniques

What is System Safety?

System Safety is Not Merely…

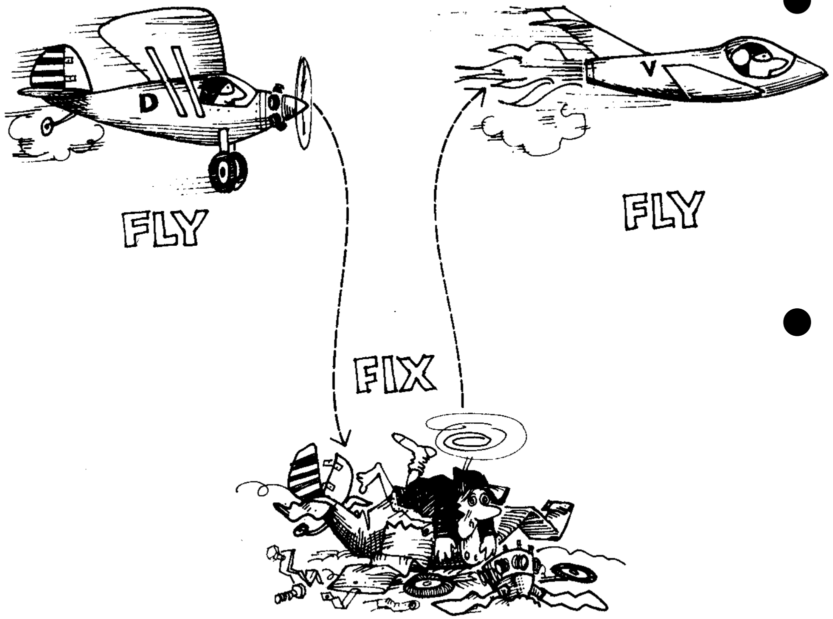
- A hazard logging system;
- A set of quantitative Reliability, Availability, Maintainability, and Safety criteria for system design;
- An application of FMEA, PHA or QRA;
- Requirements for contractors; or
- A set of documentation to satisfy approval authority

System Safety ≠ Systems Safety

System Safety is….

- The application of engineering and management principles, criteria, and techniques to optimise Safety within the constraints of operational effectiveness, time, and cost throughout all phases of the System life cycle
- Primarily a management tool that applies special technical and managerial skills to the systematic, forward-looking identification and control of hazards throughout the life cycle of a project, program, or activity
- Addressing safety at a system level. (A system is a composite, at any level of complexity, of personnel, procedures, materials, tools, equipment, facilities, and software)

History of System Safety

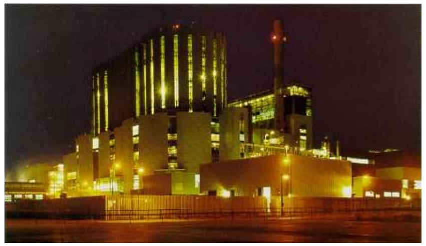


- The System Safety Program grew out of the aerospace and military programs to improve safety
- The proactive system-level approach replaced the fly-fix-fly approach

- **1962: System Safety Engineering for the Development of Air Force Ballistic Missiles**
- **1969: MIL-STD-882, System Safety Program Requirements**

History of System Safety

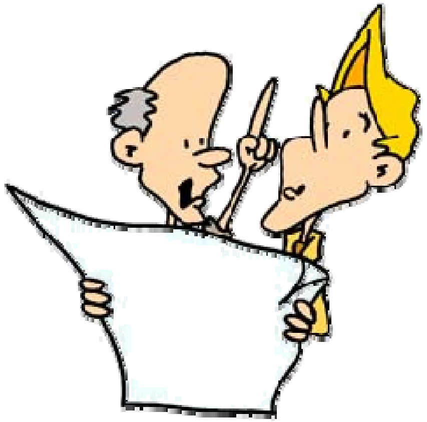
- The aviation industry significantly improved its safety records in the 60s and 70s
- “Today, there are more people killed by donkeys annually than by air crashes”
- Nowadays, System Safety has been commonly applied in major industries such as military/ defense, chemical processing, aerospace, power generation and distribution, transportation, etc.



Objective of System Safety

- To achieve acceptable mishap risk through a systematic approach of hazard analysis, risk assessment, and risk management

MIL-STD-882D, Department of Defense, USA



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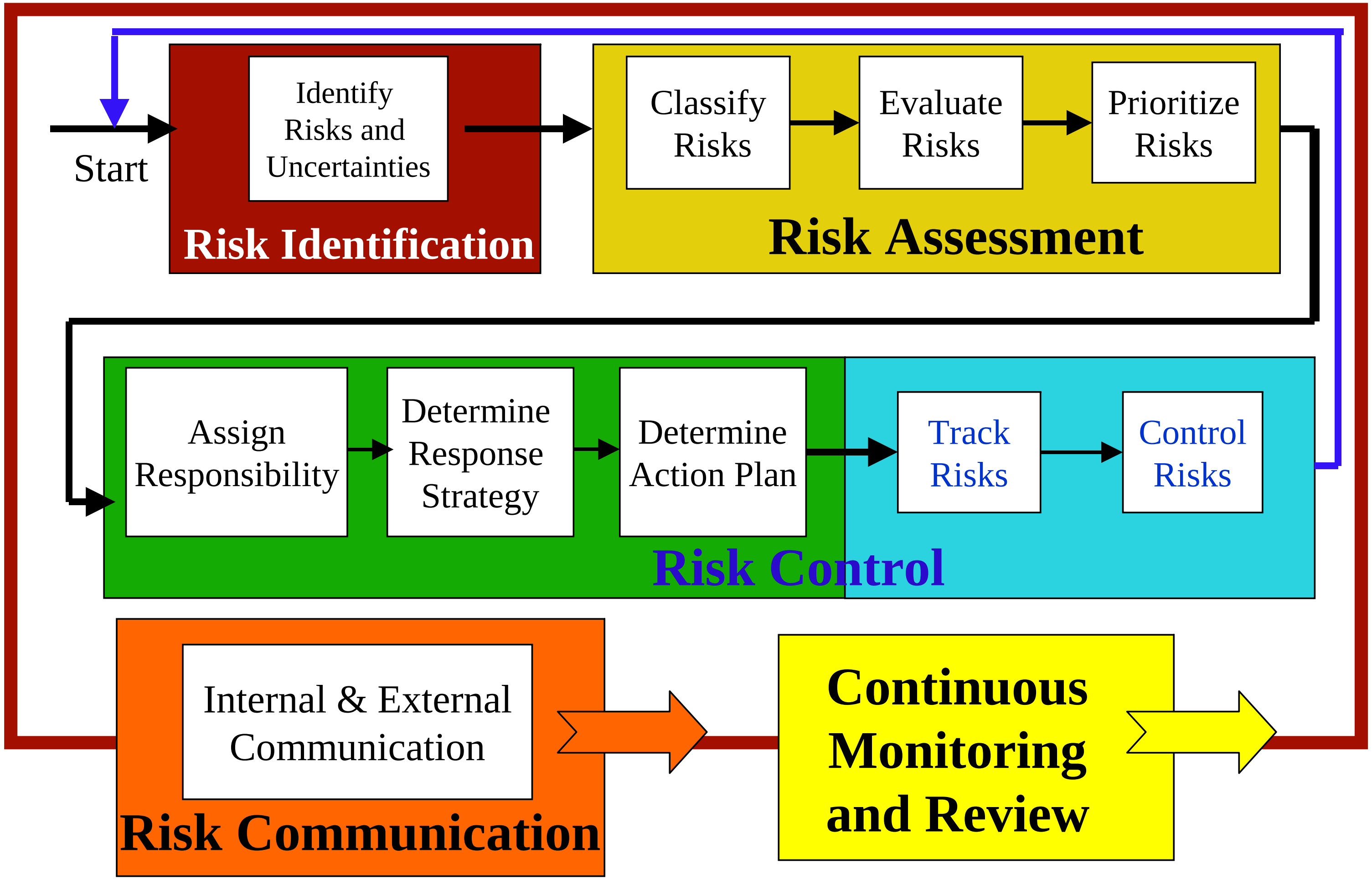
Key Steps in a Risk Management Programme



