OPTIMIZING
SYSTEM SAFETY

38TH INTERNATIONAL SYSTEM
SAFETY CONFERENCE

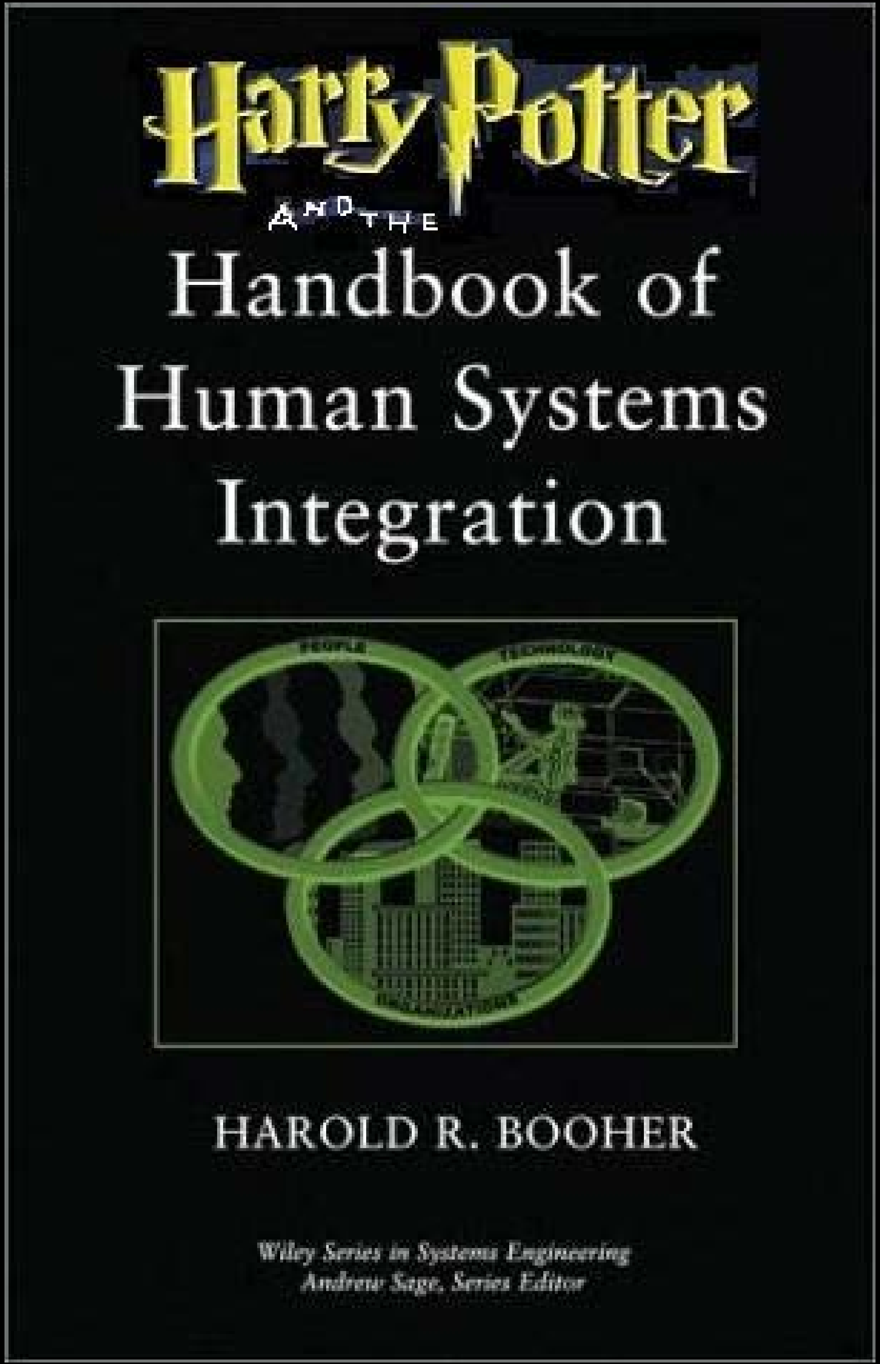
Mathematical Techniques to Improve the Utility of a Hazard Risk Matrix

Don Swallom
United States Army Aviation and Missile Command
Redstone Arsenal, Alabama

Handbook of Human Systems Integration

HAROLD R. BOOHER

Wiley Series in Systems Engineering
Andrew Sage, Series Editor



Harry Potter

AND THE

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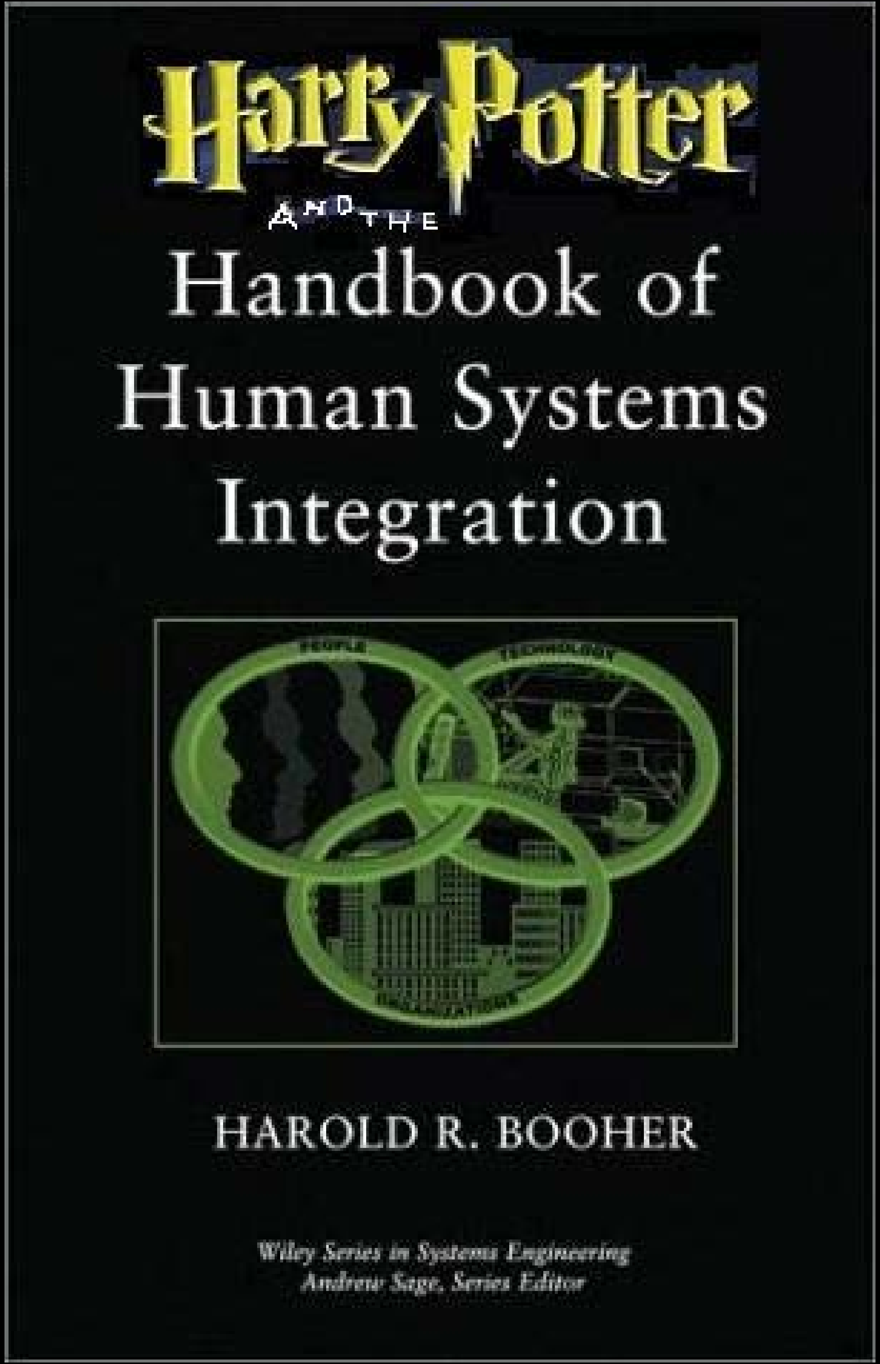

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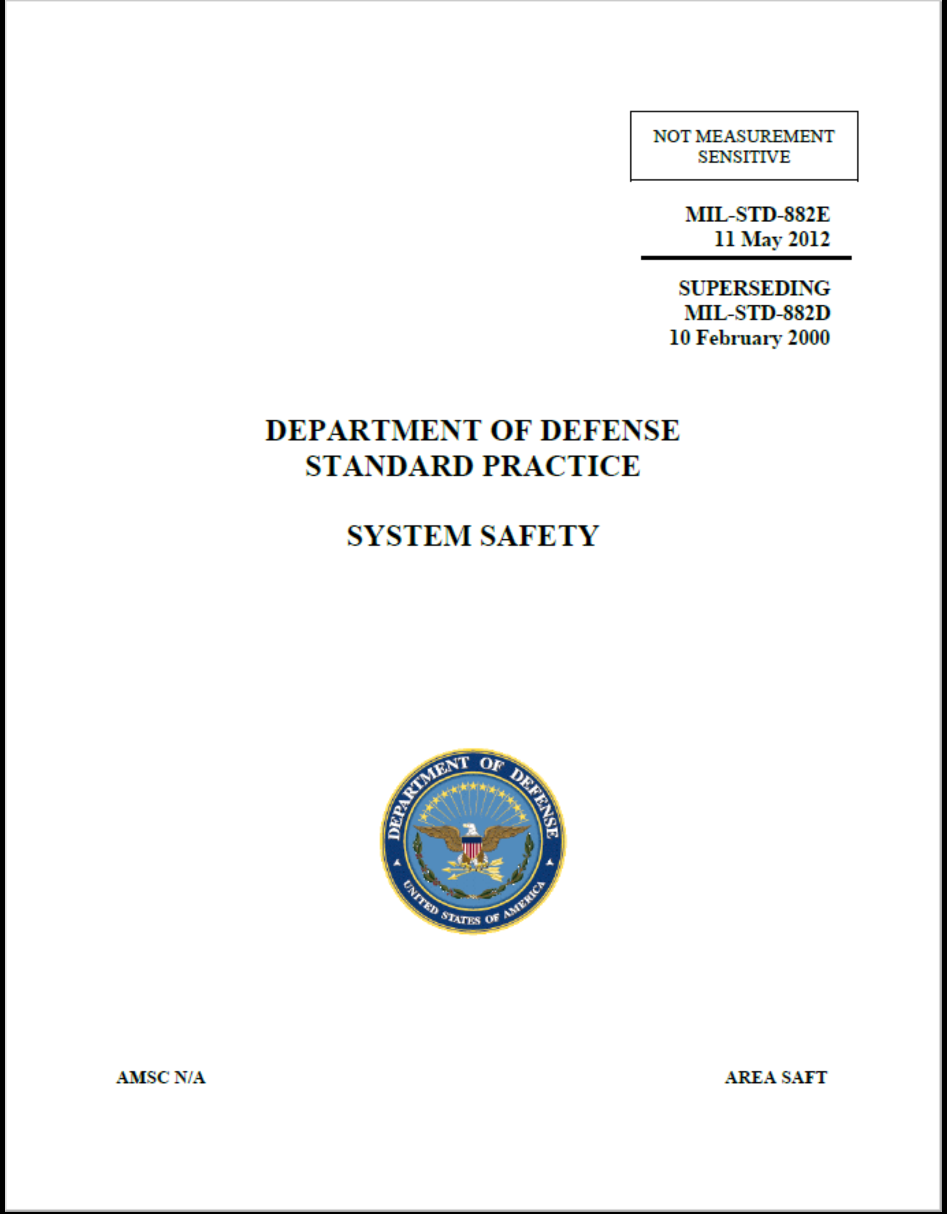


