

# **Risk Matrices - The Good, the Bad and the Ugly**

## **Common Pitfalls in their Design and Use**

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# Background

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- We do risk assessments for a variety of reasons:
  - ↳ “The boss asked me”
  - ↳ “The regulations tell me to do it”
  - ↳ “Sounds like a good thing; I was bored anyway”
  - ↳ “We are having too many accidents. I want to know what else can happen, so that we can cut our losses”
  - ↳ “We have a good accident record; I want to keep it that way”
  - ↳ “We have an exemplary accident record; I want to make it better”
  - ↳ Save money
  - ↳ Due diligence
  - ↳ Resource allocation
  - ↳ Proving a pre-determined decision...

## Outcome of a Risk Assessment

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- A long list of things that can go wrong, and a long list of associated recommendations for prevention or mitigation
  - ↳ These can all be good, technically valid
- If we are lucky, there is some prioritization

# Approaches to Prioritization

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- Prioritization can be based on:
  - ↳ “The boss’s pet priorities”
  - ↳ “The risk assessment team’s pet priorities”
  - ↳ “Whether the findings result from contravention of
    - “government edicts (laws/regulations/guidelines),
    - “company edicts (policies/standards/guidelines),
    - “industry edicts (policies/standards/guidelines/best practices)”
  - ↳ “According to the *risk* of ‘what can go wrong’”
- Hopefully, we are using the “risk-based” approach (also considering the “edicts”: “or else ...”)
- And this is where the trouble starts ...
  - ↳ that “good”, “bad” and “ugly” word “risk”, and the associated innocent-looking formula for quantifying risk:
    - Risk = Consequence x Likelihood

## Objectives of the presentation

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Our objectives are to

- Discuss
  - ↳ What these “troubles” are
  - ↳ How they are related to a “risk matrix”
  - ↳ How these “troubles” lead to the “bad” and “ugly” practices in designing and using risk matrices and
- Suggest ways of avoiding the pitfalls, and design “good” practices

## Trouble #1: What is *Risk*? - Its definitions:

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- e.g., ANSI/AIHA Z10-200X (draft):
  - ↳ “An estimate of the combination of the *likelihood* of an occurrence of a hazardous *event* or exposure(s), *and* the *severity* of injury or illness that may be caused by the event or exposures.”
    - NOTE the emphasis: *likelihood* of event, and *severity* of event
    - and what exactly is an “event”?
      - ❖ a “car accident”? or a “car accident with fatality”?

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- If we want to quantify the risk of an “event” using the ANSI definition, and define “event” as a “car accident”
    - ↳ risk of car accident = likelihood of car accident x  
severity of car accident
  
  - In my experience, likelihood of me (“individual”) getting involved in a car accident (like collision with another object, mobile or otherwise, worth speaking about, including somebody hitting your car while you are parked) is about 1 in 10 years
    - ↳ risk of car accident = 0.1 car accidents/year x  
severity of a car accident
  
  - Looking at the possible “severities” of a car accident,
    - ↳ death
    - ↳ injury
    - ↳ “total” the car, no injury or death
    - ↳ some damage to car, no injury or death
  
  - Which one of these should I attach to the 1 in 10 yrs likelihood?

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- If I attach “death” to this likelihood, the risk is 0.1 death/year, which is too high an estimate of risk.
  - If I attach “injury” to this likelihood, the risk is 0.1 injury/year, which is again too high an estimate of risk, and I do not take into account the possibility of death in my thinking for the purposes of further decision making.
  - If I attach “total” destruction of the car to this likelihood, the risk is 0.1 car destroyed/year, which is again too high an estimate of risk, and I do not take into account the possibility of death or injury in my thinking for the purposes of further decision making.
  - If I attach “some damage” to car to this likelihood, the risk is 0.1 car damaged/year, which is a reasonable estimate of risk, but I do not take into account the possibility of death or injury or “total” destruction in my thinking for the purposes of further decision making.
  - Clearly, the above approach, with the ANSI definition as the starting point, is wrong!!

## Other definitions

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- e.g., AS/NZS 4360:
  - ↳ “Risk is the **chance** of something happening that will have an impact on objectives.”
- e.g., BC Hazard, Risk and Vulnerability Analysis Tool Kit (2003):
  - ↳ “Risk does **not** mean **chance**, probability or likelihood.
  - ↳ “Risk is a **total concept** of *likelihood of occurrence* of a hazard and the *severity of possible impacts*.”
    - ➔ “occurrence of a hazard”? really?

Not much help here!!

## Other definitions

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- The Canadian Institute of Chartered Accountants:
  - ↳ “Left undefined, ‘risk’ can mean different things to different people.
  - ↳ “For example, traditionally a ‘risk’ was defined as a **specific peril or threat** and “risk management” meant buying insurance and taking other steps to protect against financial losses.
  - ↳ “Today, the terms ‘risk’ and ‘risk management’ have come to cover **all aspects of being in business** and include **both opportunities and threats.**”
  
- Treasury Board of Canada (Integrated Risk Management Framework, 2001)
  - ↳ “Risk refers to the uncertainty that surrounds future events and outcomes.
  - ↳ “It is the expression of the **likelihood** and **impact** of an **event** with the potential to influence the achievement of an organization’s objectives.”

Do you think there is light at the end of the tunnel?? !!

## Other definitions

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- CCPA Manufacturing Code Of Practice, Site Acute Risk Assessment Implementation Aid:
  - ↳ “Risk is a much abused term which is used interchangeably with the word ‘hazard’.
  - ↳ “In this document, risk is taken to be a function of a hazard, a consequence and a frequency, i.e.:
    - ➔ “RISK = f (HAZARD, CONSEQUENCE, FREQUENCY)”
  
- IEC Guide 73:
  - ↳ “Combination of the *probability of an event* and its *consequence*”
    - ➔ really?

## Other definitions

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- CSA-Q634-91
  - ↳ “A measure of the **probability** and **severity of an adverse effect** on health, property, or the environment.”
    - NOTE emphasis: **probability** (of an adverse effect) and **severity of an adverse effect**
  
- CSA - Q850
  - ↳ “Chance of injury or loss as defined as a measure of the **probability** and **severity of an adverse effect** to health, property, the environment, or other things of value”
    - NOTE again the emphasis: **probability** (of an adverse effect) and **severity of an adverse effect**

Hmmm!

That means, if we define the event as a “car accident with fatality”, and not as just “car accident”, the ANSI definition (and most of the others) will be OK!!

This looks like light at the end of the tunnel !