Risk vs Hazard

RISK

↓

What might go wrong

How it might happen

HAZARD

↓

Sources of harm

Causing a damage

Different Types of Hazards

- Construction hazards
- Site-specific hazards
- Human errors
- Machine failure
- Electrical hazards
- Chemical hazards

Definition of Hazard

- Hazard is a relative term
  - Fire is a hazard to life
  - Gasoline is a fire hazard
- Hazard can have many meanings
  - Potential of a situation to cause harm
  - A source of danger, etc.
- A source of danger, the presence of a condition or a situation, that has the potential of resulting in personnel injury, property loss, or delay in services
- Description of Hazards must be meaningful and unambiguous, it should not be too detailed or too broad

Example of Hazards

- A foreign material, e.g., methane gas in confined space
- A situation or a condition, e.g., loose slope
- A design compromise or inadequacy, e.g., a weak structure or a lack of safety measures
- A failure of a component or a system, e.g., lifting apparatus failure
- A latent failure of a component or a system, e.g., gas detector fails to detect gas at dangerous level

How To Find Hazards

- Records of accidents and near hits
- Knowledge and common sense
- Manufacturers instructions, DG lists, etc
- Suggestions from staff
- Experience, News, references
- Workplace inspections
- Formal hazard identification tools

The lack of accidents does not necessarily indicate the presence of safety

Typical Hazard AnalysisTools

- Open ended questions with brainstorming - what if
- Check lists, Hazard lists
- Preliminary hazard analysis
- Failure Mode and Effect Analysis
- Hazop
- Fault Trees

Hazard Evaluation

- No standard way, the complexity of the evaluation depends on the application and industry
- Typically use MIL-STD-882 style look up table to characterise likelihood and consequence
  - Very popular, quick and easy
  - Has become “the” method in hazard evaluation due to lack of expertise and resources
- Look up tables → risk matrices

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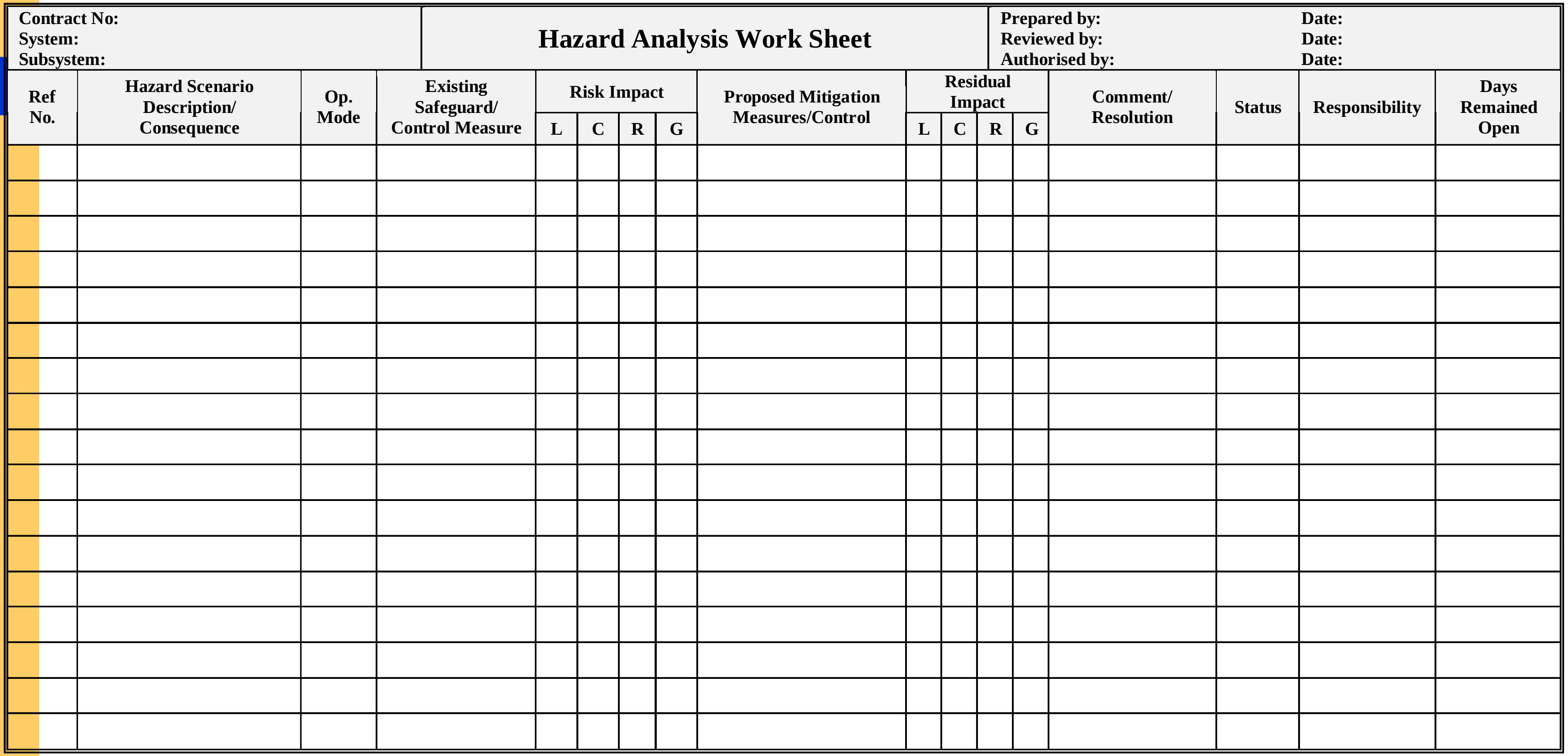

Contract No:
System:
Subsystem:

Hazard Analysis Work Sheet

Prepared by: Date:
Reviewed by: Date:
Authorised by: Date:

Ref No.	Hazard Scenario Description/ Consequence	Op. Mode	Existing Safeguard/ Control Measure	Risk Impact				Proposed Mitigation Measures/Control	Residual Impact				Comment/ Resolution	Status	Responsibility	Days Remained Open
				L	C	R	G		L	C	R	G				

People often mistakenly think that it is THE” only way to do hazard or risk analysis… NOT

Worksheet Methods

- The most popular safety analysis approach is the risk-ranking method using worksheets to define hazard scenarios
- Each record (row) in the worksheet describes an independent scenario
- The approach uses discrete risk-ranking matrices to character likelihood, consequence and risk class

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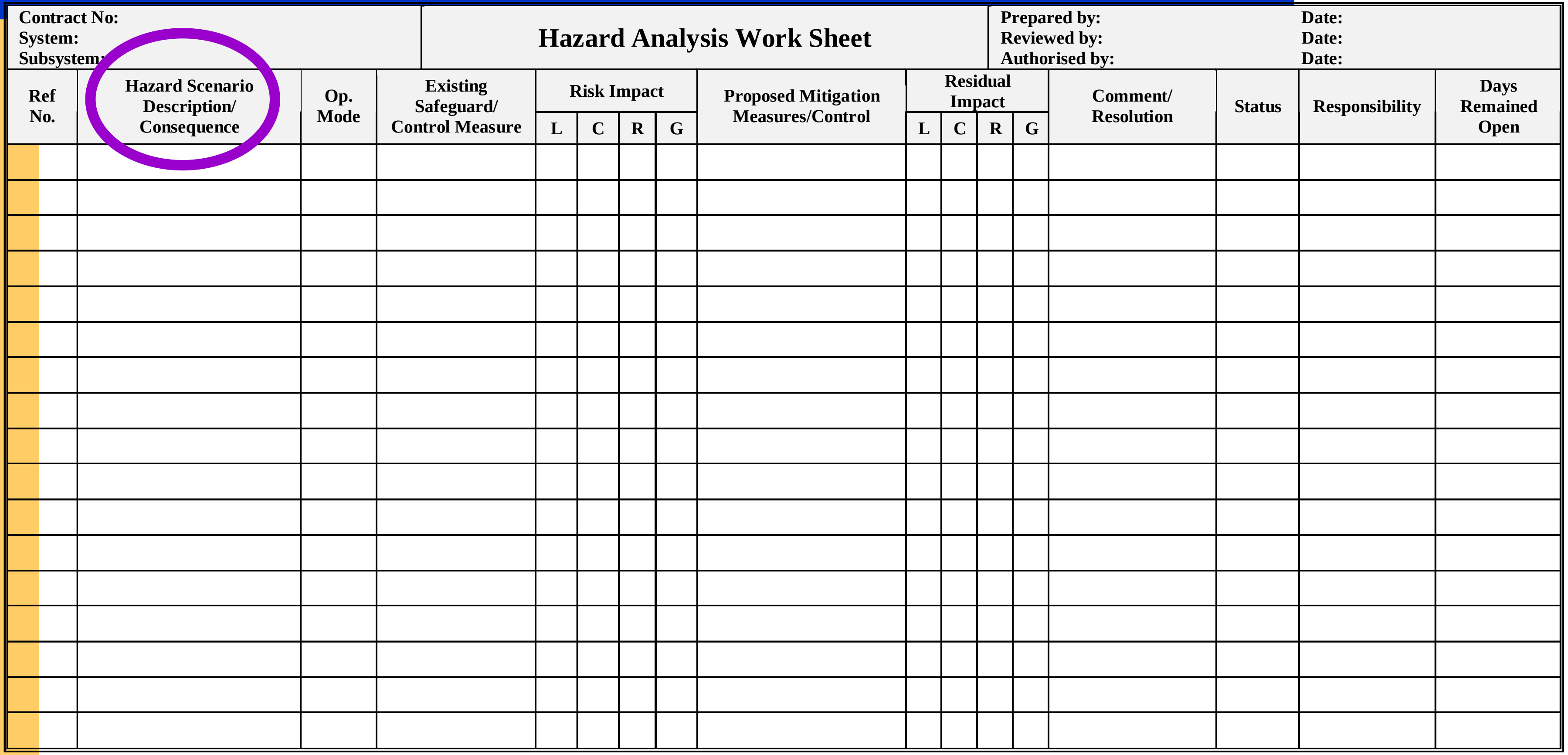
Hazard Description