NOT MEASUREMENT SENSITIVE

MIL-STD-882E
11 May 2012

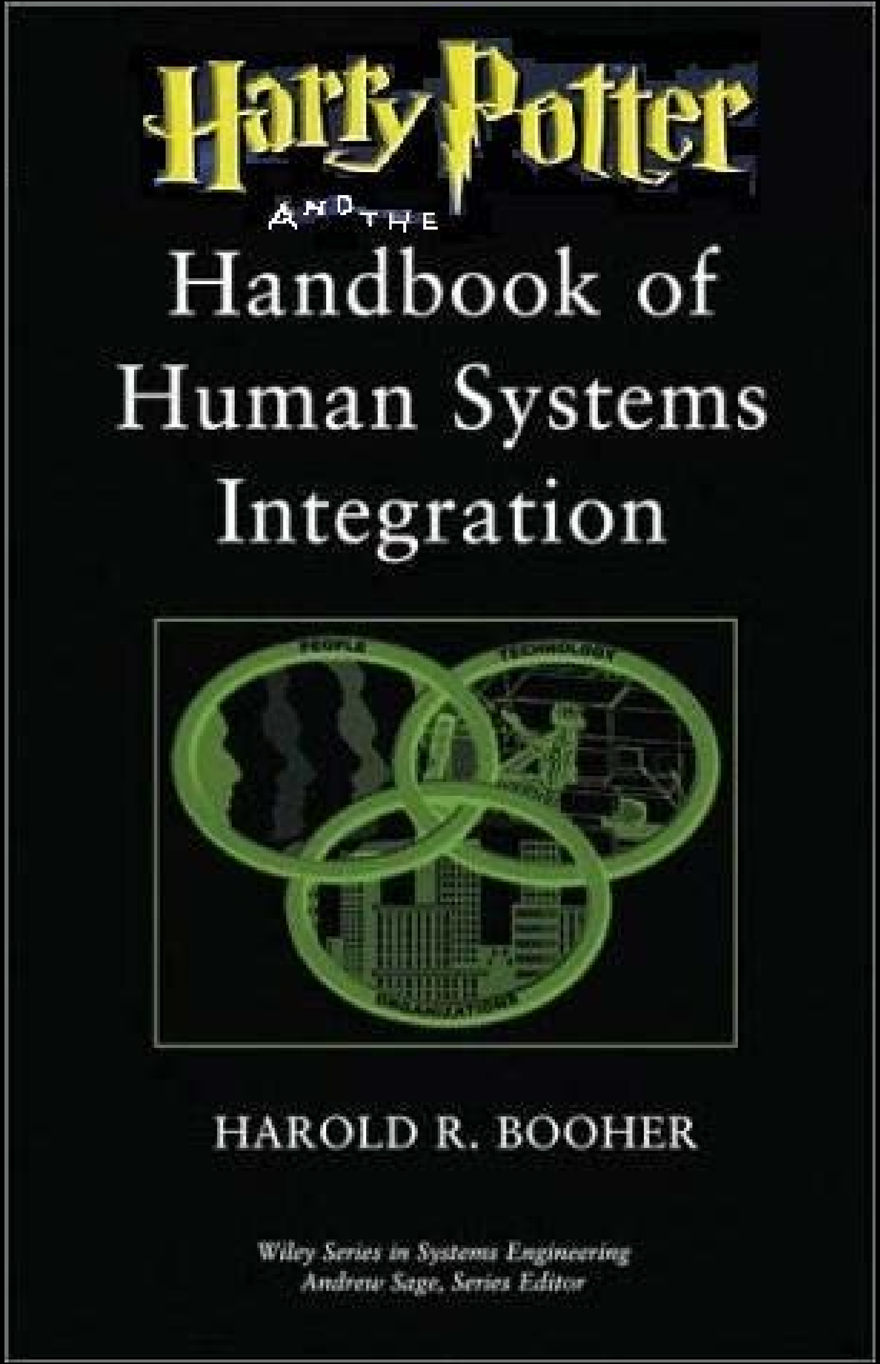
SUPERSEDING
MIL-STD-882D
10 February 2000

DEPARTMENT OF DEFENSE
STANDARD PRACTICE

SYSTEM SAFETY

AMSC N/A

AREA SAFT



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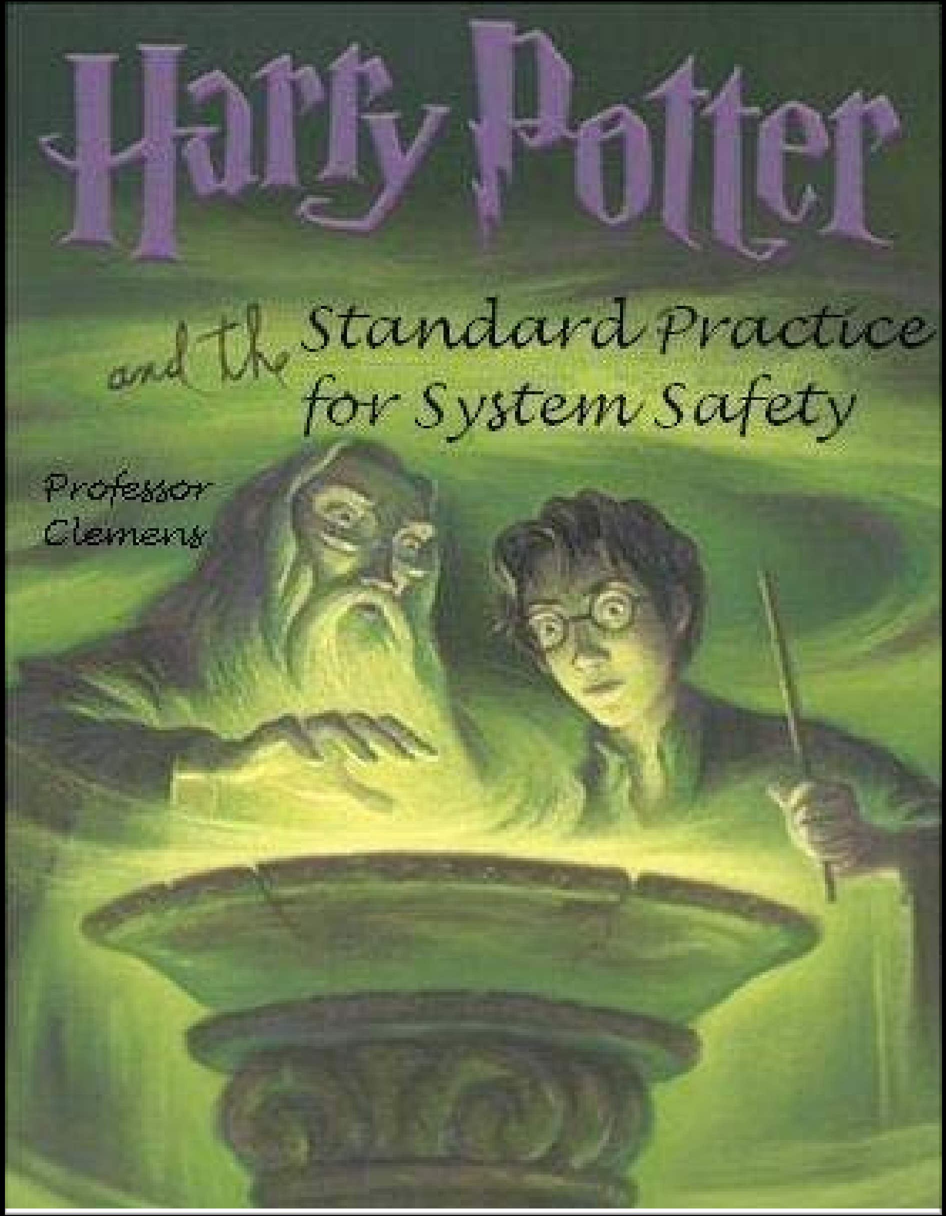
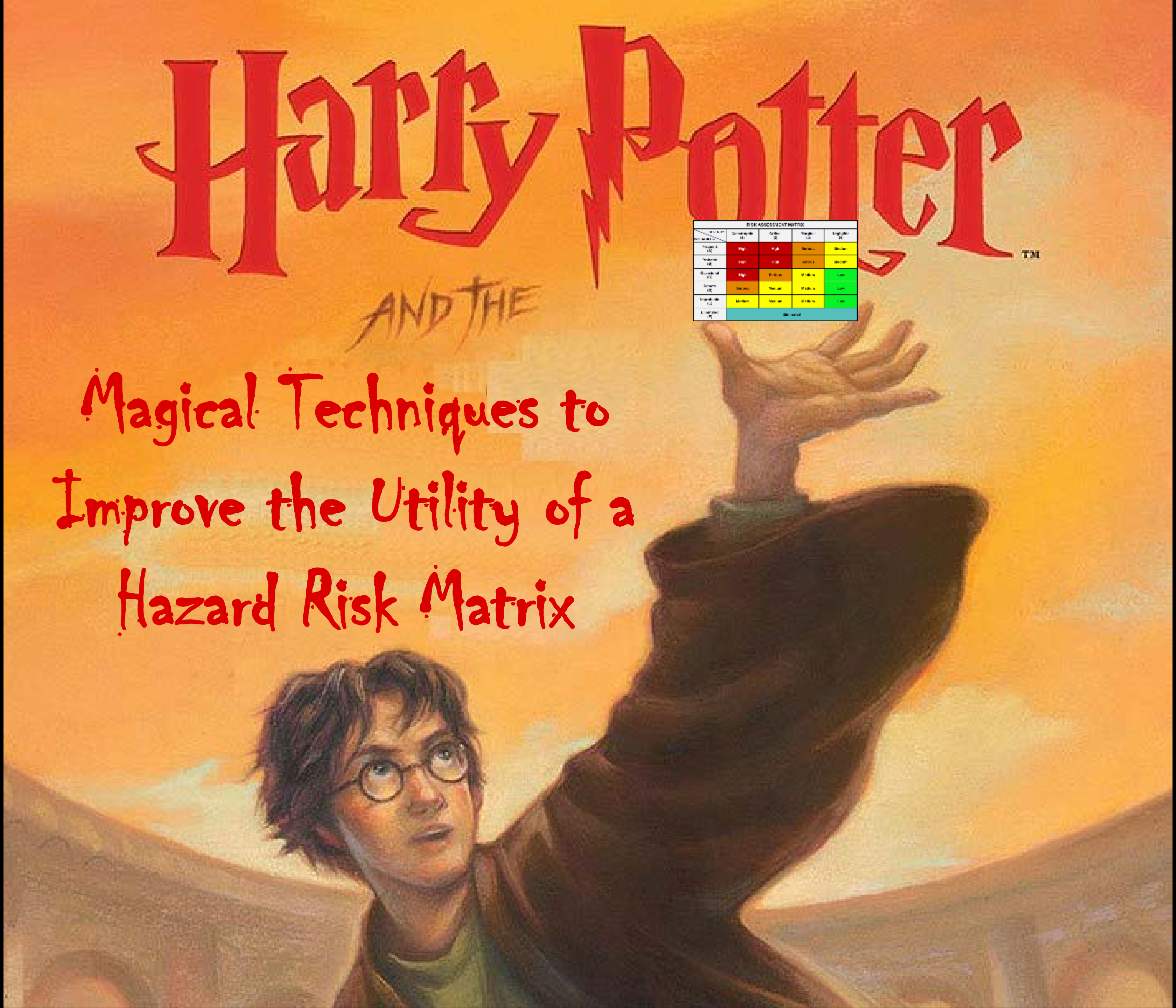