## Light at last, but other type of trouble brews ...

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- This thinking implies the following formula to quantify risk:

$$\text{Risk of adverse effect} = \text{severity of adverse effect (consequences)} \\ \times \text{likelihood of adverse effect}$$

- And, if there are many possible *adverse effect* outcomes of a given type of event, you sum the risk of each adverse effect, to calculate the total risk of that type of event.
  - ↳ Unfortunately, one needs to be able to express the *severity* in the same units of measurement for the different adverse effects
  - ↳ This is **Trouble #2**
- One way of resolving this issue is using a common measure that everyone understands - \$ - and most hate:
  - ↳ “how much is your life worth?”
    - ➔ However, lets leave that discussion for another day ...
- In fact, there is another way of resolving this issue – but we shall come to that after we discuss Trouble #3, because this other way provides a resolution to both Trouble #2 and Trouble #3.

## Trouble #2 (continued)

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- Returning to our car accident example, just to complete our train of thought:

*Risk of car accident fatalities = deaths/fatal accident x fatal accidents/year*  
*= car accident deaths/year*

*Risk of car accident injuries = injuries/injury accident x injury accidents/year*  
*= car accident injuries/year*

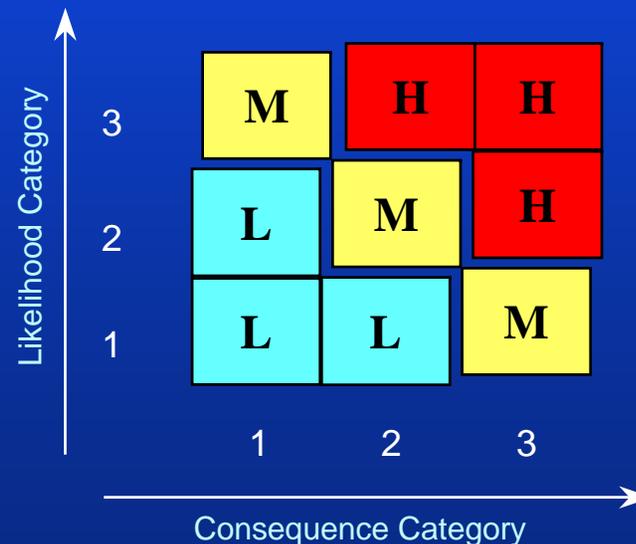
*Risk of "totalled car" accidents = "totalled cars"/car accident x*  
*"totalled car" accidents/year*  
*= "totalled cars"/year*

*Risk of "damaged-car" accident = "damaged-cars"/car accident x*  
*"damaged-car" accidents/year*  
*= "damaged-cars"/year*

- One can see why it is difficult to add these risks to get the total risk of car accidents unless the units of measurement are the same for each

## Trouble #3 – The formula is too complex

- The formula for risk involves a multiplication
- Beyond our formal school years, *multiplication is far too complex* for most of us
- We like to use simpler approaches than multiplication
- Therefore, we use a visual aid, remembering our elementary graphing expertise



- We call this a “Risk Matrix”

# Focusing on People Health & Safety for the Moment

- As an example, define the Consequence and Likelihood Categories as

Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

# Bad Practice #1 – worst consequence with total likelihood

Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequences		

➤ Returning to our car accident example, and taking the “event” as the “car accident”:

↳ Likelihood: 0.1/yr

## BP#1

↳ Following ANSI guidance, as an example,

5. Assess the severity of injury/illness. Based on experience and knowledge make an estimate of the **worst** credible injury or illness consequence(s) should an incident occur.

↳ Consequence can be death: Consequence Category 3

↳ The combination gives you “H” risk – oops!!

❖ and you cannot do much about it either.

## Bad Practice #1 (continued 2)

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- Unfortunately, this way of thinking is very prevalent in today's risk assessments across many industries,
  - ↳ gives risk assessment a very bad name among operations people that are told everything is "high risk" according to "THE MATRIX", even though common sense says otherwise.
  
- Why do people do it?
  - ↳ They use the term "risk" incorrectly, confusing it with "consequence".
  - ↳ They want to emphasise the potential worst outcome, even though the actual "risk" of that worst outcome may not actually be "High".
  - ↳ They want to show to others that, if they do not practice "safety", the consequence **would be** very bad, and the risk **would be** very high (even though the current actual risk may not be that high!)
    - "assume no controls are in place" syndrome
    - A legitimate approach if the controls that are assumed to be failing are specified precisely!
      - ❖ But, alas! That does not happen very often!

## Typical recording format for Bad Practice #1

Hazardous Event	Event Frequency	Event Consequence	Event Risk
	$f_e$	C	R
Car accident	2	3	H

- Typical Footnote (if you are lucky): “Event consequence assumes no controls are in place”

## Why is Bad Practice #1 so prevalent?

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- Consider LOPA – Layers of Protection Analysis
- It is a relatively new technique, that serves to fill the gap between fully qualitative process hazard analysis (PHA) techniques such as HAZOPs, and the fully quantitative techniques such as consequence modelling and fault and event tree analysis.
- It is limited to evaluating a single cause-consequence pair as a scenario.

## LOPA - continued

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- LOPA typically uses order of magnitude estimates of initiating event frequency, consequence severity, and the likelihood of failure of independent protection layers (IPLs) to approximate the risk of a scenario.
- The starting point is an event scenario with an unacceptable consequence, identified through some qualitative PHA technique during a design review or management of change review.
- The scenario is defined through the description of a cause-consequence pair.
- The LOPA is then used to determine which engineering and administrative controls as envisaged at that time can be considered as IPLs, what the risk is from that scenario considering the initiating event (cause) frequency, consequence severity, and the likelihood of failure of these IPLs.
- If this risk is considered unacceptable (through a pre-established set of criteria), then further IPLs are added until the risk from that scenario is reduced to acceptable levels.