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Some worksheet requires separate entries for Potential Cause and Consequence

Hazard vs Hazard Scenario

- The terms Hazard and Hazard Scenario, Hazard, although not theoretically correct, are frequently used interchangeably
- Strictly speaking, a Hazard should be measured by its physical properties: dimensions, mass, location, temperature, frequency of occurrence, etc.
- You can assess the risk of a Hazard Scenario but not a hazard

Hazard vs Risk

- The risk impact of a Hazard (or a Hazard Scenario) depends on
  - What can go wrong?
  - What is the likelihood if something does go wrong?
  - What is the severity of the consequence?
- Need to characterize
  - Likelihood
  - Consequence

Strictly speaking, a worksheet type analysis is a Hazard Analysis, not a Risk Analysis

Potential Cause

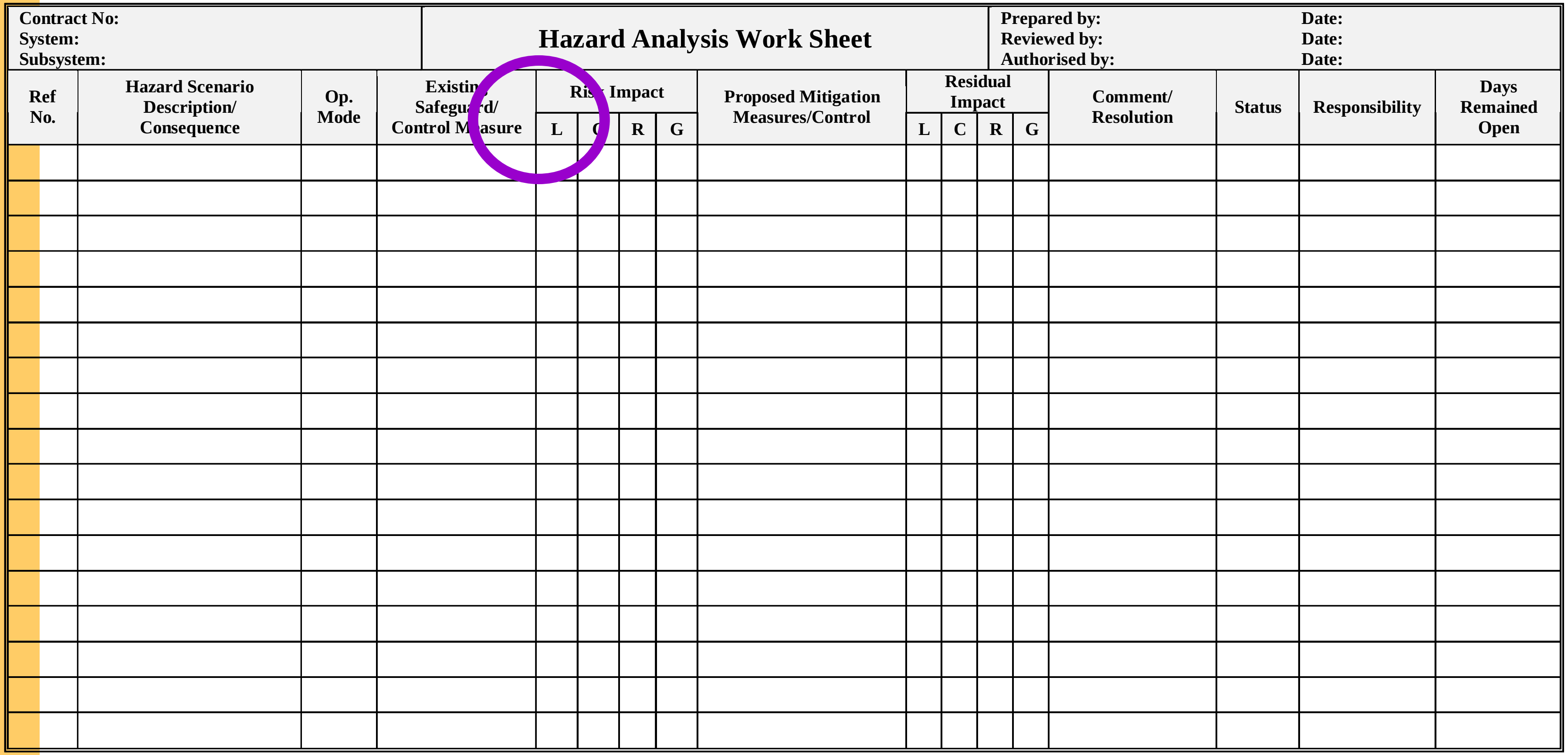
- A Potential Cause is the precursor of a Hazard Scenario, or the Triggering Event or action that brings the source of danger to an undesirable consequence
- It can be a Hazard itself that leads to another hazardous condition
- Since a Hazard can be triggered by different Potential Causes and may result in different Consequences, it is very important to clearly describe the Hazard Scenario

Hazard vs Potential Cause

Hazards	Potential Causes

Hot Substance;
Machinery or Equipment Failure or Faults; Uneven/Slippery/Steep Surface;
Poor Electricity Insulation; Inflammable/Combustible Substance/Liquid; Explosive Materials/Gases; Sharp Utensils/Objects; Toxic Fumes; Working at Height; Blockage; Heavy Materials;
Poor Ventilation, etc.
	Improper Handling; Untactful Handling;
	Unaware of Rules; Inadequate Maintenance; Dangerous Act;
	Inadequate Warning;
	Lack of Safety Awareness;
	Lack of Training;
	Unsafe Act, etc.