Harry Potter
and the Standard Practice
for System Safety

Professor
Clemens



Magical Techniques to Improve the Utility of a Hazard Risk Matrix

Caveat

Opinions expressed are those of the author and not the coordinated position of AMCOM, Army Materiel Command, the US Army or the Department of Defense.

Topics for this Tutorial

- Purpose of a Hazard Risk Matrix
- Understanding the Attributes of a well-designed risk assessment matrix
- How to Assign a Risk Assessment Code
- Understanding Probability
- Building an Expanded Matrix
- Plotting Accidents on a Matrix
- Using Relative Risk Values
- Building Hazard Risk Profiles

Source of the DOD Hazard Risk Matrix

RISK ASSESSMENT MATRIX

Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
High	High	Serious	Medium
High	High	Serious	Medium
High	Serious	Medium	Low
Serious	Medium	Medium	Low
Medium	Medium	Medium	Low
Eliminated			

Purpose of a Hazard Risk Matrix

- Determine who accepts the risk of a particular hazard

"…The Program Manager will use the methodology in MIL-STD-882E…Prior to exposing people, equipment, or the environment to known system-related ESOH hazards, the Program Manager will document that the associated risks have been accepted by the following acceptance authorities: the CAE for high risks, Program Executive Officer-level for serious risks, and the Program Manager for medium and low risks…" - Department of Defense Instruction 5000.02, January 7, 2015.

Purpose of a Hazard Risk Matrix

- Inform the risk acceptor of the nature of the risk.
- "It's a 1D, Serious" does not really do that.

"The standard for risk management is leadership at the appropriate level of authority making **informed** decisions to control hazards or accept risks."

Army Regulation 385-10

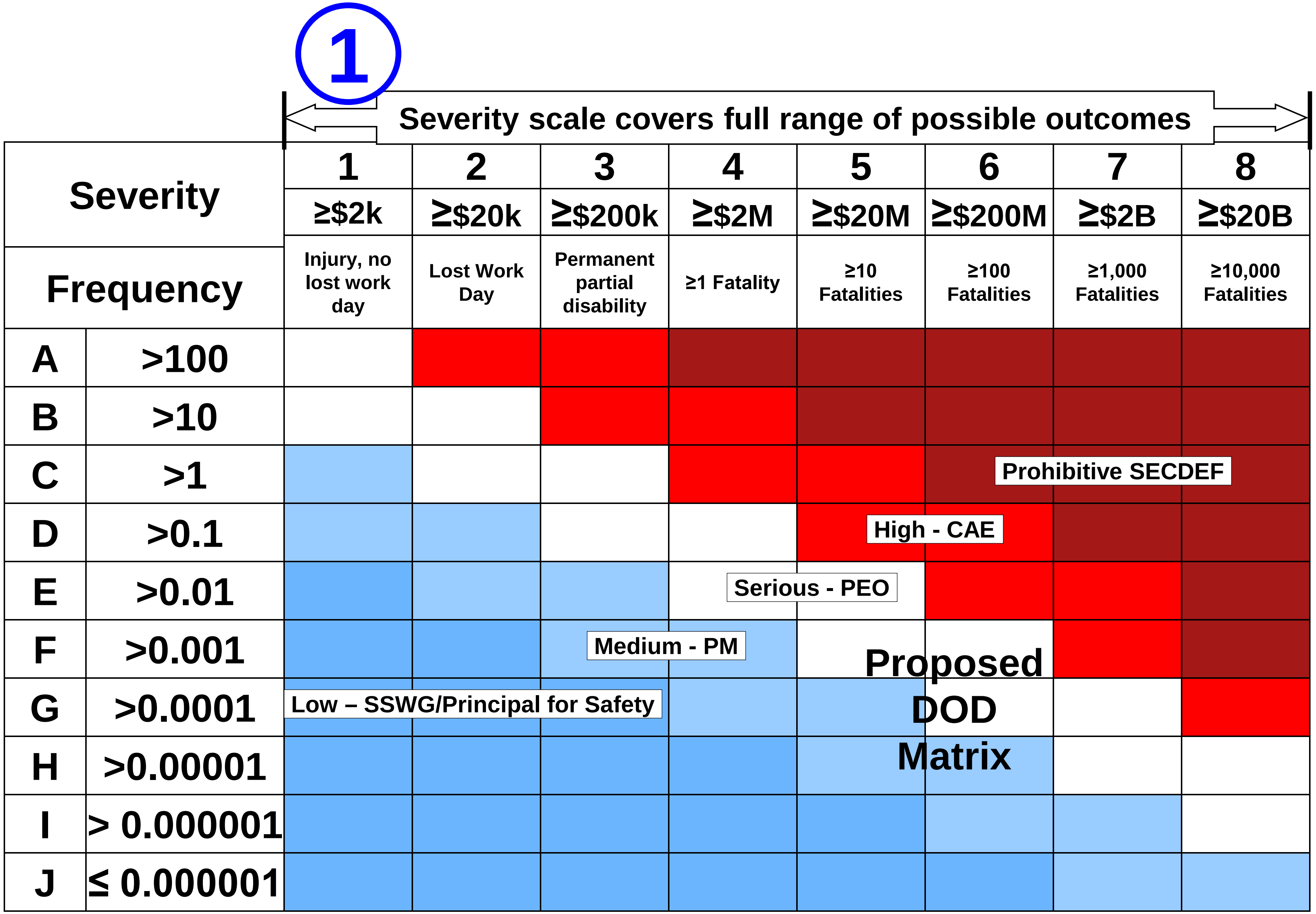
The Army Safety Program

29 February 2000

Topics for this Tutorial

- Purpose of a Hazard Risk Matrix
- **Understanding the Attributes of a well-designed risk assessment matrix**
- How to Assign a Risk Assessment Code
- Understanding Probability
- Building an Expanded Matrix
- Plotting Accidents on a Matrix
- Using Relative Risk Values
- Building Hazard Risk Profiles

Attributes of a well-designed risk assessment matrix



①

Severity scale covers full range of possible outcomes

Severity		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100	⬜	🟥	🟥	🟫	🟫	🟫	🟫	🟫
B	>10	⬜	⬜	🟥	🟥	🟫	🟫	🟫	🟫
C	>1	▨	⬜	⬜	🟥	🟥	🟫	🟫	🟫
D	>0.1	▨	▨	⬜	⬜	🟥	🟥	🟫	🟫
E	>0.01	🟦	▨	▨	⬜	⬜	🟥	🟥	🟫
F	>0.001	🟦	🟦	▨	▨	⬜	⬜	🟥	🟫
G	>0.0001	🟦	🟦	🟦	▨	▨	⬜	⬜	🟥
H	>0.00001	🟦	🟦	🟦	🟦	▨	▨	⬜	⬜
I	> 0.000001	🟦	🟦	🟦	🟦	🟦	▨	▨	⬜
J	≤ 0.000001	🟦	🟦	🟦	🟦	🟦	🟦	▨	▨