# LOPA Example (CCPS, 2001)

- Establish scenario and its worst possible (unmitigated) consequence
- Establish risk tolerance criteria
- Estimate likelihood of worst possible (unmitigated) consequence
- Consider the *Independent Protection Layers* for mitigating these consequences or preventing the scenario in the first place
  - ↳ Estimate the reduction in likelihood afforded by these IPLs
- Estimate the magnitude of any further reduction required in likelihood to reach the risk tolerance criteria (BPCS – Basic Process Control System; Human Intervention; SIF – Safety Instrumented Function; other)
  - ↳ PFD – Probability of Failure on Demand
- Identify the additional *independent* preventive or mitigation actions that can provide this reduction in likelihood

TABLE 8.4

Summary Sheet for Continuing Example 2—Scenario 2a: Numerical Criteria Method [Consequence Severity using Fatality Frequency Criteria Method (Method 3 of Chapter 3)]

Scenario Number	Equipment Number	Scenario Title: Hexane Storage Tank Overflow, Spill not contained by the dike.	
2a			
Date:	Description	Probability	Frequency (per year)
Consequence Description/Category	Release of hexane outside the dike due to tank overflow and failure of dike with potential for ignition and fatality.		
Risk Tolerance Criteria (Category or Frequency)	Maximum Tolerable Risk of a Serious Fire Maximum Tolerable Risk of a Fatal Injury		<1 × 10 <sup>-4</sup> <1 × 10 <sup>-5</sup>
Initiating Event (typically a frequency)	Arrival of tank truck with insufficient room in the tank due to failure of the inventory control system. Frequency based on plant data.		1
Enabling Event or Condition		N/A	
Conditional Modifiers (if applicable)			
	Probability of ignition	1	
	Probability of personnel in affected area	0.5	
	Probability of fatal injury	0.5	
	Others	N/A	
Frequency of Unmitigated Consequence			2.5 × 10 <sup>-1</sup>
Independent Protection Layers			
	Operator checks level before unloading (PFD from Table 6.3)	1 × 10 <sup>-1</sup>	
	Dike (existing) (PFD from Table 6.5)	1 × 10 <sup>-2</sup>	
	SIF (to be added—see Actions)	1 × 10 <sup>-2</sup>	
Safeguards(non-IPLs)			
	BPCS level control and alarm is not an IPL as it is part of the BPCS system already credited in LI read by operator.		
Total PFD for all IPLs		Note: Including added IPL	1 × 10 <sup>-5</sup>
Frequency of Mitigated Consequence			2.5 × 10 <sup>-6</sup>
Risk Tolerance Criteria Met? (Yes/No): Yes, with added SIF.			
Actions Required to Meet Risk Tolerance Criteria	Add SIF with PFD of 1 × 10 <sup>-2</sup> . Responsible Group/Person: Plant Technical/ J. Doe June 2002 Maintain dike as an IPL (Inspection, maintenance, etc.)		
Notes	Human action at 1 × 10 <sup>-1</sup> as although actions simple and no time constraints the PFD of the level indication loop sets the overall PFD for this IPL. Add action items to action tracking database.		
References (links to originating hazard review, PFD, P&ID, etc.):			
LOPA analyst (and team members, if applicable):			

## Why is this approach so prevalent? - continued

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- Note how precise the various steps are!
- Most risk assessors that undertake risk assessments using a risk matrix use the approach because it is “simple”
  - ↳ They do not have the patience to utilize the level precision of a LOPA analysis in their thinking
  - ↳ They typically do not have the technical background to carry out a LOPA level study
  - ↳ However, they are told by LOPA-type people that they should start their risk assessment by assuming “no controls are in place”

## Outcome of Bad Practice #1

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- On top of that:
  - ↳ Company policy: Every “High” risk event must be reported to the Board of Directors!
  
- And the outcome is (with a degree of exaggeration to make a point!):
  - ↳ “Car accidents are high risk events that must be reported to the Board of Directors”!
  - ↳ And a big laugh from common-sense people!

# Corresponding “Good” practice #1

➤ SOLUTION:

- Likelihood of car accident: 0.1/yr
- Probability of death if involved in a car accident (out of all the car accidents worth speaking about): 1/1000
- Likelihood of death resulting from a car accident: 0.0001 ( $10^{-4} = 0.1 \times 1/1000$ )

Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

## Good practice #1 (continued 2)

- ↳ Likelihood of car accident: 0.1/yr
- ↳ Probability of injury if involved in a car accident (out of all the car accidents worth speaking about): 1/100
- ↳ Likelihood of injury resulting from a car accident” 0.001 ( $10^{-3}$ )

Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

## Good practice #1 (continued 3)

- ↳ Likelihood of car accident: 0.1/yr
- ↳ Probability of no H&S impact if involved in a car accident (out of all the car accidents worth speaking about):
  - $1 - (1/100 + 1/1000) = 1 - 0.01 - 0.001 = 0.989$
- ↳ Likelihood of no H&S impact resulting from a car accident” approximately 0.1 (0.1 x 0.989)

Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

# Good practice #2 – Recording format for Good Practice #1

Hazardous Event	Event $f_e$	Risk Receptor = People Safety			Public		
		C	f	R	C	f	R
$f = f_e \times P_{\text{consequence}}$							
Car Accident	2	3	1	M	4	1	L
		2	1	L	3	1	VL
		1	2	L	2	2	VL

## Good practice #1 (continued 4)

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- So, is “car accident” a “M” or “L” risk event?
  - ↳ Suggest taking the highest risk level (out of the 3 combinations of (C,L)) as representative for that event = “M”
  
- Thus,
  - ↳ Scanning through all possible adverse outcomes of an event,
  - ↳ analyzing the corresponding risk, and then
  - ↳ taking the highest risk level to represent the risk of that event provides us with
    - ↳ a good conservative estimate of the overall risk of that event, for ranking/prioritization and further decision making purposes,
    - and
    - ↳ allows you to understand the worst potential consequence of the event, that will help with emergency management plans and raise awareness of the importance of good operational practices

## Bad practice #2 – typical consequence with total likelihood

- Returning to our car accident example, and taking the “event” as the “car accident”:
  - ↳ Likelihood: 0.1/yr

- BP#2** ➤ Taking the most typical outcome as “representative” consequence
- ↳ Consequence category: No H&S impact (98.9% of the time)

Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

- This approach has high potential for
  - ↳ severely underestimating risk, and
  - ↳ hiding the possibility of the worst outcome
- SOLUTION: Good practice #1

## Ugly practice #1 – not specifying clearly the “consequence”

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- Returning to our car accident example, and taking the “event” as the “car accident”:

- ↳ Likelihood: 0.1/yr

### UP#1

- ↳ Taking the **worst** or the **most typical** outcome as “representative” consequence

- ↳ depending on the mood of the team

- ↳ This practice results from not specifying clearly how you are defining the event, and not specifying clearly how you are treating the consequence

- This approach has high potential for
  - ↳ severely underestimating or overestimating the risk, and
  - ↳ hiding or emphasizing the possibility of the worst outcome depending on people’s mood!!
- SOLUTION: Good practice #1

## Ugly practice #2 – “Refining” events

- As a thought experiment, let us assume, across our 10 operating facilities, we experience 100 broken pipes per year, 1 broken pipe per year that leads to an injury (and, let’s say, 0.01 broken pipe per year leading to death).
- This would fall into a “High” risk event category on our matrix.

Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

- Remember: Company policy - Every “High” risk event must be reported to the Board of Directors!
- We decide to investigate, and become curious about breaks of what size pipe lead to these injuries.

## Ugly practice #2 (continued 2)

- We analyze the data, many years' worth and across many industries, classify the incidents into categories of pipe sizes, and rank the risk associated with different pipe sizes using our risk matrix.
- We decide to use 10 pipe size categories.
- We find that 10% of incidents with injuries fall into each size category, i.e., likelihood of 0.1 /yr (1 /yr x 10% per size category)
- We plot these 10 types of events (breaks of pipe size category 1, 2, etc.) on the risk matrix (a “risk map”).
- Suddenly, we discover that a “high” risk event has become ten “medium” risk events, by “refining” the definition of that event! and none of these 10 needs to be reported!
- The possibilities of abuse are limitless.

**UP#2**

Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

# Good practice #3 – Graduating to use of Risk Profiles

- SOLUTION: Do not rely on risk maps alone for reporting; also use risk profiles (complementary cumulative frequency distributions, or “FN curves”)

**Risk Map**  
“unrefined”  
event  
definition: 1  
“high” risk  
event

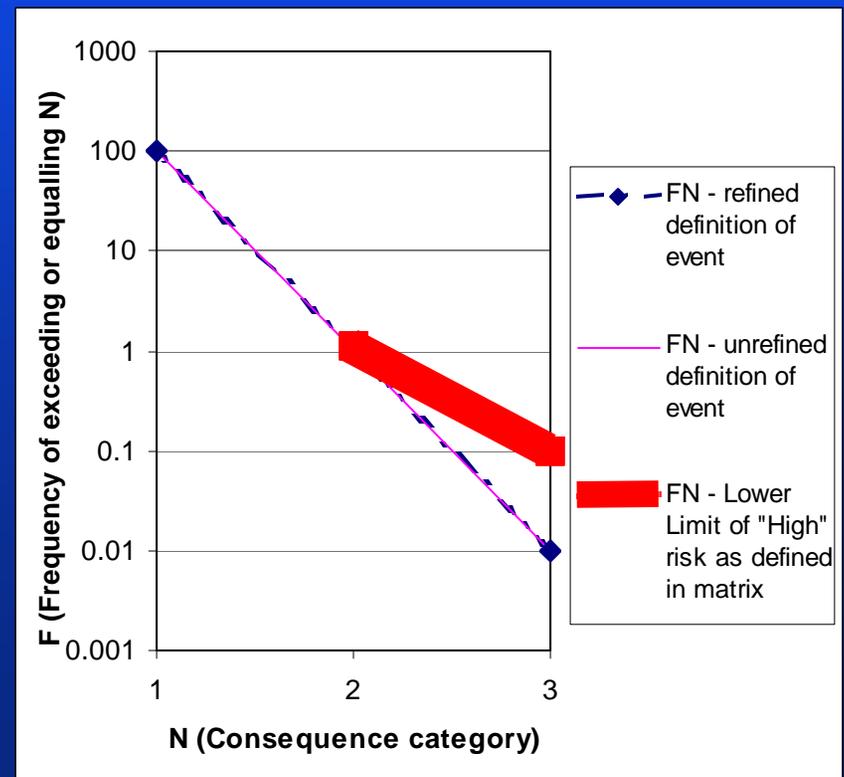
Frequency	1 / yr	3	M	<b>H</b>	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

**Risk Map**  
“refined”  
event  
definition:  
10  
“medium”  
risk  
events

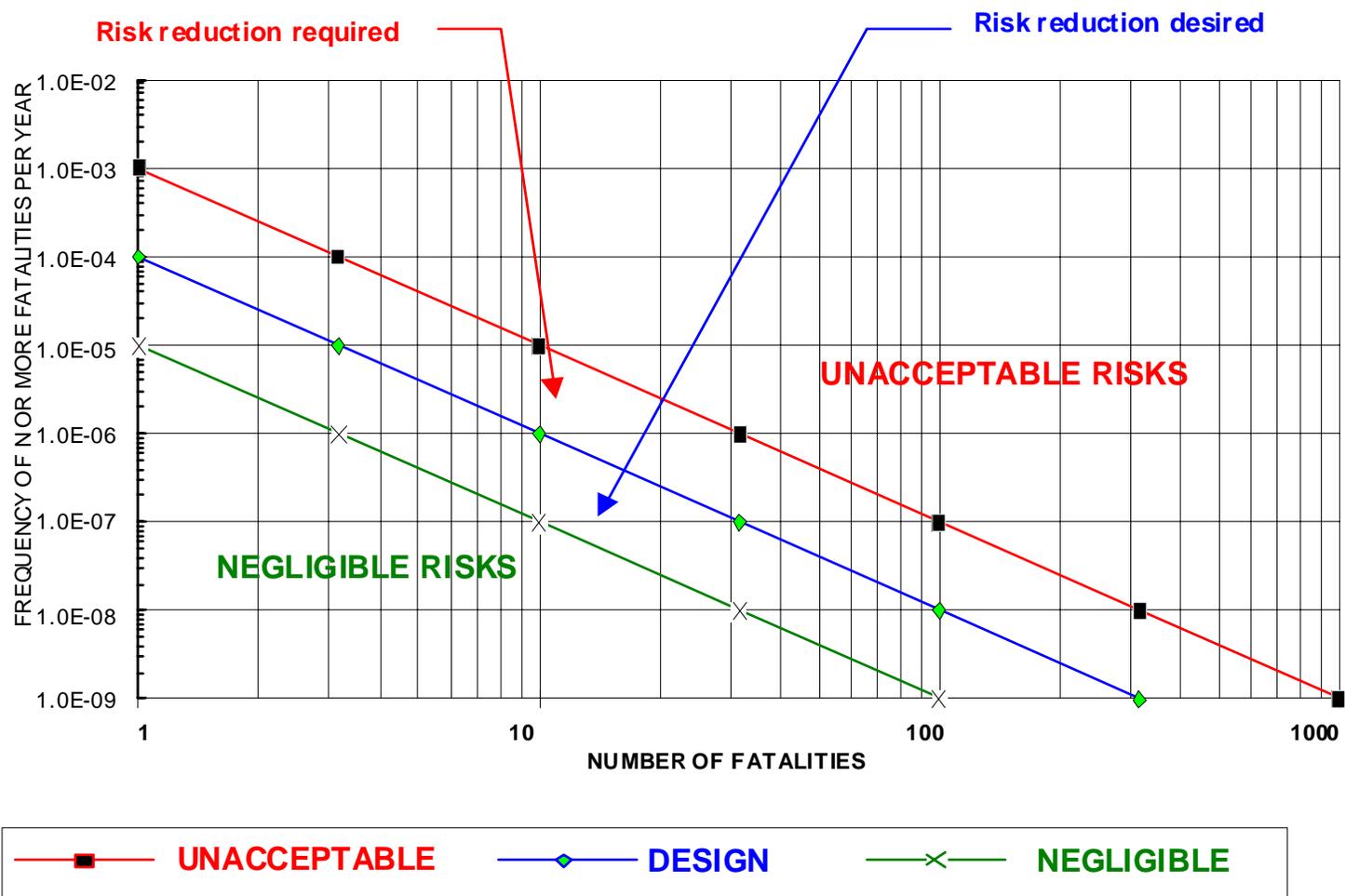
Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	<b>M</b>	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