Likelihood



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Likelihood

- Address how likely a particular loss occurs
- Can be a probability; i.e., the chance of something happens
- Can be statistics; i.e., how often something happens
  - Expected time (or demand) between occurrences – return period
  - Expected occurrences within a period – a rate
- Must consider the elements of the whole scenario
  - Likelihood of Potential case
  - Window of exposure
  - Failure of existing safeguard

Analysing Likelihood

- Engineering judgment, expert knowledge, educational guesstimate
- Historical data, loss and accident statistics
- Computer models for probability scattering
  - e.g., fire and explosion models, plane crash
- Frequency = exposure x Likelihood x factors

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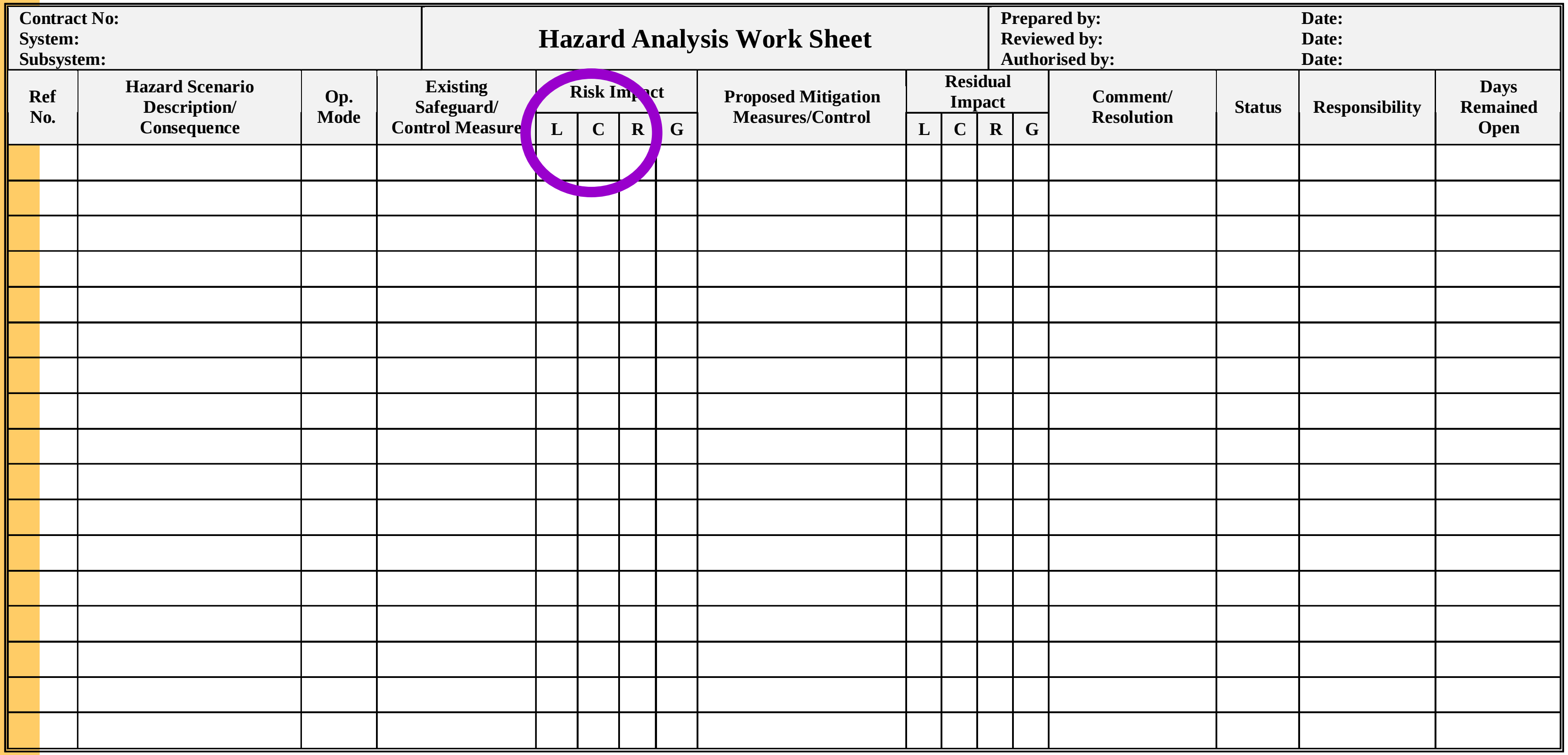
Consequence



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Consequence

- Address what might happen
  - Often there could be several outcomes
  - Usually, scenario with the most severe consequence is the most concerned but may not necessarily be the one with the highest risk
- Must consider factors affecting the consequences; who/what/where are affected
  - People
  - Property
  - Environment
  - Production
  - Objectives and mission

Hazard vs Consequence

- “Consequence” is an end-state or damage state of an accident caused by a Hazard and a Triggering Event
- For example,
  - Fires are the consequence of igniting (Triggering Event) flammable or combustible materials (Hazard)
  - Suffering burn is the consequence of people in contact with fire
- Consequence should indicate the result of the accident and the extent of the injuries; thus, sometimes, called severity

Analysing Consequences

- Engineering judgment, expert knowledge, educational guesstimate
- Historical data, loss and accident statistics
- Must consider the elements of the whole scenario
  - Damage transfer process
  - Extent of damage
  - Failure of existing safeguard
  - Reasonable worst-case consequence

Analysing Likelihood and Consequences

- For all intents and purposes, the worksheet method asks for a quick but reasonably estimate of the likelihood an consequence of a hazard scenario
- Users are not advised to use sophisticated method or spend much efforts in conducting numerical analyses to come up with the likelihood and consequence classes
- Worksheet method is used to screen items for risk importance, not to calculate the exact risks

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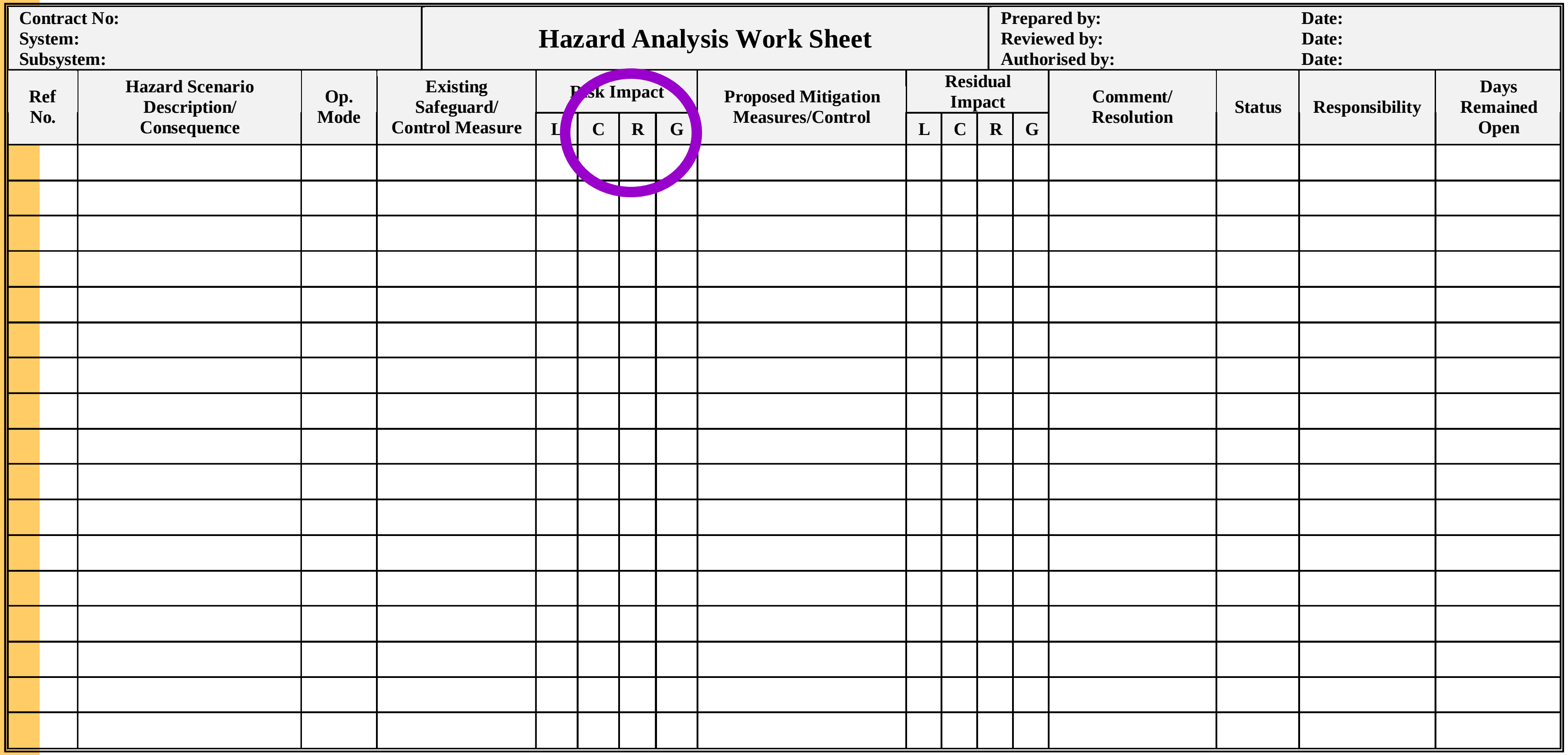
Risk Ranking