Prohibitive SECDEF

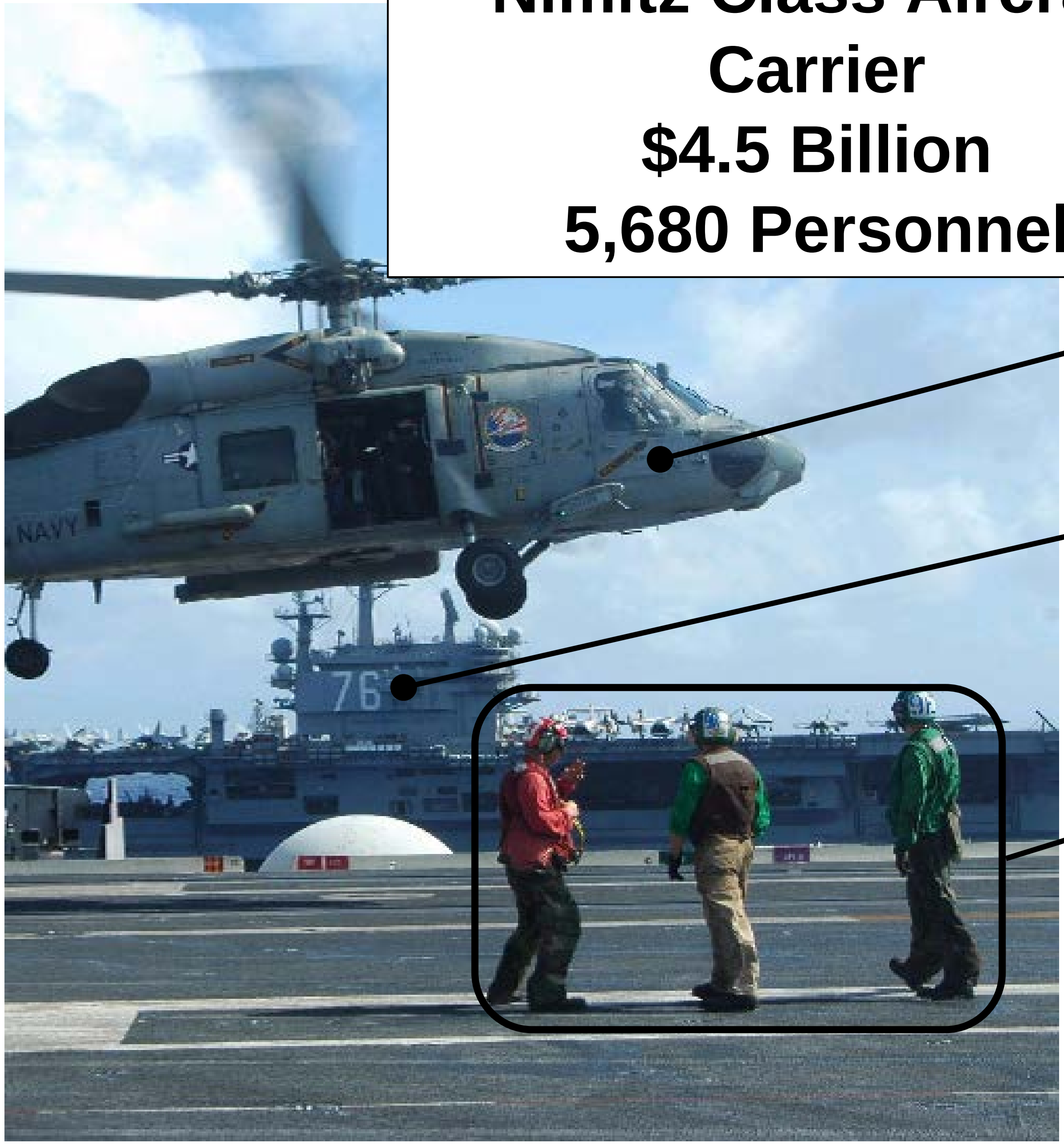
High - CAE

Serious - PEO

Medium - PM

Low – SSWG/Principal for Safety

Proposed DOD Matrix



Nimitz Class Aircraft Carrier
$4.5 Billion
5,680 Personnel

Today

Severity 1

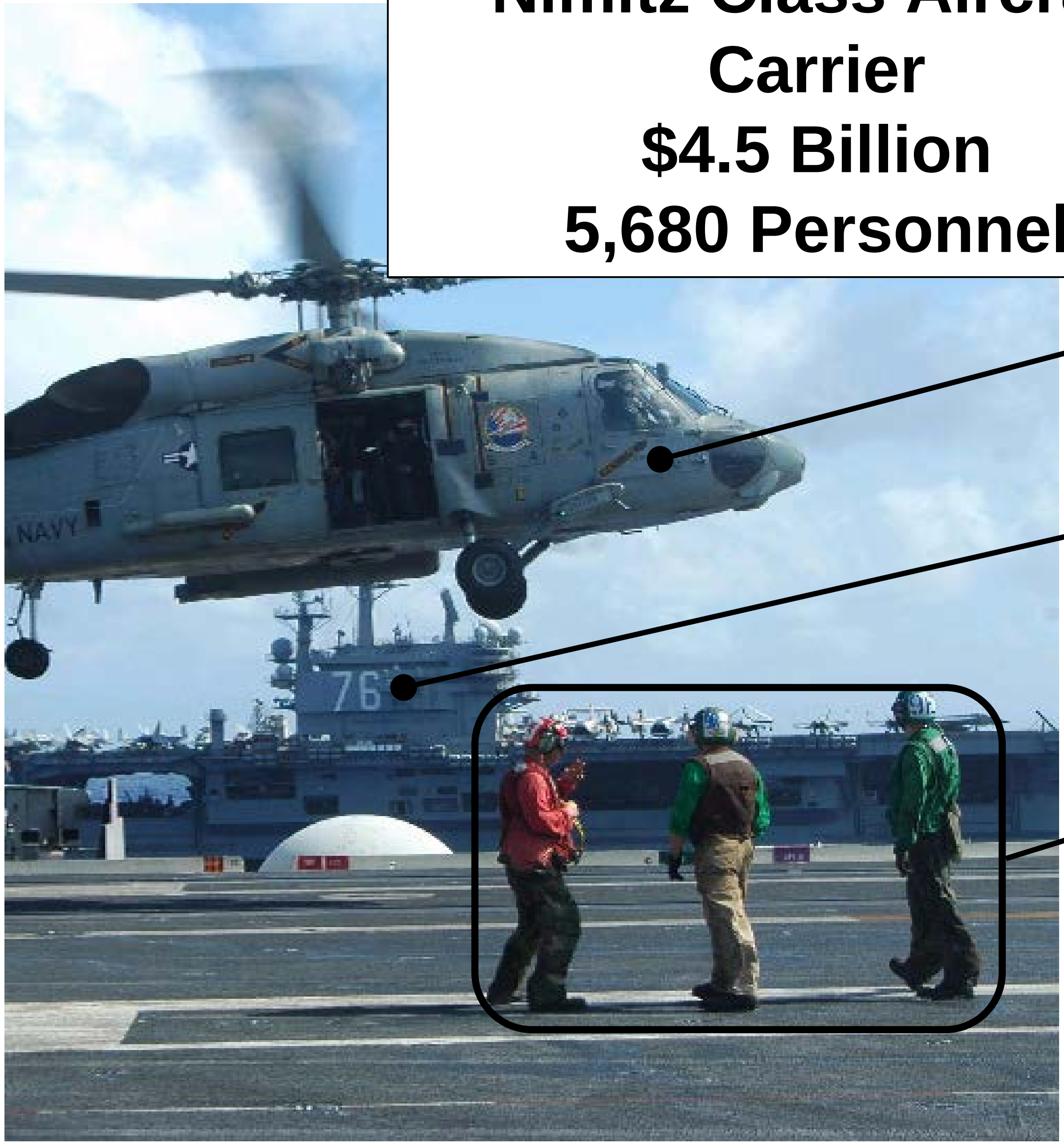
Severity 1

Severity 1

Nimitz Class Aircraft Carrier

$4.5 Billion

5,680 Personnel



Severity 5

Severity 7

Severity 4

Politics

Navy Seeks $30 Million to Fix Gear That Hobbled Its New Carrier

By Anthony Capaccio

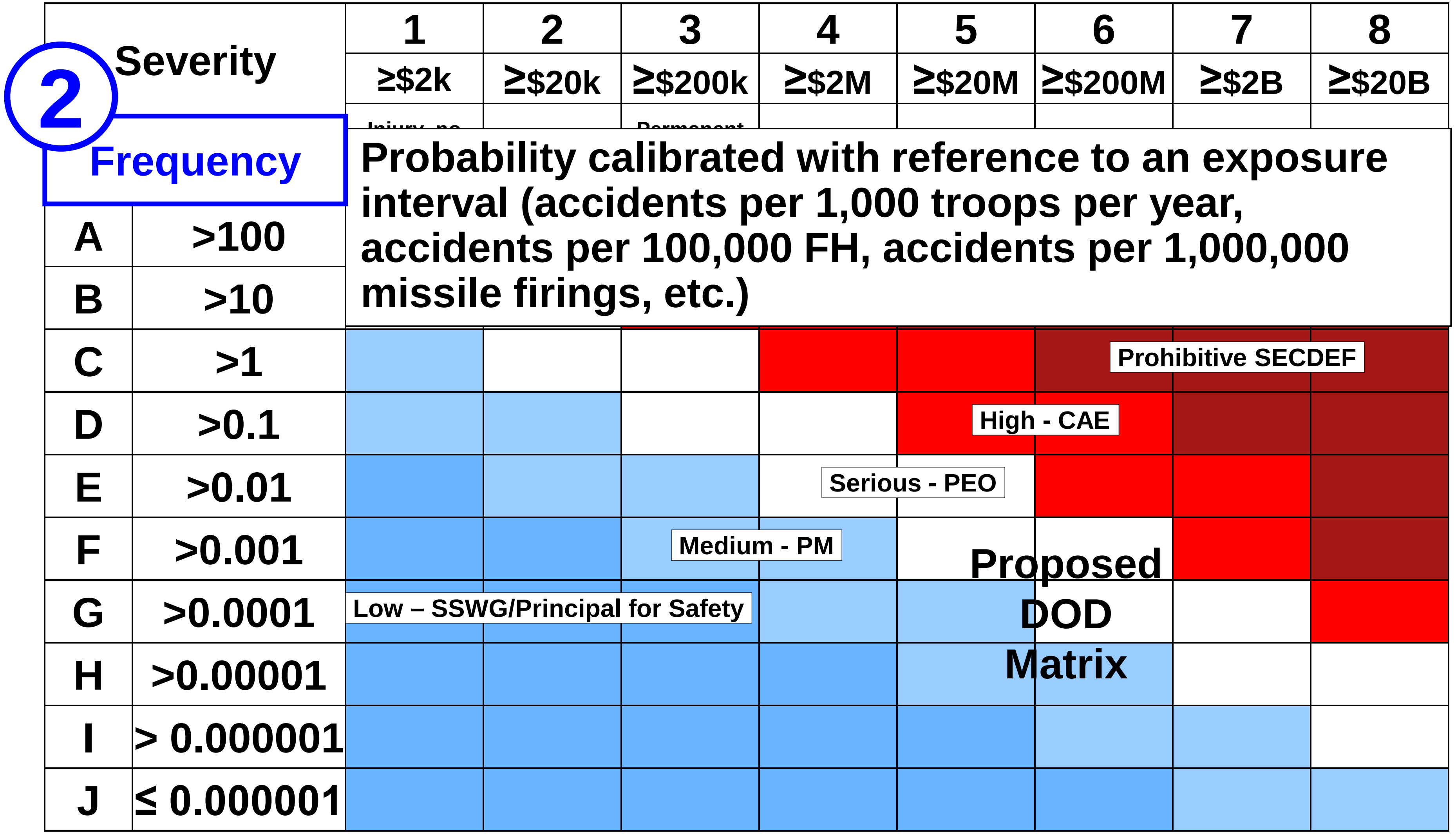
July 25, 2018, 10:04 AM CDT

- Congress asked to shift funds to repair Ford aircraft carrier
- Huntington Ingalls continues talks with General Electric

The Navy is asking Congress to shift $30 million from other accounts to start repairing a damaged gear on the service’s costliest warship, the Gerald R. Ford aircraft carrier.

The request for funds to repair the $13 billion carrier is part of a Pentagon package asking congressional approval to shift $4.7 billion in previously approved Army, Air Force and Navy funding into new programs or higher-priority projects. The package must be approved by all four congressional defense committees, where it’s pending.