## Risk Profile

Regardless of “unrefined” or “refined” event definitions, the profile shows “High” risk at the (2,1) point (intersection with the “High” risk definition line based on the matrix)



# Example of Ground Rules



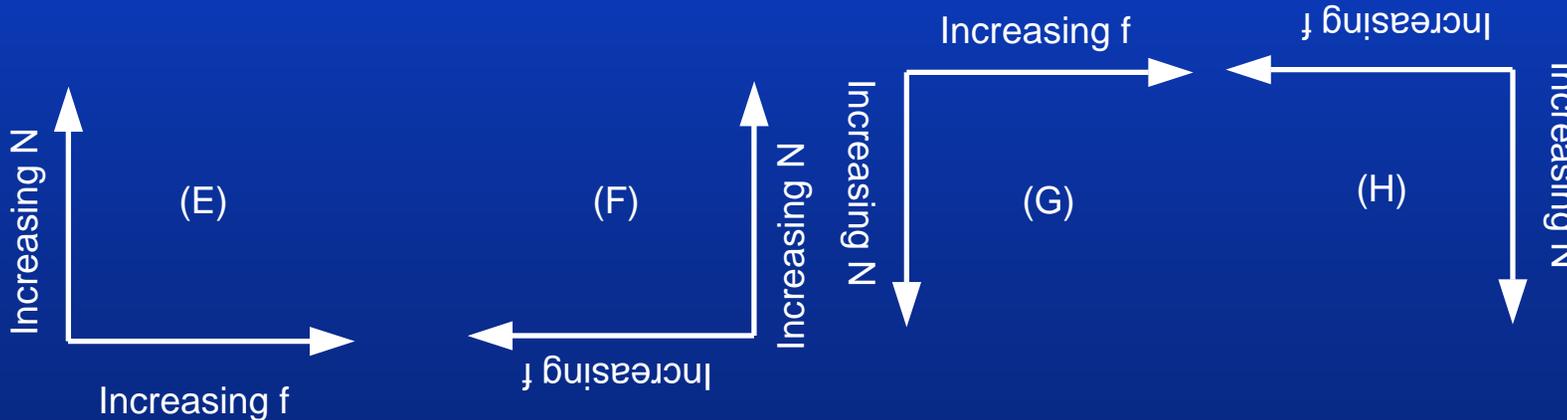
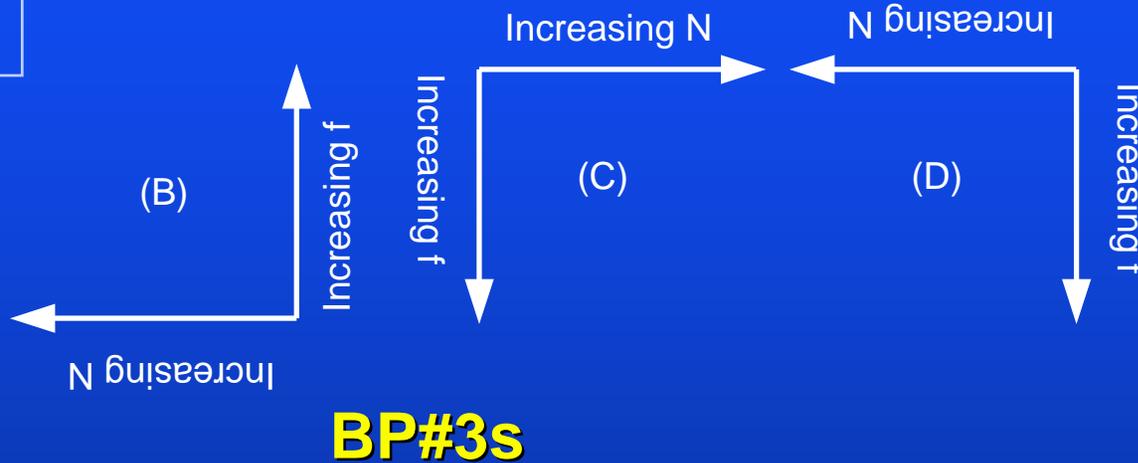
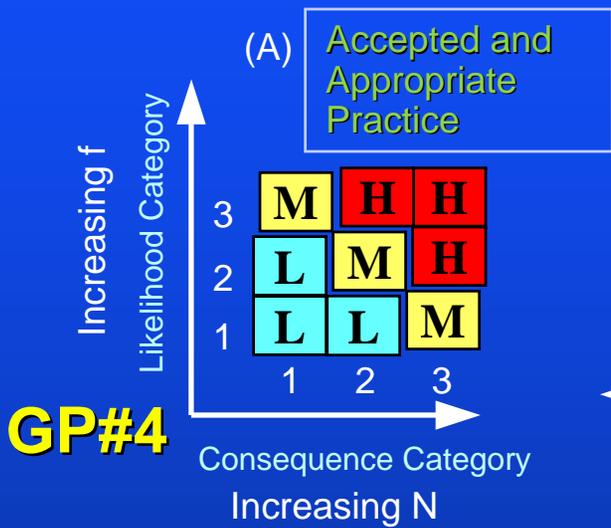
CSCHE PSLM 2004 Conference