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Using Risk Matrix

- Rank the safety risk using function of likelihood and consequence classes in the form of look up tables
- Unique combination of likelihood and consequence gives a risk class
- Mainly use for rank-ordering hazard/risk scenarios

THERE IS NO STANDARD RISK MATRIX

Example of Likelihood Classes

Class	Description
F1 – Frequent	More than 10 incidents per year; $F1>10/yr$
F2 – Common	1 to 10 incidents per year; $1/yr \le F2 \le 10/yr$
F3 – Likely	1 incident per year to 1 every 10 years; $0.1/yr \le F3 < 1/yr$
F4 – Unlikely	1 incident per 10 year to 1 every 100 years; $0.01/yr \le F4 < 0.1/yr$
F5 – Rare	1 incident per 100 year to every 1000 years; $0.001/yr \le F5 < 0.01/yr$
F6 – Improbable	1 incident per 1000 year to 1 every 10,000 years; $0.0001/yr \le F6 < 0.001/yr$
F7 – Incredible	Less than 1 in 10,000 years; $F7 < 0.0001/yr$

Another Example of Likelihood Classes (with numerical scores)

Continuous	Many times daily	10
Frequently	Once per day	6
Occasionally	once/week to once / month	3
Infrequent	once/month to once/year	2
Rare	Has been known to occur	1
Very Rare	Not known to have occurred	0.5

Typical Consequence (Severity) Classes

Class	Description
S1 – Insignificant	• No injuries, or injuries that do not require first aid or any medical treatment.
S2 – Minor	• Injuries requiring first aid treatment or attention of a doctor but without the need of hospitalisation. • Injuries to staff resulting in 7 days or less off work.
S3 – Moderate	• Injuries resulting in hospitalisation or extended care (less than 1 year). • Injuries resulting in more than 7 days but less than 1 year off work. • The effects are not likely to be long-term and do not affect quality of life; e.g., broken bones.
S4 – Severe	• Injuries resulting in permanent debilitating injuries or serious long-term illness that requires 1 year or more hospitalisation or extended care • Injuries to staff resulting in 1 year or more off work. • The effects are long-term and affect quality of life; e.g., loss of limb, loss of eyesight
S5 – Fatal	• Resulting in death (less than ten fatalities).
S6 – Disastrous	• Resulting in ten or more fatalities

Another Example of Consequence Classes (with numerical scores)

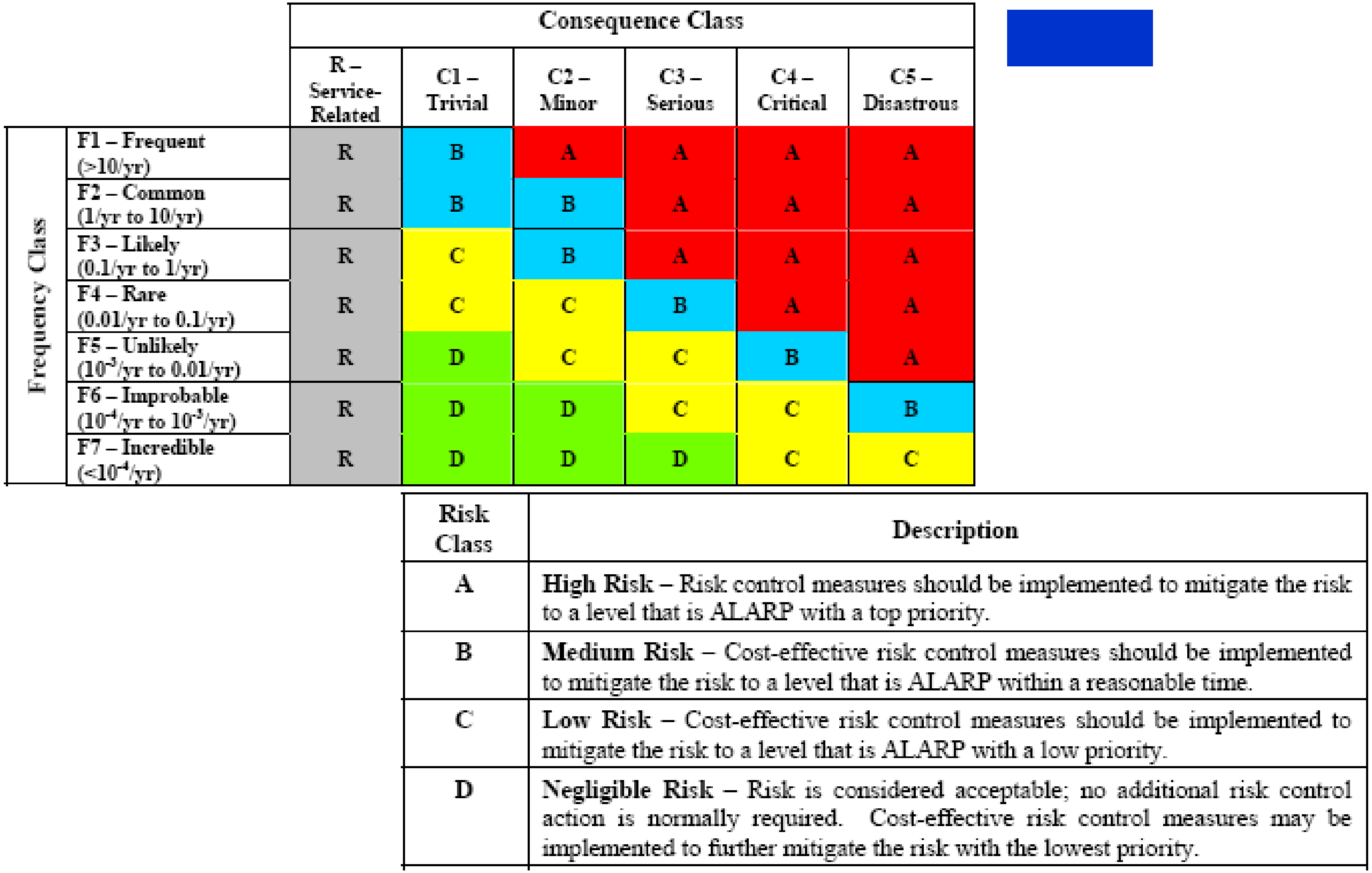
Catastrophe	multiple fatalities damage over $1million, closure of activity, permanent extensive damage environmental	100
Disaster	fatality, permanent local damage to environment, loss $500,000 - $2,000000	50
Very Serious	permanent disability / ill health, non permanent environmental damage $50,000- $500,000 loss	25
Serious	Serious but non permanent injury or ill health. adverse effect on environment,$5000- $50,000 loss	15
Important	Medical attention needed, off site emission but no damage. $500 - $5000 loss	5
Noticeable	Minor cuts and bruises or sickness, minor damage <$500, short loss of production, small loss of containment no off site consequences	1

Typical Risk Matrix

Consequence Likelihood	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Almost Certain A	S	S	H	H	H
Likely B	M	S	S	H	H
Moderate C	L	M	S	H	H
Unlikely D	L	L	M	S	H
Rare E	L	L	M	S	S

H = High risk detailed research and management planning required at senior levels
S = Significant risk senior management attention needed
M = Moderate risk management responsibility must be specified
L = Low risk : manage by routine procedures

Example of Risk Matrices



		Consequence Class					
		R – Service-Related	C1 – Trivial	C2 – Minor	C3 – Serious	C4 – Critical	C5 – Disastrous
Frequency Class	F1 – Frequent (>10/yr)	R	B	A	A	A	A
	F2 – Common (1/yr to 10/yr)	R	B	B	A	A	A
	F3 – Likely (0.1/yr to 1/yr)	R	C	B	A	A	A
	F4 – Rare (0.01/yr to 0.1/yr)	R	C	C	B	A	A
	F5 – Unlikely (10^{-3}/yr to 0.01/yr)	R	D	C	C	B	A
	F6 – Improbable (10^{-4}/yr to 10^{-3}/yr)	R	D	D	C	C	B
	F7 – Incredible (<10^{-4}/yr)	R	D	D	D	C	C

Risk Class	Description
A	**High Risk** – Risk control measures should be implemented to mitigate the risk to a level that is ALARP with a top priority.
B	**Medium Risk** – Cost-effective risk control measures should be implemented to mitigate the risk to a level that is ALARP within a reasonable time.
C	**Low Risk** – Cost-effective risk control measures should be implemented to mitigate the risk to a level that is ALARP with a low priority.
D	**Negligible Risk** – Risk is considered acceptable; no additional risk control action is normally required. Cost-effective risk control measures may be implemented to further mitigate the risk with the lowest priority.