Attributes of a well-designed risk assessment matrix

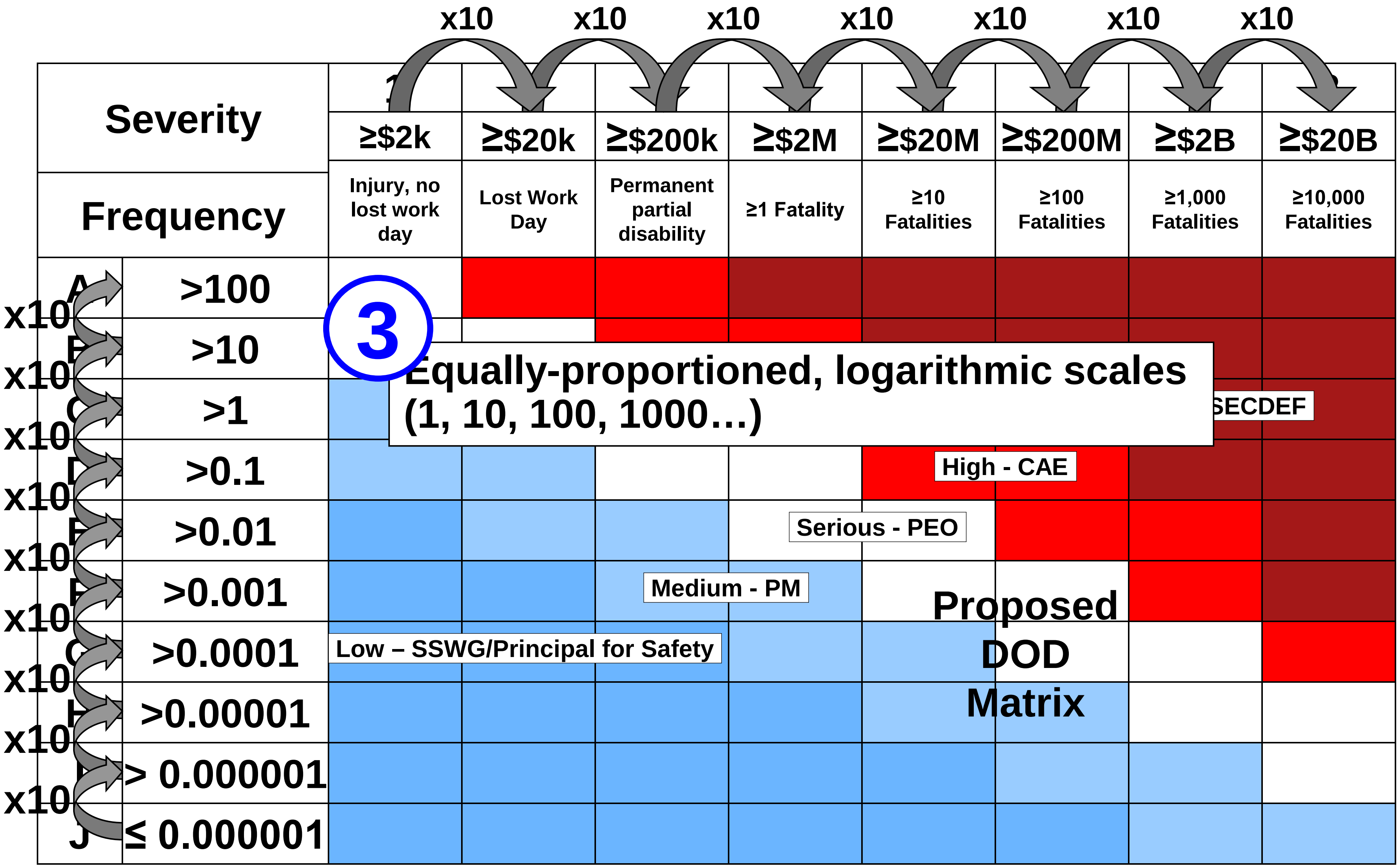


② Severity		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
		Injury, no		Permanent					
Frequency									
A	>100								
B	>10								
C	>1							Prohibitive SECDEF	
D	>0.1					High - CAE			
E	>0.01				Serious - PEO				
F	>0.001			Medium - PM					
G	>0.0001	Low – SSWG/Principal for Safety							
H	>0.00001								
I	> 0.000001								
J	≤ 0.000001								

Probability calibrated with reference to an exposure interval (accidents per 1,000 troops per year, accidents per 100,000 FH, accidents per 1,000,000 missile firings, etc.)

Proposed DOD Matrix

Attributes of a well-designed risk assessment matrix

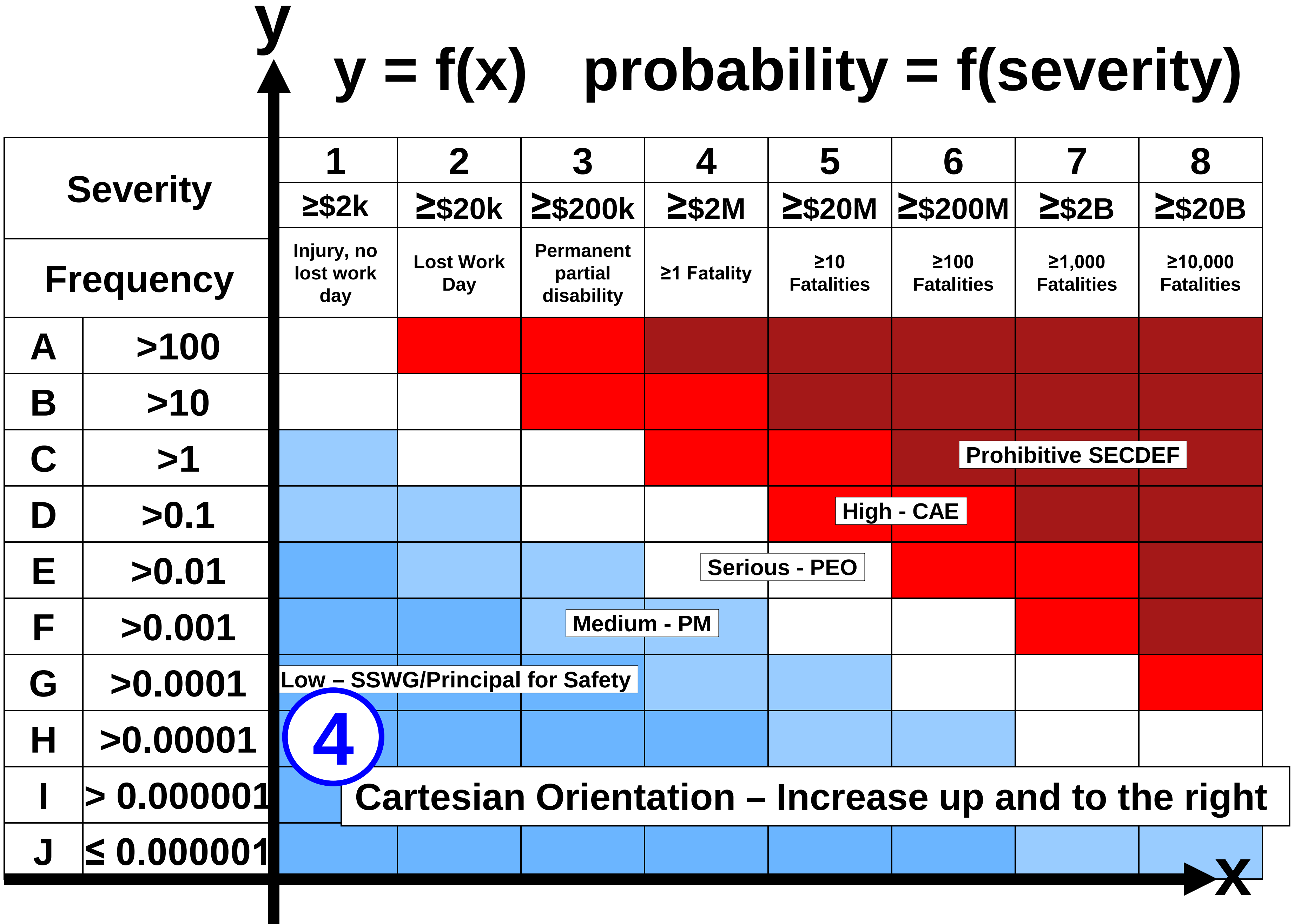


Severity		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100								
B	>10								
C	>1								SECDEF
D	>0.1						High - CAE		
E	>0.01					Serious - PEO			
F	>0.001				Medium - PM				
G	>0.0001	Low – SSWG/Principal for Safety							
H	>0.00001								
I	> 0.000001								
J	≤ 0.000001								

Equally-proportioned, logarithmic scales (1, 10, 100, 1000…)

Proposed DOD Matrix

Attributes of a well-designed risk assessment matrix



y = f(x) probability = f(severity)

Severity		1 ≥$2k Injury, no lost work day	2 ≥$20k Lost Work Day	3 ≥$200k Permanent partial disability	4 ≥$2M ≥1 Fatality	5 ≥$20M ≥10 Fatalities	6 ≥$200M ≥100 Fatalities	7 ≥$2B ≥1,000 Fatalities	8 ≥$20B ≥10,000 Fatalities
Frequency									
A	>100	⬜	🟥	🟥	🟫	🟫	🟫	🟫	🟫
B	>10	⬜	⬜	🟥	🟥	🟫	🟫	🟫	🟫
C	>1	▦	⬜	⬜	🟥	🟥	🟫	🟫	🟫
D	>0.1	▦	▦	⬜	⬜	🟥	🟥	🟫	🟫
E	>0.01	🟦	▦	▦	⬜	⬜	🟥	🟥	🟫
F	>0.001	🟦	🟦	▦	▦	⬜	⬜	🟥	🟫
G	>0.0001	🟦	🟦	🟦	▦	▦	⬜	⬜	🟥
H	>0.00001	🟦	🟦	🟦	🟦	▦	▦	⬜	⬜
I	> 0.000001	🟦							
J	≤ 0.000001	🟦	🟦	🟦	🟦	🟦	🟦	▦	▦