Successful Process Safety Management — Strategic Positioning



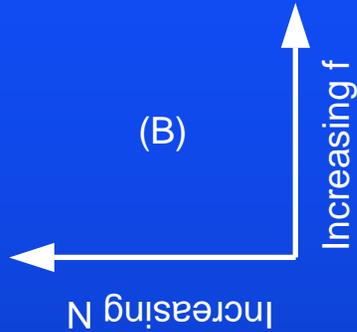
# Bad practice(s) #3

- There are many options for setting up the risk matrix



# Bad practice(s) #3 (continued)

➤ Example from an international standard



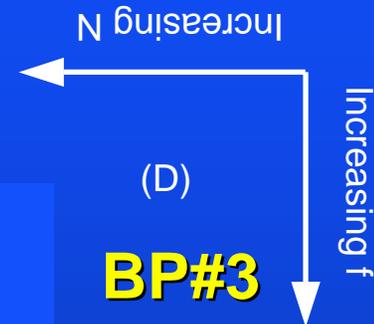
**BP#3**

Example of a Risk Assessment Matrix				
Likelihood of OCCURRENCE or EXPOSURE For selected Unit of Time or Activity	←----- Severity of Injury or Illness Consequence and Remedial Action -----→			
	<b>CATASTROPHIC</b> Death or permanent total disability	<b>CRITICAL</b> Disability in excess of 3 months	<b>MARGINAL</b> Minor injury, lost workday accident	<b>NEGLIGIBLE</b> First Aid or Minor Medical Treatment
<b>Frequent</b> Likely to Occur Repeatedly	<b>HIGH</b> Operation not permissible	<b>HIGH</b> Operation not permissible	<b>SERIOUS</b> High Priority Remedial action	<b>MEDIUM</b> Take Remedial action at appropriate time
<b>Probable</b> Likely to occur several times	<b>HIGH</b> Operation not permissible	<b>HIGH</b> Operation not permissible	<b>SERIOUS</b> High Priority Remedial action	<b>MEDIUM</b> Take Remedial action at appropriate time
<b>Occasional</b> Likely to occur sometime	<b>HIGH</b> Operation not permissible	<b>SERIOUS</b> High Priority Remedial action	<b>MEDIUM</b> Take Remedial action at appropriate time	<b>LOW</b> Risk Acceptable: Remedial Action Discretionary
<b>Remote</b> Not likely to occur	<b>SERIOUS</b> High Priority Remedial action	<b>MEDIUM</b> Take Remedial action at appropriate time	<b>MEDIUM</b> Take Remedial action at appropriate time	<b>LOW</b> Risk Acceptable: Remedial Action Discretionary
<b>Improbable</b> Very unlikely – may assume exposure will not happen	<b>MEDIUM</b> Take Remedial action at appropriate time	<b>LOW</b> Risk Acceptable: Remedial Action Discretionary	<b>LOW</b> Risk Acceptable: Remedial Action Discretionary	<b>LOW</b> Risk Acceptable: Remedial Action Discretionary

# Bad practice #3 and Bad practice #4 and Good practice #5

**BP#4** ➤ lower numerical value indicates higher consequence or likelihood!!

**GP#5** ➤ using alphabetical characters for risk levels



		C O N S E Q U E N C E				
		1	2	3	4	5
P R O B A B I L I T Y	5	C	C	D	E	E
	4	B	C	D	D	E
	3	B	B	C	D	D
	2	A	B	C	C	D
	1	A	A	B	C	C

# Bad Practice #5 – imprecise specification of frequency categories

➤ In my zeal for simplicity:

Frequency	1 / yr	3	M	H	H
	0.1 / yr	2	L	M	H
	0.01 / yr	1	L	L	M
			1	2	3
			No H&S	Injury	Death
			Consequence		

- Which frequency category do you put an event that occurs 1 in 3 years (or so)?
  - ↳  $1 \text{ event}/3 \text{ yrs} = 0.3 \text{ event/yr}$

## Good Practice #6

- Higher precision by defining a range, accompanied by verbal description

	Range	Description				
Frequency	$f \geq 1 / \text{yr}$	Happens once or more per year	3	M	H	H
	$1 / \text{yr} > f > 0.01 / \text{yr}$	Expected to happen during facility lifetime	2	L	M	H
	$f \leq 0.01 / \text{yr}$	Not expected to happen during facility lifetime	1	L	L	M
				1	2	3
				No H&S impact	Injury	Death
				Consequence		

## Bad Practice #6

- Again, in my zeal for simplicity

	Range	Description				
Frequency	$f \geq 1 / \text{yr}$	Happens once or more per year	3	M	H	H
	$1 / \text{yr} > f > 0.01 / \text{yr}$	Expected to happen during facility lifetime	2	L	M	H
	$f \leq 0.01 / \text{yr}$	Not expected to happen during facility lifetime	1	L	L	M
				1	2	3
				No H&S impact	Injury	Death
				Consequence		

- Not enough frequency resolution in the range that covers a human career lifetime

## Good practice #7

### ➤ Higher frequency category resolution

Likelihood Category	Frequency Guidelines (company basis)	Description
6	$f \geq 10/\text{year}$ (larger than or equal to 10/year)	Happens several times per year in each facility
5	$1/\text{year} \leq f < 10/\text{year}$ (between 1/year and 10/year)	Happens several times per year in company
4	$0.1 \leq f < 1/\text{year}$ (between 1/10 years and 1/year)	Expected to occur several times in the company lifetime
3	$0.01 \leq f < 0.1/\text{year}$ (between 1/100 years and 1/10 years)	Expected to occur in the company lifetime
2	$0.001 \leq f < 0.01/\text{year}$ (between 1/1000 and 1/100 years)	Has happened in this industry
1	$f < 0.001/\text{year}$ (less than 1/1000 years)	Has never happened in this industry

- This also allows for ranking typical occupational safety events using the same matrix
- For LOPA applications, even this resolution at the low frequency end is not sufficient
  - ↳ Need 7 or 8 likelihood categories for a more universally applicable matrix

## Good Practice #8 – Enhancements for other disciplines

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- E.g., maintenance – “% probability over a month” equivalents of the frequency ranges
  - ↳ Category 6: “over 80% in the next month”

# Bad Practice #7: Risk = Likelihood + Consequence

## HAZARD RATING

### Exposure

- 1 Unlikely (1x year or less)
- 2 Occasionally (1x/ month or less)
- 3 Often (1 or 2x/month but less than 4x/month)
- 4 Frequent (1 or 2x/week)
- 5 Continuous (1 or 2x/day)

### Probability

- 1 Unlikely to occur
- 2 Some chance
- 3 Could occur
- 4 Good chance
- 5 Will occur if not attended to

### Consequence

- 1 Insignificant
- 2 First aid or minor property damage
- 3 Lost time injury or significant property damage, seeks medical assistance.
- 4 Severe injury, serious health effects
- 5 Fatality/permanent disability or major property damage.