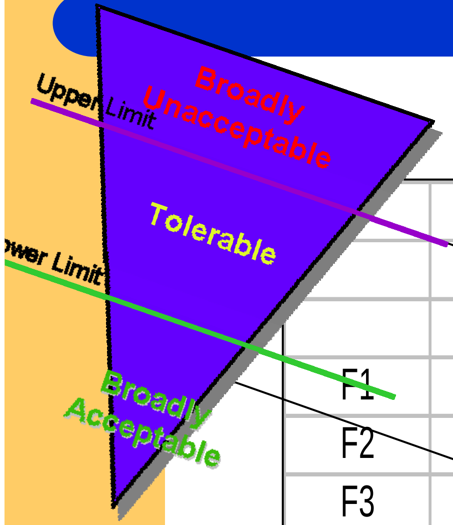
Another Example of Risk Matrix

				CONSEQUENCE						
				7	6	5	4	3	2	1
				Trivial	Negligible	Marginal	Serious	Critical	Catastrophic	Disastrous
	Staff/Contractor Safety	Fatality						<5	5 or more	
		Major Injury					<5	5 or more		
		Minor Injury	with ≥ 3 days sick leave			<5	5 or more			
			with < 3 days sick leave		<5	5 or more				
	Passenger/Public Safety	Fatality						<5	5-50	51-500
		Major Injury					<5	5-50	51-500	501 - 5000
		Minor Injury				<5	5-50	51-500	501 - 5000	>5000
	Service	System Disruption				<20 min	1 hour	1 day	1 week	1 month
		Line Disruption			20-60min	few hours	1 day	1 week	1 month	few months
		Station Disruption		<20min	few hours	1 day	1 week	1 month	few months	1 year
FREQUENCY	A	Few times per week or more	≥ 100 /year	R3	R1	R1	R1	R1	R1	R1
	B	Few times per month	≥ 10 - <100 /year	R4	R2	R1	R1	R1	R1	R1
	C	Few times per year	≥ 1 - <10 /year	R4	R2	R2	R1	R1	R1	R1
	D	Few times in 10 years	≥ 0.1 - <1 /year	R4	R3	R2	R1	R1	R1	R1
	E	Once since operation	≥ 1E-2 - <1E-1 /year	R4	R3	R3	R2	R1	R1	R1
	F	Unlikely to occur	≥ 1E-3 - <1E-2 /year	R4	R4	R3	R3	R2	R1	R1
	G	Very unlikely to occur	≥ 1E-4 - <1E-3 /year	R4	R4	R4	R3	R3	R2	R1
	H	Remote	≥ 1E-5 - <1E-4 /year	R4	R4	R4	R4	R3	R3	R2
	I	Improbable	≥ 1E-6 - <1E-5 /year	R4	R4	R4	R4	R4	R3	R3
	J	Incredible	< 1E-6 /year	R4	R4	R4	R4	R4	R4	R3

Risk Matrix Can Also be Simple

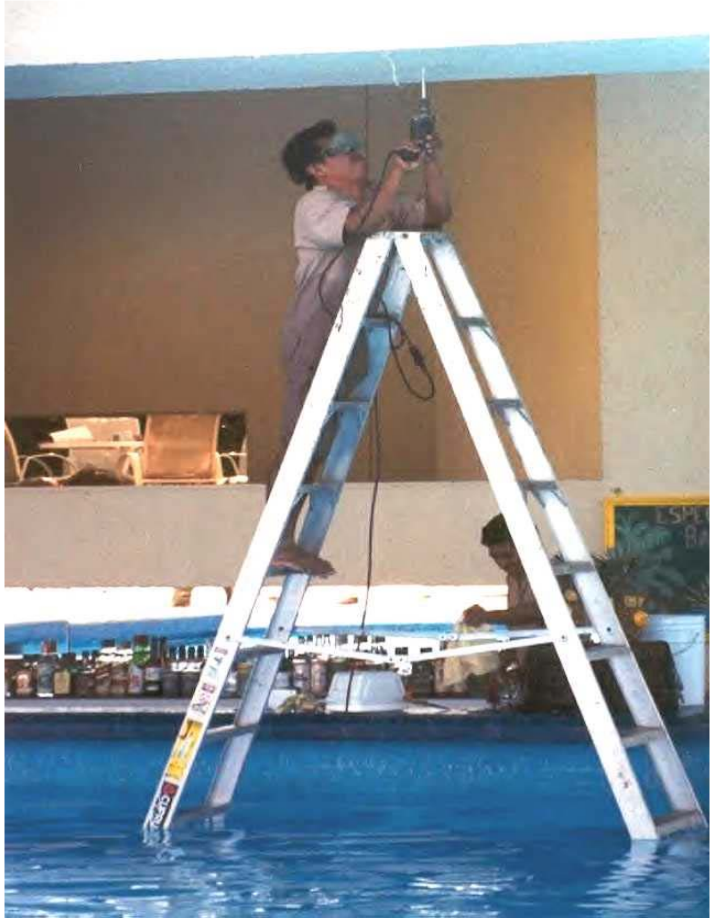
Risk Level	Description
High Risk	The hazard may cause fatal or multiple serious injuries, for all ranges of frequency
Medium Risk	The hazard may cause single serious injuries, and the likelihood of having these kinds of injuries is quite probable
Low Risk	Other risk which is neither high nor medium

Risk Matrix Should Actually be Designed by Quantitative Input



		0	0.001	0.01	0.1	1	10	20
		S1	S2	S3	S4	S5	S6	S7
	G. Mean	0.000	0.003	0.03	0.32	3.16	14.14	44.72
F1	31.62	1.00E-02	0.10	1.00	10.12	99.93	447.15	1414.21
F2	3.16	1.00E-03	1.00E-02	0.10	1.01	9.99	44.71	141.42
F3	0.32	1.00E-04	1.00E-03	1.00E-02	0.10	1.00	4.47	14.14
F4	3.16E-02	1.00E-05	1.00E-04	1.00E-03	1.01E-02	0.10	0.45	1.41
F5	3.16E-03	1.00E-06	1.00E-05	1.00E-04	1.01E-03	9.99E-03	0.04	0.14
F6	3.16E-04	1.00E-07	1.00E-06	1.00E-05	1.01E-04	9.99E-04	4.47E-03	0.014
F7	0.00	1.00E-08	1.00E-07	1.00E-06	1.01E-05	9.99E-05	4.47E-04	1.41E-03

Work Example.. Find Hazards



- Working at height – no work platform, ladder not locked
- Electrical hazards – extension cord, working near water, sparks
- Mechanical hazards – rotating tools
- Fire hazards – flammable substances
- Dust, debris – irritation to eyes and respiration
- Manual handling – strain, sprains
- Water hazards – slippery floor, drowning