Prohibitive SECDEF

High - CAE

Serious - PEO

Medium - PM

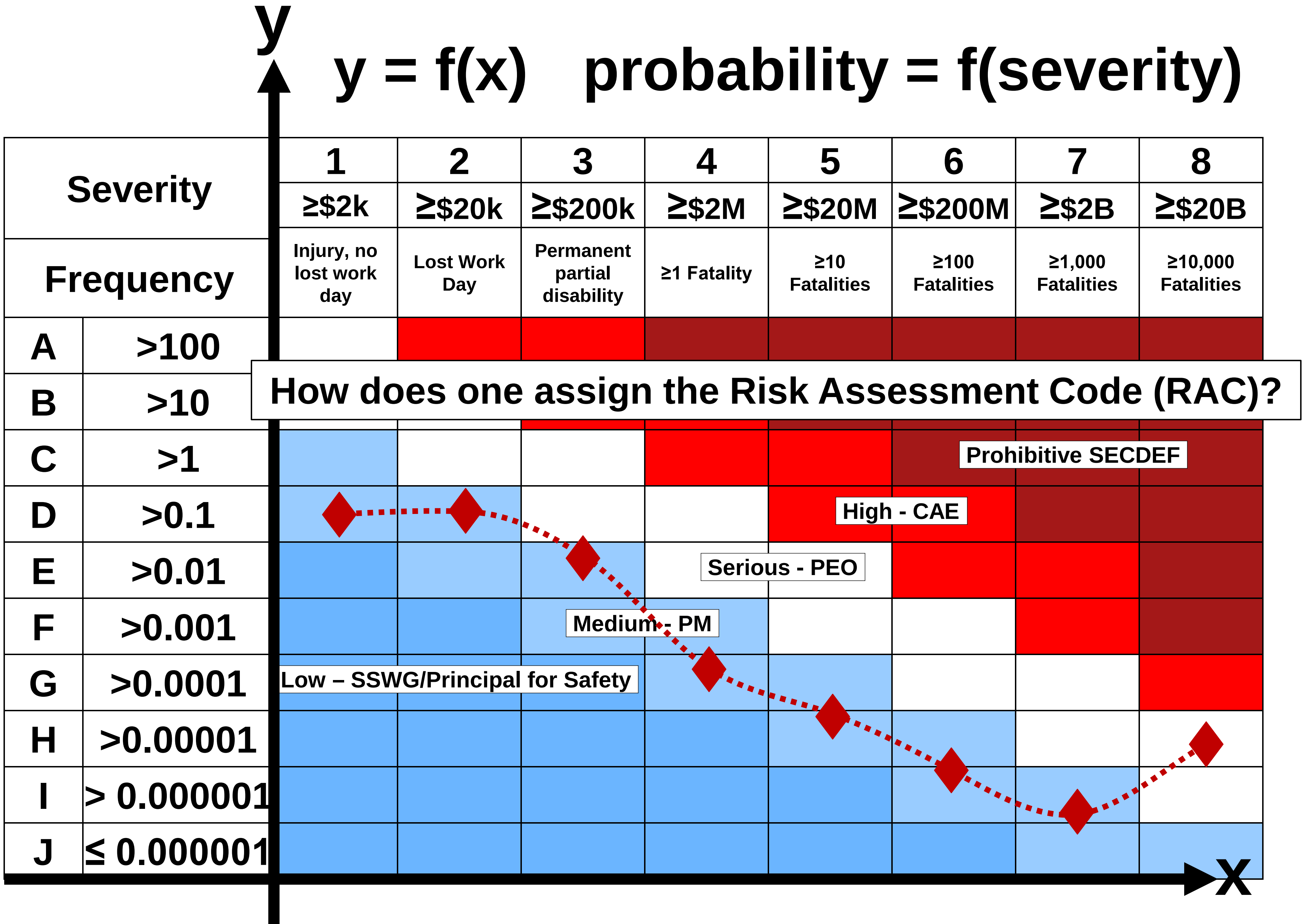
Low – SSWG/Principal for Safety

④

Cartesian Orientation – Increase up and to the right

Attributes of a well-designed risk assessment matrix

y = f(x)   probability = f(severity)



Severity		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100								
B	>10								
C	>1								
D	>0.1								
E	>0.01								
F	>0.001								
G	>0.0001								
H	>0.00001								
I	> 0.000001								
J	≤ 0.000001								

How does one assign the Risk Assessment Code (RAC)?

Prohibitive SECDEF

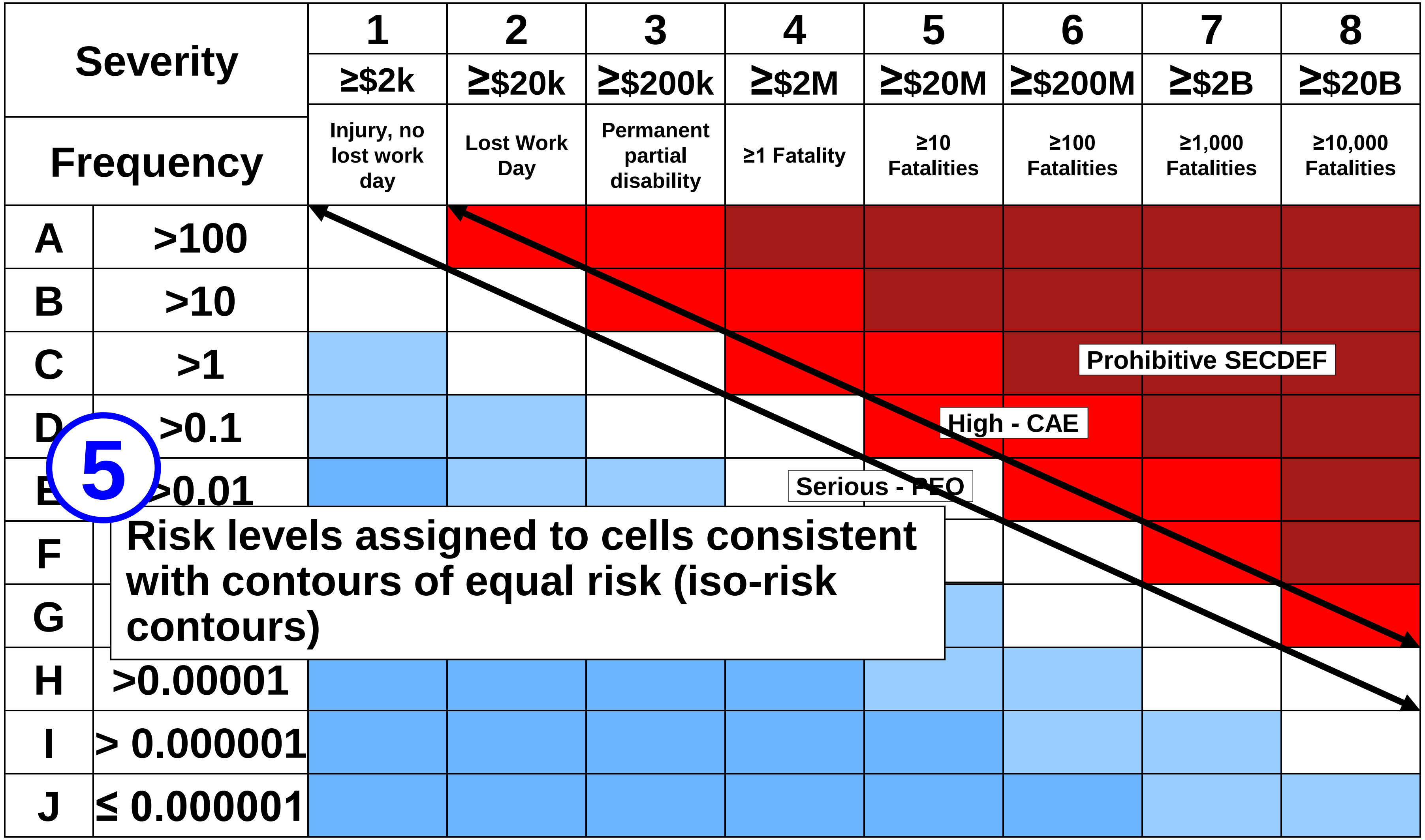
High - CAE

Serious - PEO

Medium - PM

Low – SSWG/Principal for Safety

Attributes of a well-designed risk assessment matrix



Severity		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100								
B	>10								
C	>1								
D	>0.1								
E	>0.01								
F									
G									
H	>0.00001								
I	> 0.000001								
J	≤ 0.000001								

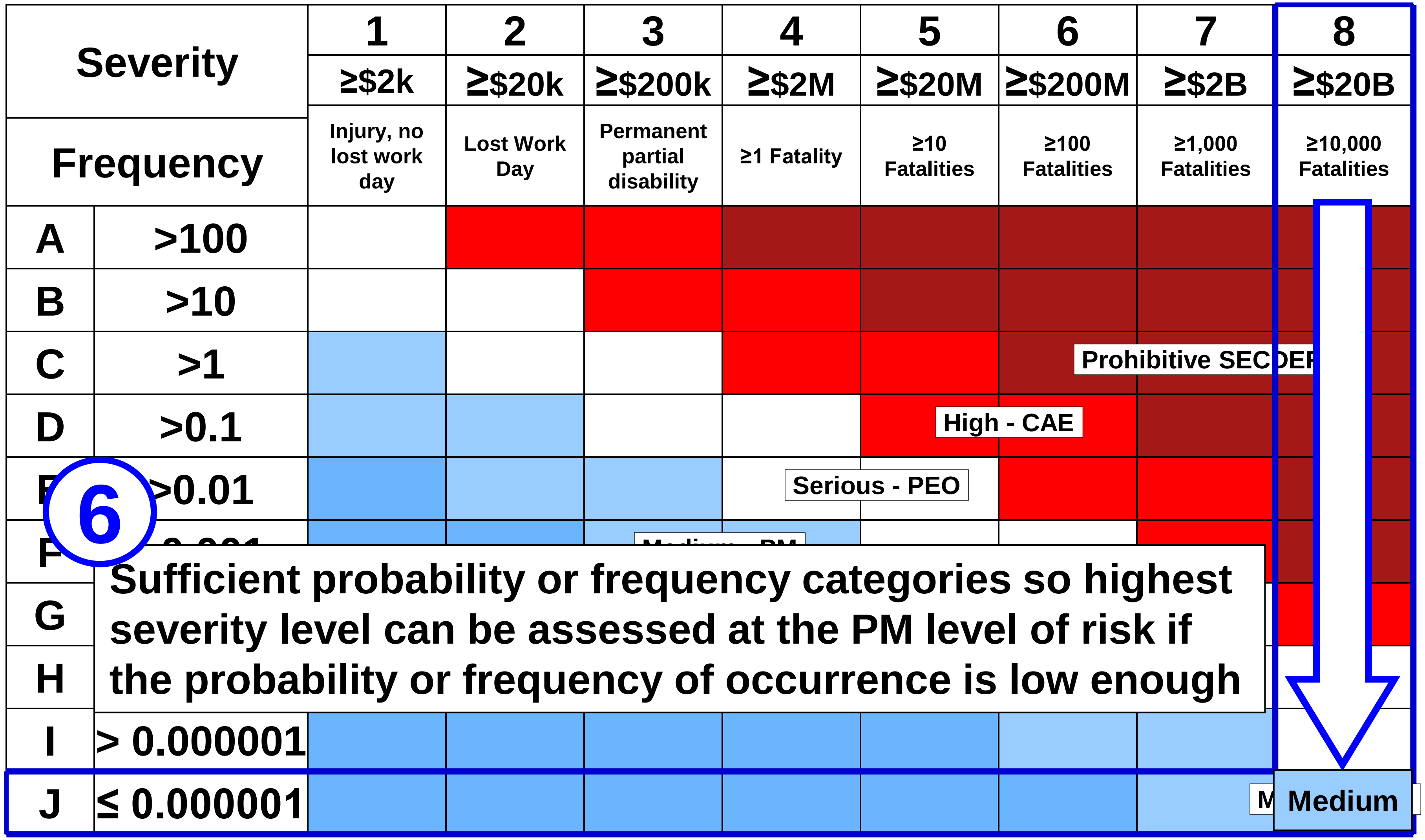
Prohibitive SECDEF

High - CAE

Serious - PEO

⑤ Risk levels assigned to cells consistent with contours of equal risk (iso-risk contours)