**E + P + C = Total**

**Risk Rating:**

- Serious:** requires immediate attention      **Total of 11 – 15**
- Moderate:** requires attention      **Total of 6 – 10**
- Low:** requires monitoring      **Total of 3 – 5**

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## Use of different size matrices

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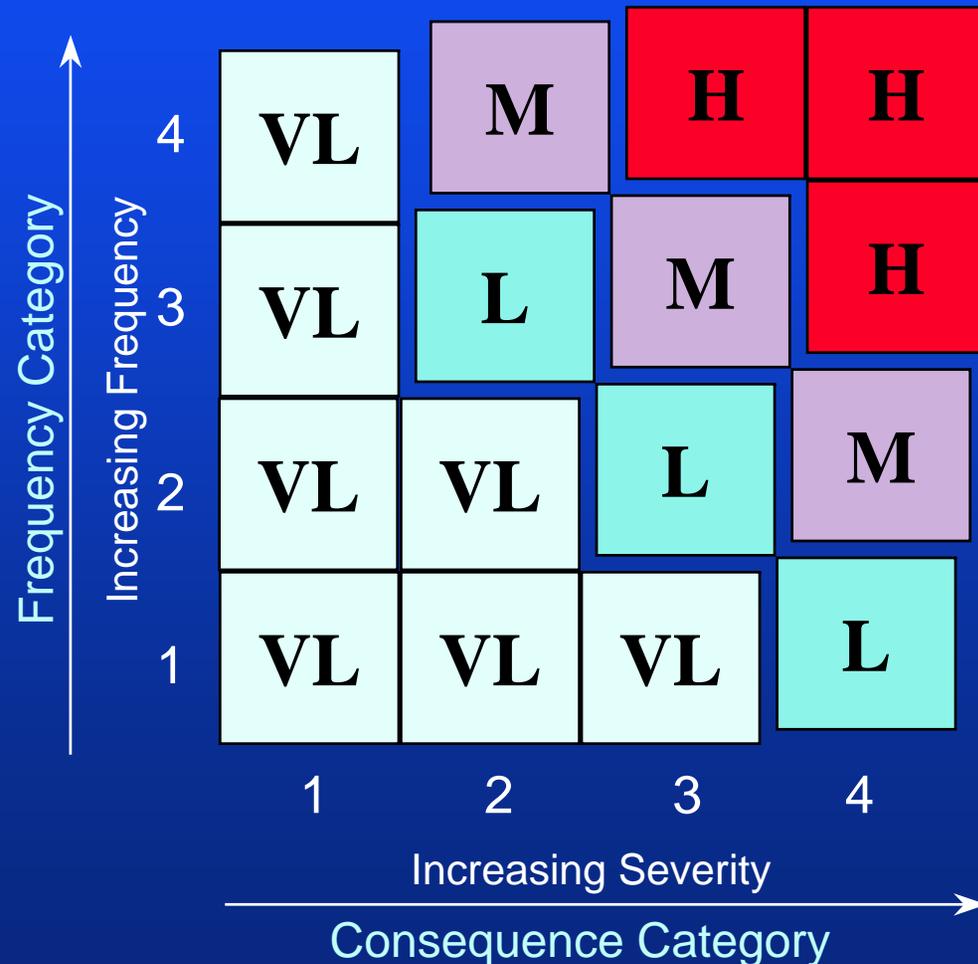
- 2x2
- 3x3 (our simplified example)
- 4x4 (CCPS, 1992)
- 4x5 (example international standard)
- 5x5
- 6x6
- 7x7
- 8x8
- 9x9

# Example 4x4 Matrix (CCPS)

➤ Asymmetric WRT the 45 degree bisector of quadrant

**GP#9** ➔ Builds in our societal value judgements

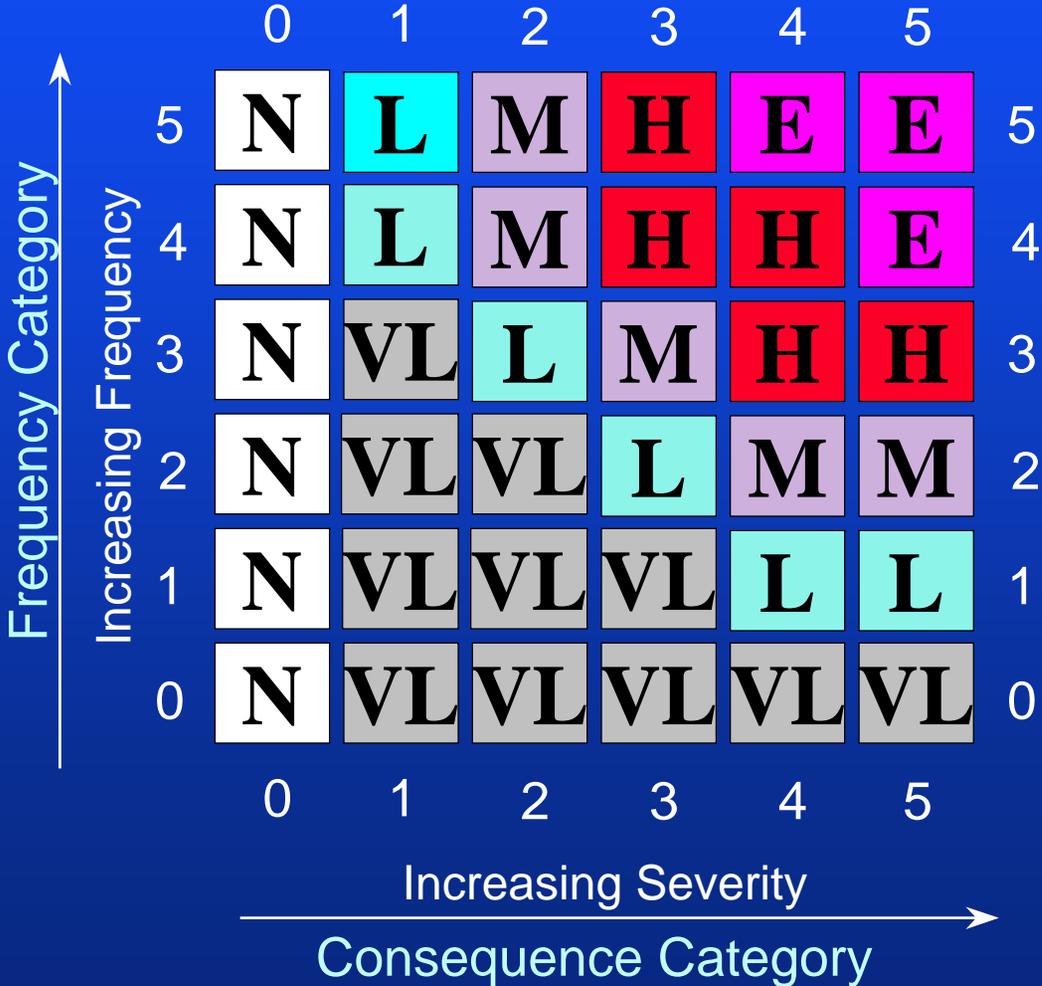
<b>H</b>	High
<b>M</b>	Medium
<b>L</b>	Low
<b>VL</b>	Very Low