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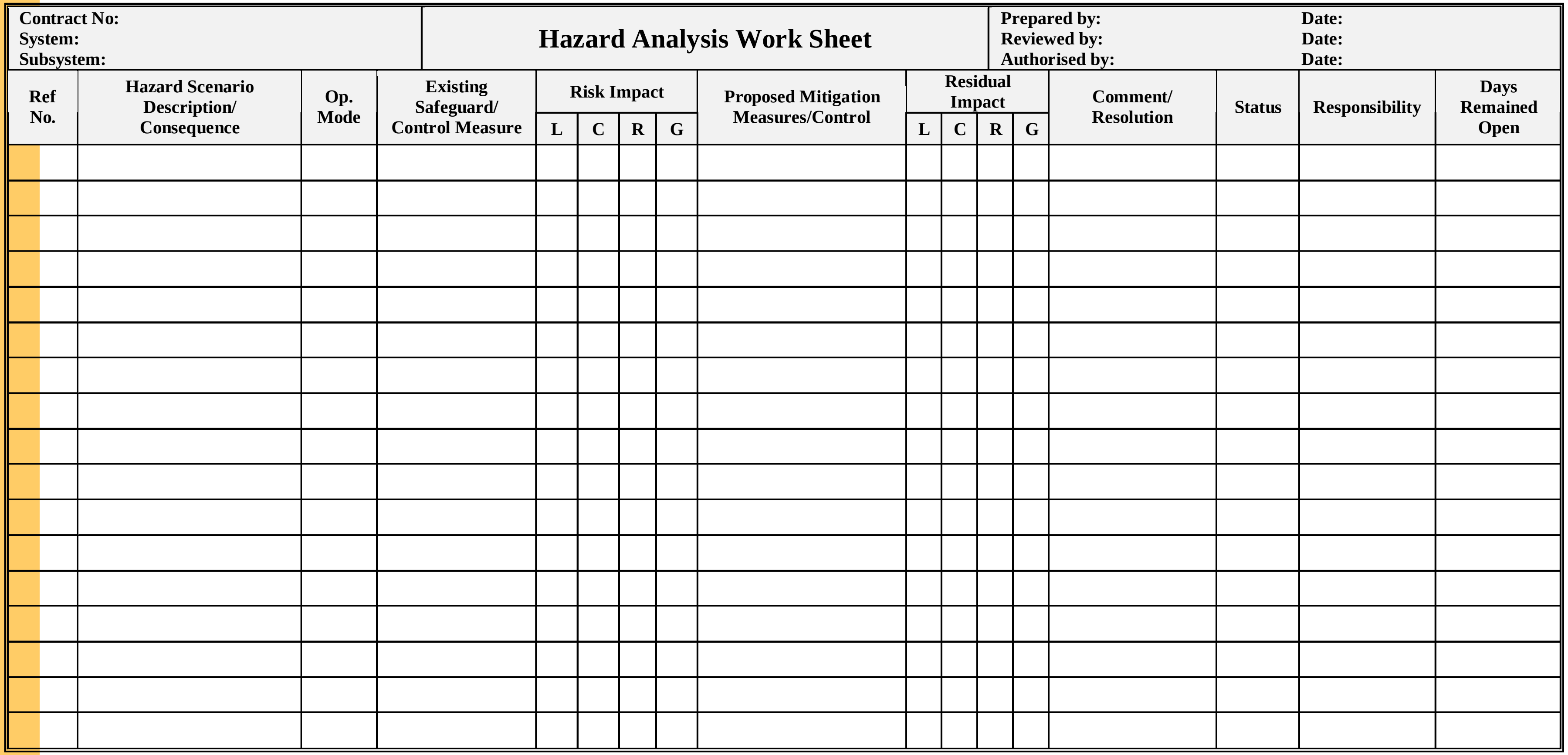
Work Example.. Filling the Worksheet



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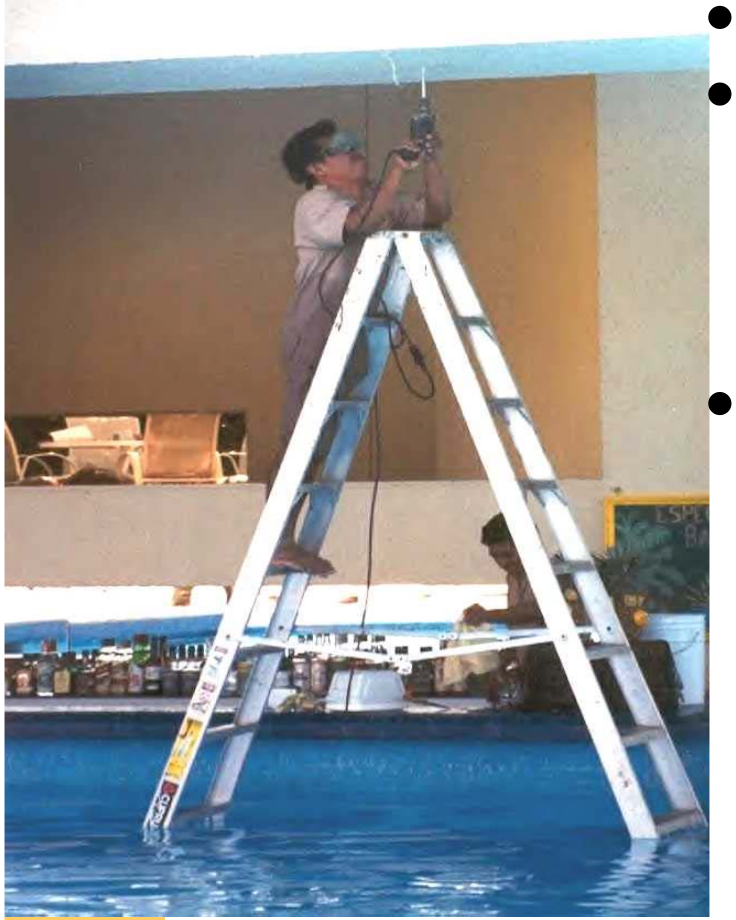
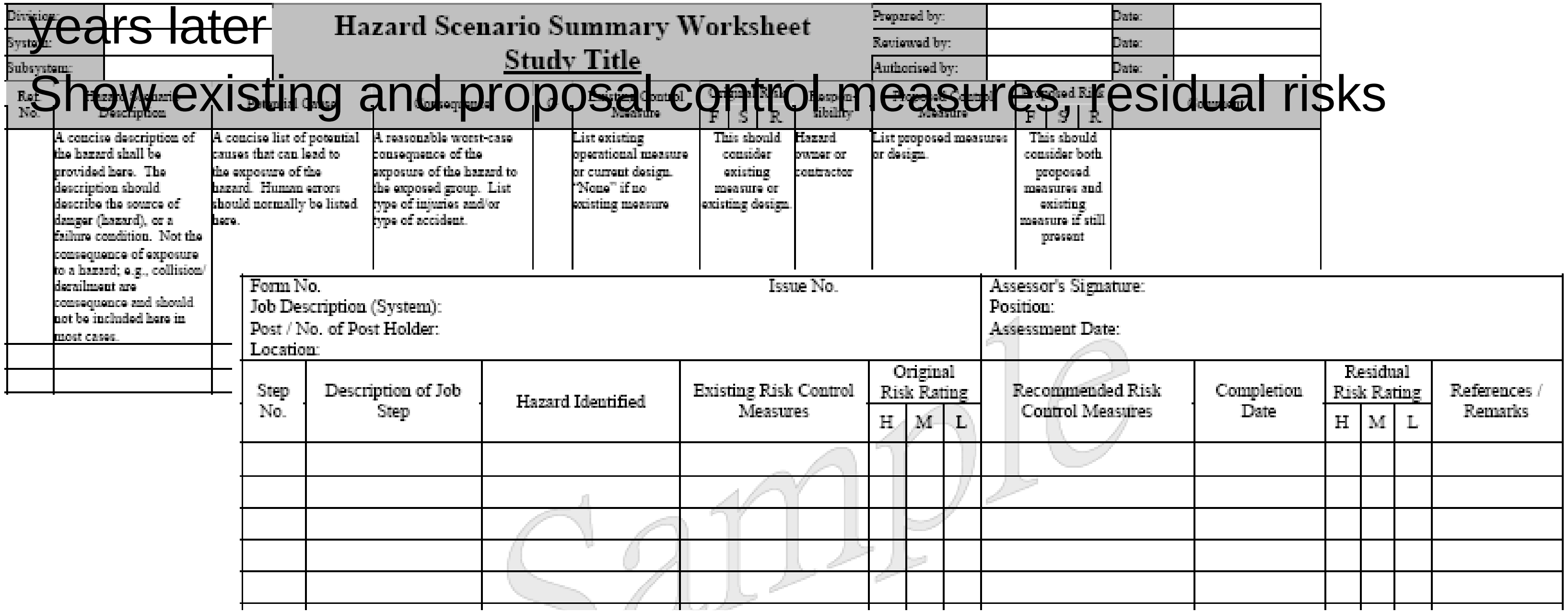
Work Example.. Filling the Worksheet