Attributes of a well-designed risk assessment matrix

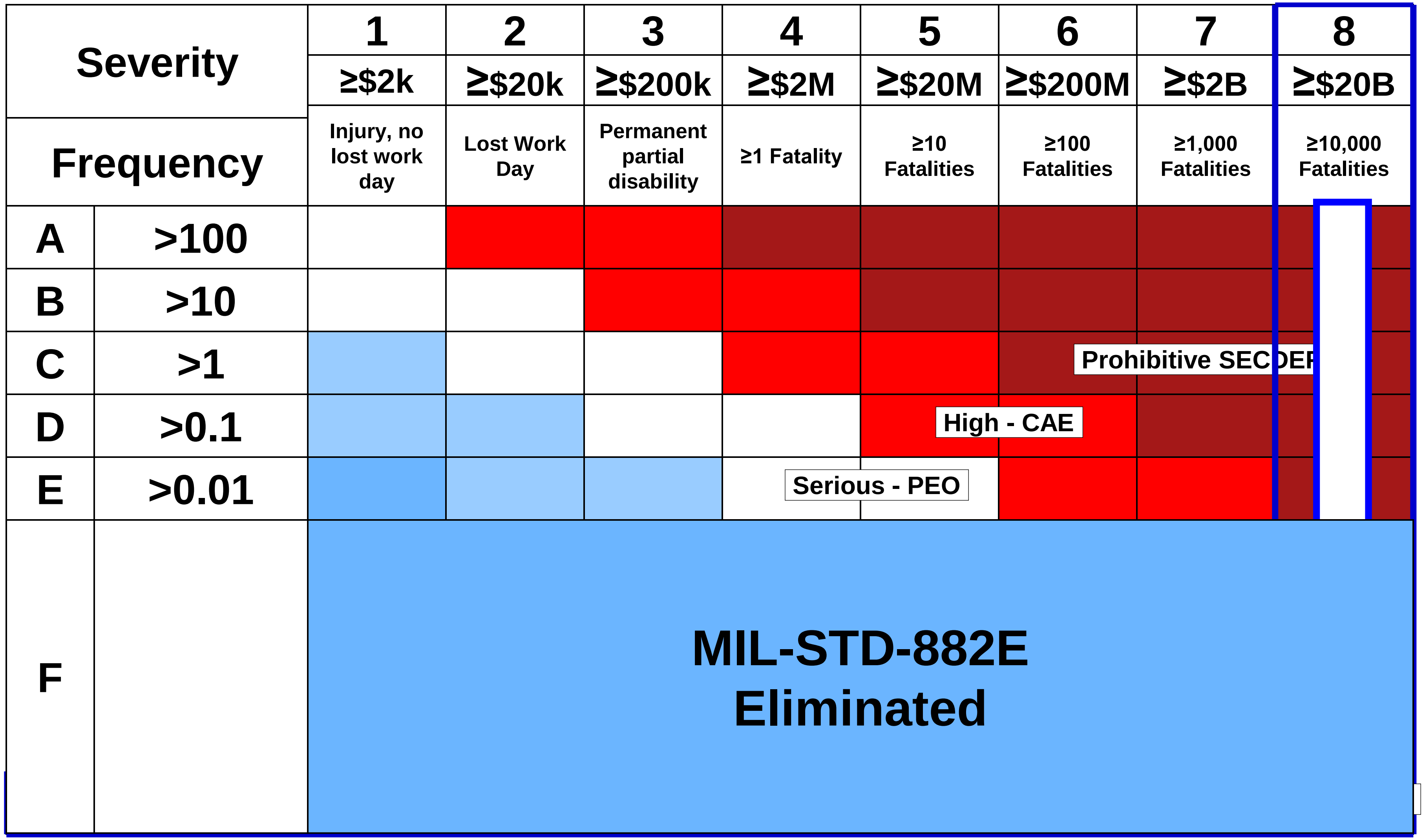


Severity		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100								
B	>10								
C	>1						Prohibitive SECDEF		
D	>0.1					High - CAE			
E	>0.01				Serious - PEO				
F				Medium - PM					
G									
H									
I	> 0.000001								
J	≤ 0.000001							M	Medium

6

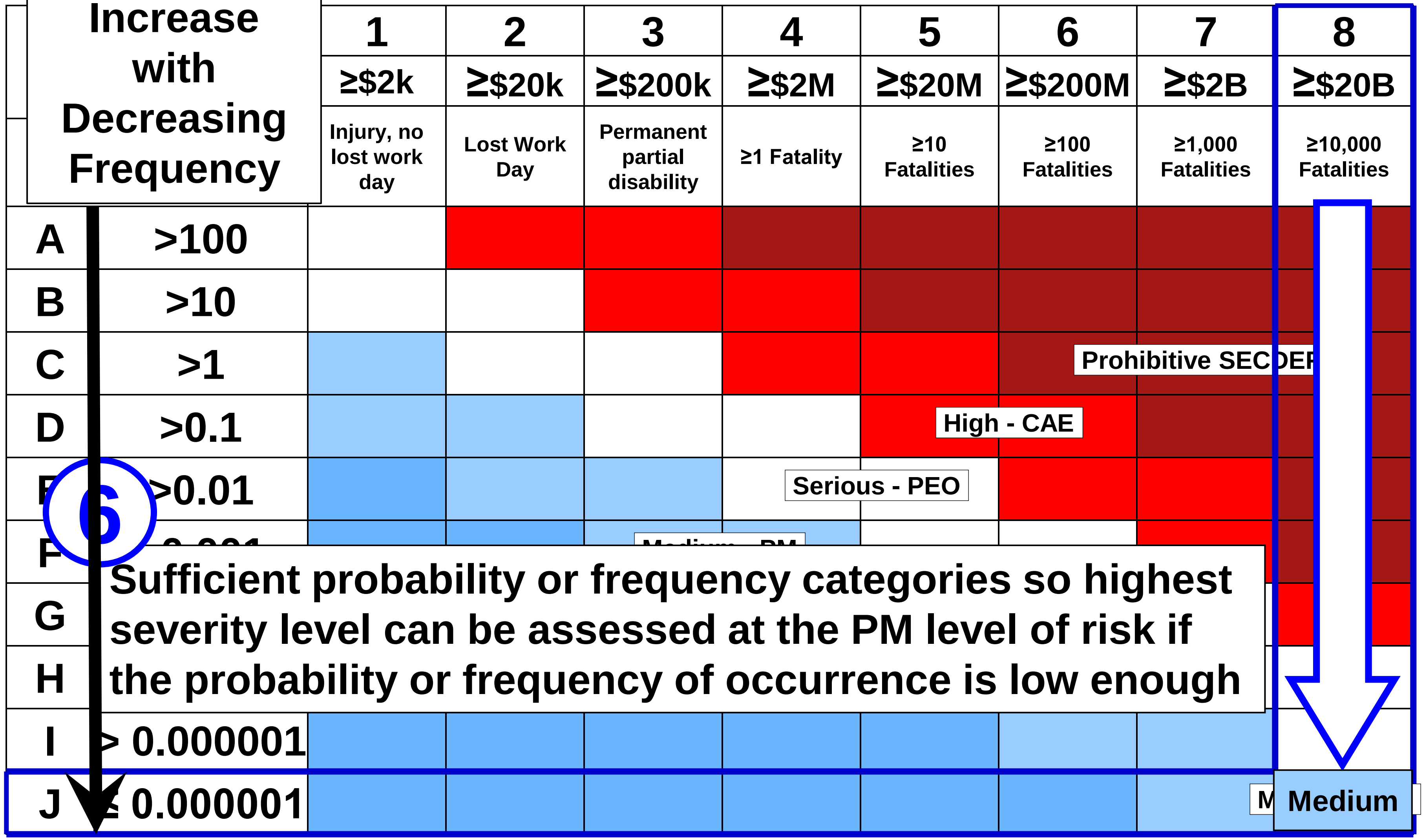
Sufficient probability or frequency categories so highest severity level can be assessed at the PM level of risk if the probability or frequency of occurrence is low enough

Attributes of a well-designed risk assessment matrix



Severity		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100	⬜	🟥	🟥	🟫	🟫	🟫	🟫	🟫
B	>10	⬜	⬜	🟥	🟥	🟫	🟫	🟫	🟫
C	>1	🟦	⬜	⬜	🟥	🟥	🟫 Prohibitive SECDEF	🟫	🟫
D	>0.1	🟦	🟦	⬜	⬜	🟥 High - CAE	🟥	🟫	🟫
E	>0.01	🟦	🟦	🟦	⬜ Serious - PEO	⬜	🟥	🟥	🟫
F		MIL-STD-882E Eliminated							