# Example 6x6 Risk Ranking Matrix

➤ Good or bad?

<b>E</b>	Extreme
<b>H</b>	High
<b>M</b>	Medium
<b>L</b>	Low
<b>VL</b>	Very Low
<b>N</b>	None



# Example Frequency & Consequence Categorization for 6x6 Matrix

Category	Frequency Range	Description
0	< 10 <sup>-8</sup> /year	Less frequent than 1 in 100,000,000 years ( <b>Very Remote</b> )
1	10 <sup>-8</sup> - 10 <sup>-6</sup> /year	Between 1 in 100,000,000 and 1 in 1,000,000 years ( <b>Remote</b> )
2	10 <sup>-6</sup> - 10 <sup>-4</sup> /year	Between 1 in 1,000,000 and 1 in 10,000 years ( <b>Unlikely</b> )
3	10 <sup>-4</sup> - 0.01/year	Between 1 in 10,000 and 1 in 100 years ( <b>Moderately Likely</b> )
4	0.01 – 0.1/year	Between 1 in 100 years and 1 in 10 years ( <b>Likely</b> )
5	> 0.1/year	More frequent than 1 in 10 years ( <b>Very Likely</b> )

Category	Environmental Consequences (clean-up cost/ regulatory fines/ loss of resource use)	Category	Public and Employee Consequences
1	Less than \$1,000	0	No impact
2	Between \$1,000 - \$10,000	1	Annoyance impact
3	Between \$10,000 - \$100,000	2	Minor injury
4	Above \$100,000	3	Major injury
		4	Limited number of fatalities ( $\leq 3$ )
		5	Multiple fatalities ( $> 3$ )

Frequency Guidelines (company basis)	Description								
$f \geq 10/\text{year}$ (larger than or equal to 10/year)	Happens several times per year in each facility	Frequency	6	3	4	5	U	U	U
$1/\text{year} = f < 10/\text{year}$ (between 1/year and 10/year)	Happens several times per year in company		5	2	3	4	5	U	U
$0.1 = f < 1/\text{year}$ (between 1/10 years and 1/year)	Expected to occur several times in the company lifetime		4	2	3	3	4	5	U
$0.01 = f < 0.1/\text{year}$ (between 1/100 years and 1/10 years)	Expected to occur in the company lifetime		3	1	2	3	3	4	5
$0.001 = f < 0.01/\text{year}$ (between 1/1000 and 1/100 years)	Has happened in this industry		2	1	1	2	3	4	5
$f < 0.001/\text{year}$ (less than 1/1000 years)	Has never happened in this industry		1	1	1	2	2	3	4
			A	B	C	D	E	F	
<b>Environmental</b>	No impact	Release to on-site environment	Legal or permit violation	Detrimental impact on-site	Detrimental impact off-site	Catastrophic off-site release			
<b>Financial/Damage</b>	$C < \$10k$	$\$10k = C < \$100k$	$\$100k = C < \$1M$	$\$1M = C < \$10M$	$\$10M = C < \$100M$	$C > \$100M$			
<b>Political/Regulatory/Reputation</b>	None: No complaints or suspicions of public concern	Low: Second-hand knowledge of public concern	Med-Low: Complaints to the company, or minor political/regulatory involvement	Medium: Complaints to regulators/authorities requiring management involvement	Med-High: Negative local or regional news coverage of protests, of serious damage to reputation	High: Negative national or international news coverage of protests, of irreparable damage to reputation			
<b>Safety</b>	Negligible	Minor first aid	Minor injuries	Temporary disability	Permanent disability/fatality	Multiple fatalities			

**GP#9** ➤ Slight asymmetry

**GP#5** ➤ Use of a combination of letters and numbers for ease of reference

**GP#10** ➤ Treatment of different risk receptors separately (for integrated risk assessments)

**GP#11** ➤ Specification of the basis for frequency categorization (“company basis” as opposed to, for example, “site basis”, or “unit operation basis”) for clarity





## Summary and Conclusions

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- Risk Matrices are very powerful tools for ranking of risks and assisting in decision making
  - ↳ They can and should be used for assisting decision making at different levels of an organization
- However, before we even get to the more value-laden issues such as “level of risk acceptability”, ALARP, etc., one needs to deal with many pitfalls at a more fundamental level.
- Some of these pitfalls have the potential for abuse and hiding of reality
  - ↳ e.g., “refining” event definitions
    - ↳ Use of FN curves rather than the fN risk matrix will help avoid under-reporting of risk through “refining” of event definitions
- The “no controls are in place” syndrome result in many incorrect assessments leading to unnecessary investments, or at least unnecessary time spent on discussions

## Summary and Conclusions (continued)

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- Increasing the resolution on the likelihood side allows
  - ↳ use of the same matrix across small and large facilities/ business units of a multi-facility/multi-business unit company,
    - ↳ may require different specification of H, M, L risk levels for different size units/facilities
      - ❖ i.e., the same (C,L) combination should not be used to mean a H, M, L risk for a small and a large unit/facility
  - ↳ use of the same matrix for different disciplines, such as occupational safety, process safety engineering, project engineering, maintenance, other corporate risk management
- Increasing the resolution on the consequence side also allows use of the matrix more universally across a company for comparing risks that fall under different disciplines, such as corporate finance, plant engineering, project engineering
- Design of a risk matrix should allow for integrated risk assessment through consideration of risks to different risk receptors/ stakeholders
- Design of a risk inventory table should allow for demonstration of risk to all the risk receptors in an integrated risk assessment
- Design of a risk inventory table should allow for demonstration of risk reduction benefits and costs of “before” and “after” risk control scenarios