- Describe the scenarios, not listing the hazards
- Need a concise, self-explanatory description of a hazard scenario:
  - (a) "…*Hazard Description*…" due to "…*Potential Cause*…" resulting in "…*Consequence*…" or
  - (b) "…*Potential Cause* …" causing "…*Hazard Description*…" that results in "…*Consequence*…"
- Hazard: Electrical rotating tool
  - **(a) The worker suffers electrical shock due to improper grounding resulting in fatality**
  - **(b) Improper grounding of electrical drill causing the worker to suffer electrical shock that results in fatality**
  - **(c) The worker dropped the electrical into water due to carelessness resulting in electrical shorts that lead to fire, when the shorts were in contact with the alcohol, causing fatality**
  - **(d) The drill got into the worker's hands due to carelessness and lack of PPE resulting in puncture and fracture wounds**

Work Example.. Filling the Worksheet

- Be creative but realistic
- Each row is one scenario that gives one set of H/M/L or F/S/R; if you lump different scenarios together, hard to justify H/M/L or F/S/R
- Be able to know what you are talking about by you and others years later
- Show existing and proposal control measures, residual risks



Hazard Scenario Summary Worksheet

Study Title

Division:							Prepared by:			Date:			
System:							Reviewed by:			Date:			
Subsystem:							Authorised by:			Date:			

Ref No.	Hazard Scenario Description	Potential Causes	Consequences	G	Existing Control Measure	Original Risk F	S	R	Responsibility	Proposed Control Measure	Proposed Risk F	S	R	Comment
	A concise description of the hazard shall be provided here. The description should describe the source of danger (hazard), or a failure condition. Not the consequence of exposure to a hazard; e.g., collision/ derailment are consequence and should not be included here in most cases.	A concise list of potential causes that can lead to the exposure of the hazard. Human errors should normally be listed here.	A reasonable worst-case consequence of the exposure of the hazard to the exposed group. List type of injuries and/or type of accident.		List existing operational measure or current design. "None" if no existing measure	This should consider existing measure or existing design.			Hazard owner or contractor	List proposed measures or design.	This should consider both proposed measures and existing measure if still present			

Form No. Issue No.
Job Description (System):
Post / No. of Post Holder:
Location:

Assessor's Signature:
Position:
Assessment Date:

Step No.	Description of Job Step	Hazard Identified	Existing Risk Control Measures	Original Risk Rating H	M	L	Recommended Risk Control Measures	Completion Date	Residual Risk Rating H	M	L	References / Remarks

Work Example.. Filling the Worksheet

Hazard ID.	Hazard Description	Potential Cause	Consequence	Existing Control Measure	Original Risk			Proposed Control Measure	Residual Risk			Comment
					F	C	R		F	C	R	
1	The worker dropped the electrical into water due to carelessness resulting in electrical shorts to the metal ladder	Lack of safety awareness	Possible fatality due to electrical shock and/or downing	none	F2	C4	A	Drain water before work, use rechargeable drill if possible or GFCI protected circuit	F4	C2	C	

Work Example.. Filling the Worksheet

- Must tell people which risk matrices you are using
- Be consistent - If you use H/M/L type simple matrix, do not use Frequency and Severity classes
- If you use Likelihood and Consequence classes, you must show L/C/R explicitly for each scenario
- If your tables have numeric scores, you must show scores

Work Example.. Typical Mistakes

- Mix up risk matrices, if use L/C/R must show all 3 values
- Show scoring matrices but did not show scores
- Mix up potential cause and hazard scenarios
- Scenario description not concise
- Did not show residual risk
- Miss key hazards (fire, water hazards)
- Provide PPE is not the best bet

Priority of Risk Control Applications

(a) Eliminate the hazard (e.g., Physically remove the hazard, design change);

(b) Substitute the hazard with a safe alternative (e.g., replace a hazardous material with a safe material);

(c) Prevent exposure of personnel to the hazard;

(d) Use of active and/or passive safe guards, minimise failure of safe guards with redundancy (e.g., install safety barriers or warning devices) and/or special procedure and administration control;

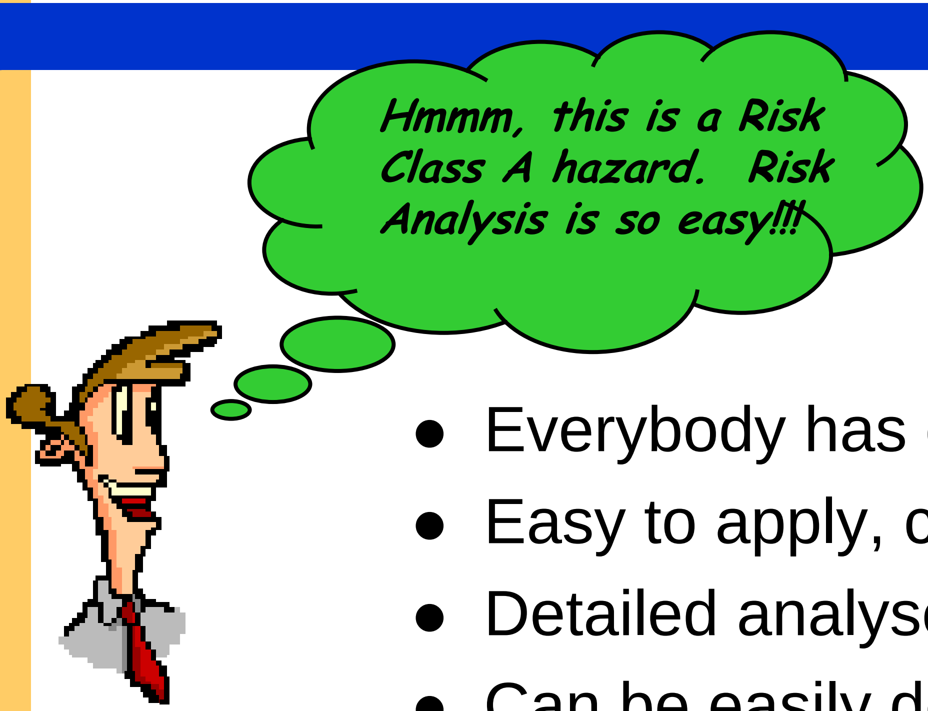
(e) Use of personal protection equipment;

(f) Develop response plan to reduce the consequence;

(g) Conduct focused training to improve the competency of staff and reduce human errors (this should not be the only control measure for high risk hazards); and

(h) Accept the hazard and monitor the hazard continuously (this should not be the only control measure for high risk hazards).

Advantages of Worksheet Methods


Hmmm, this is a Risk Class A hazard. Risk Analysis is so easy!!!

- Everybody has done one before
- Easy to apply, can be used by non-experts
- Detailed analyses not required
- Can be easily done in spreadsheet such as Excel
- Useful in evaluating a large number of alternatives with obvious differential risks

Disadvantages of Worksheet Methods

- Anyone can be an instant expert, results can be inconsistent between users
- Cannot evaluate complex situation or common cause failures

- **Cannot give the total risk of a system**
- **Cannot address Severe Accident Vulnerabilities**

Example of Mis-Using a Risk-Ranking Worksheet

Hazard	Consequence	Prob	Severity	Risk Class
Pump Room fire	Both pumps fail	Med	High	A

Severity Probability	Low	Med	High
Low	D	C	B
Medium	C	B	A
High	B	A	A

- **Pump Room fire is not a rare event**
- **Losing both pumps will loss cooling**

Example of Mis-Using a Risk-Ranking Worksheet

Hazard	Consequence	Prob	Severity	Risk Class
Pump A on fire	Pump A damaged	Low	Med	C

Severity Probability	Low	Med	High
Low	D	C	B
Medium	C	B	A
High	B	A	A

- A high risk location can be easily broken down into components many sub-items (rows) with a lower risk for each sub-item

Problems with Most Identification Tools

- What if thinking is difficult for some
- People do not perceive normal work conditions to be a hazard
- People not trained in safety may not know what is a hazard
- People are reluctant to spend time and effort at the planning stage
- Copying other people's hazard list is easy... But often meaningless

HKARMS

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Mark Your Calendar…

Safety & Risk Management Systems

Safety Culture & Commitment

Risk Control & Emergency Preparedness

Risk Management & Safety

Audit, Review & Continual Improvement

Risk Communication & Social Responsibility

Resources Planning & Business Strategy

Disaster: Preparedness, Recovery and Response

A HKIE-SSC Conference

18 July 2008
8:45 am to 5 pm
Hong Kong Polytechnic University

Without risk,
there is no opportunity.

END