⑦ Attributes of a well-designed risk assessment matrix



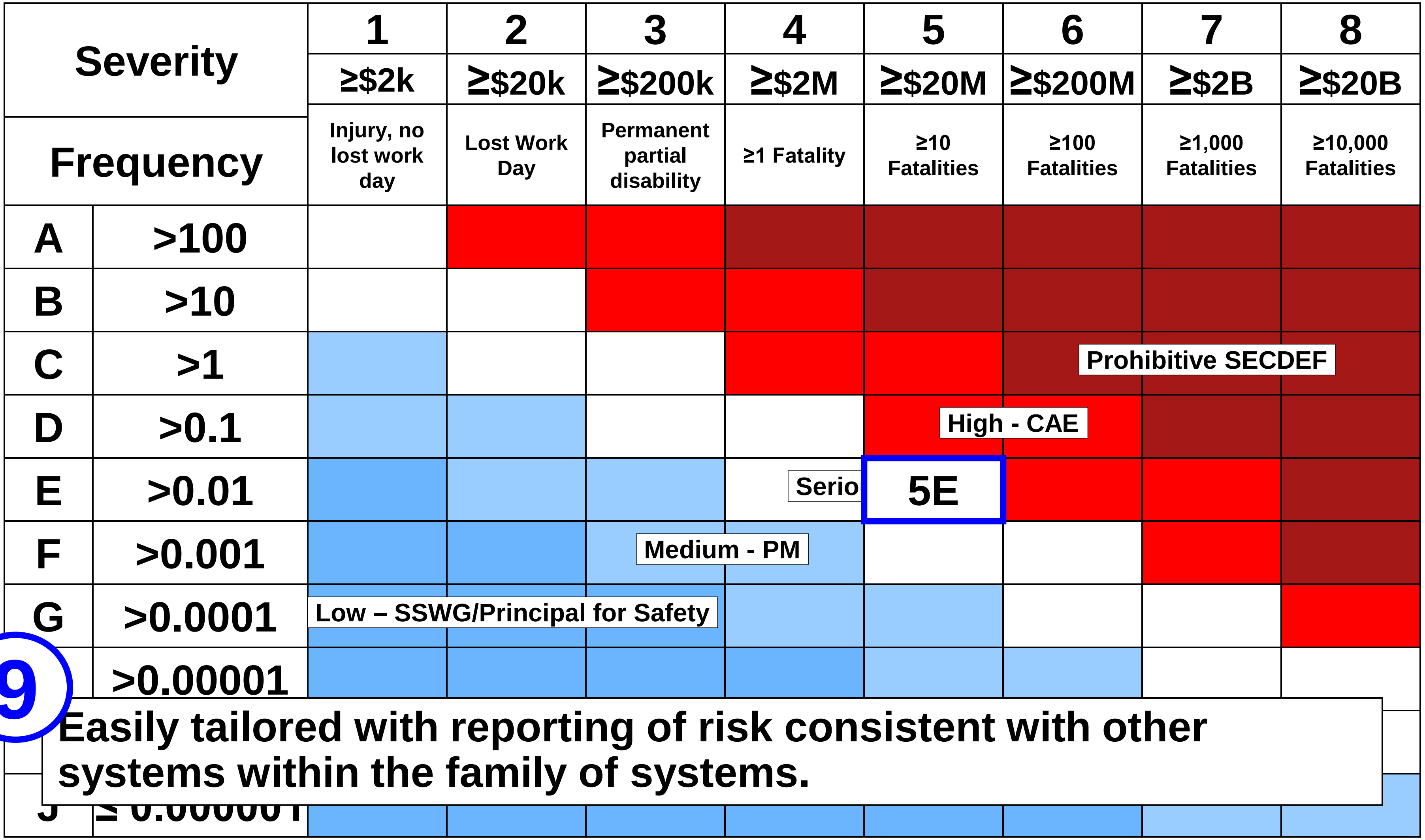
		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100								
B	>10								
C	>1								
D	>0.1								
E	>0.01								
F	0.001								
G									
H									
I	> 0.000001								
J	≤ 0.000001								

Frequency Category Letters Increase with Decreasing Frequency

⑥ Sufficient probability or frequency categories so highest severity level can be assessed at the PM level of risk if the probability or frequency of occurrence is low enough

⑧ Attributes of a well-designed risk assessment matrix

A risk assessment code for hazards whose risk has been eliminated. Suggest: 0R “Zero R” as in Zero Risk in lieu of F.



Severity		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100								
B	>10								
C	>1								
D	>0.1								
E	>0.01					5E			
F	>0.001								
G	>0.0001								
	>0.00001								
J	≥ 0.000001								

Prohibitive SECDEF

High - CAE

Serio

Medium - PM

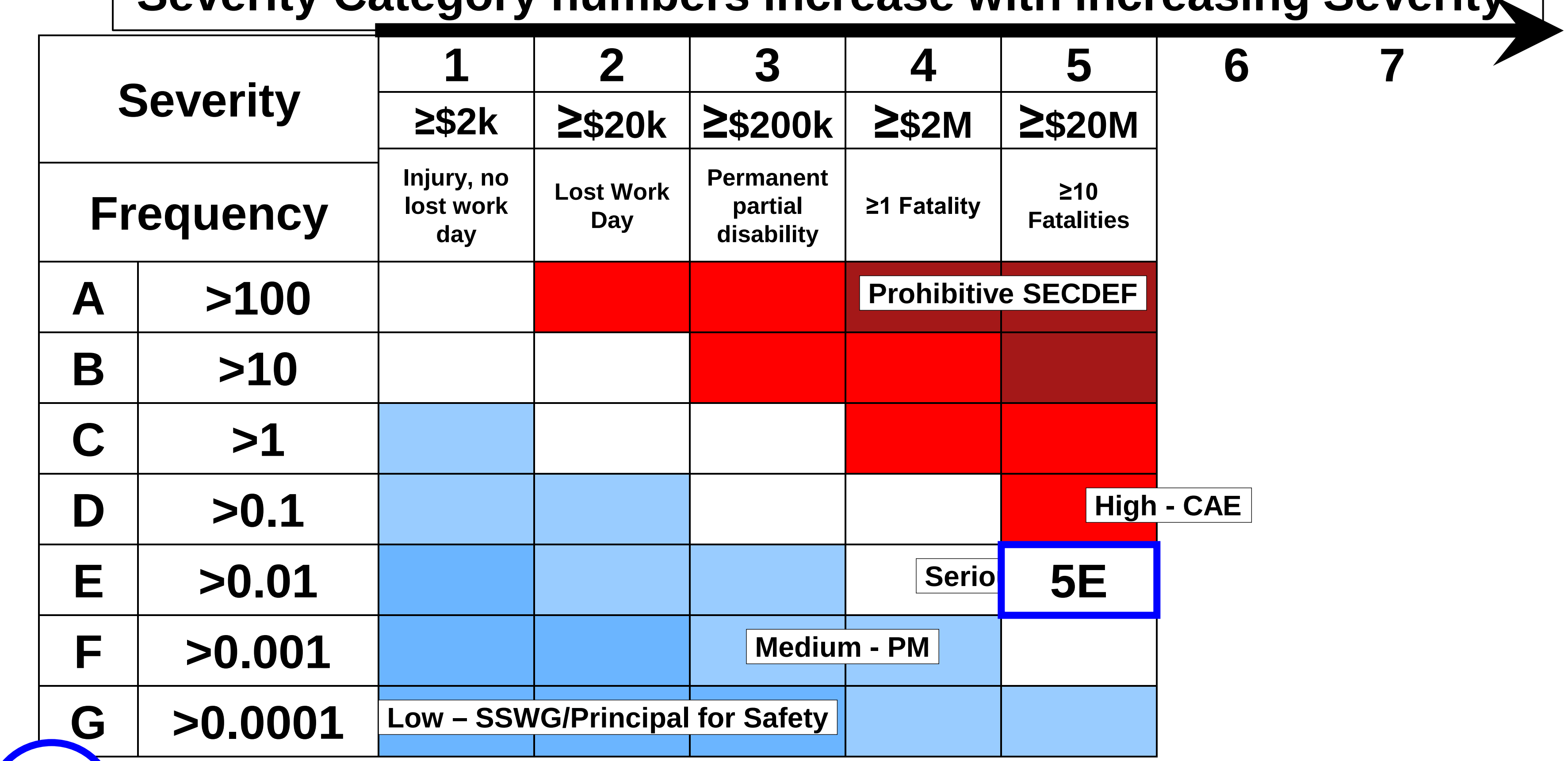
Low – SSWG/Principal for Safety

⑨

Easily tailored with reporting of risk consistent with other systems within the family of systems.

Attributes of a well-designed risk assessment matrix

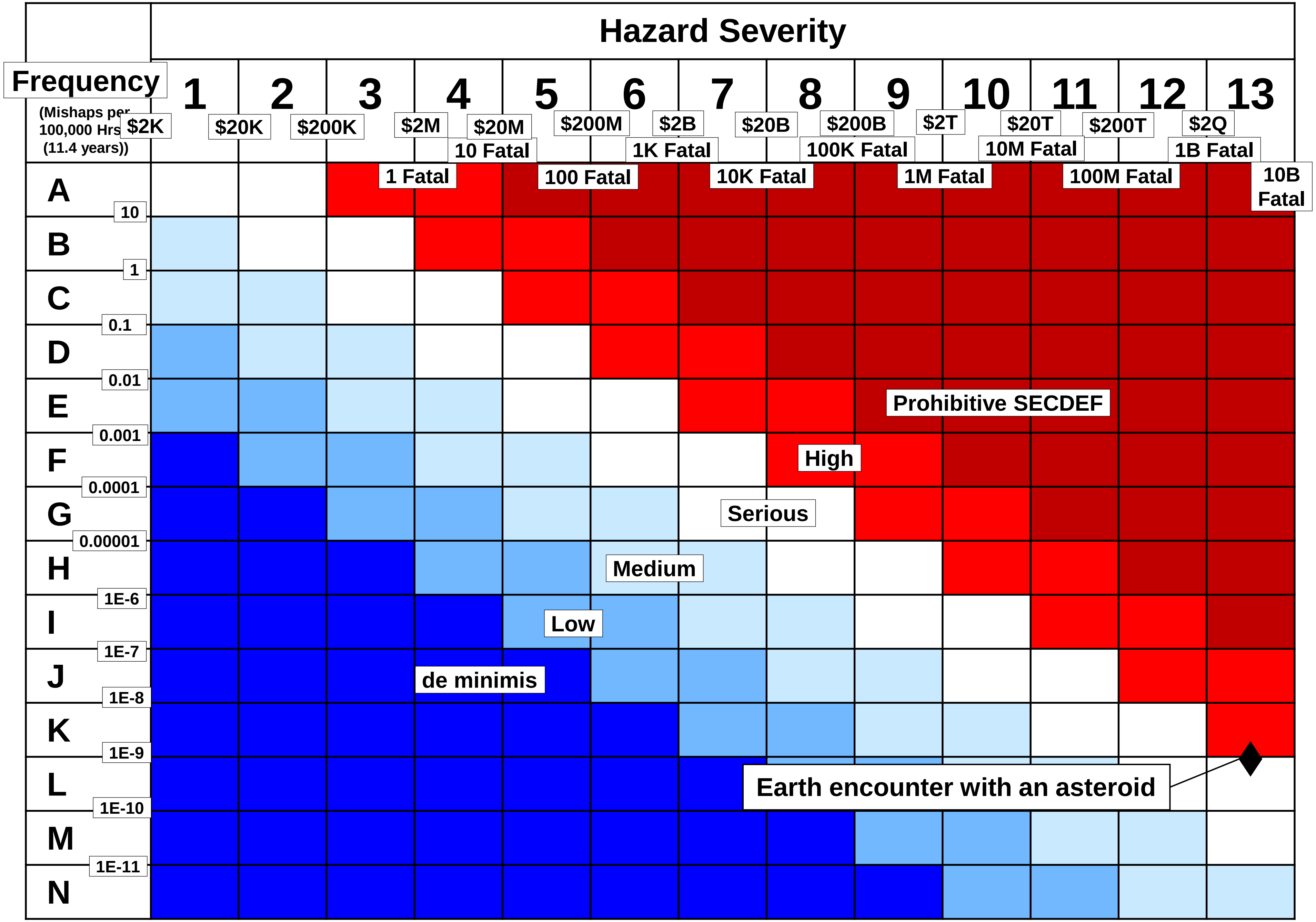
⑩ Severity Category numbers increase with increasing Severity



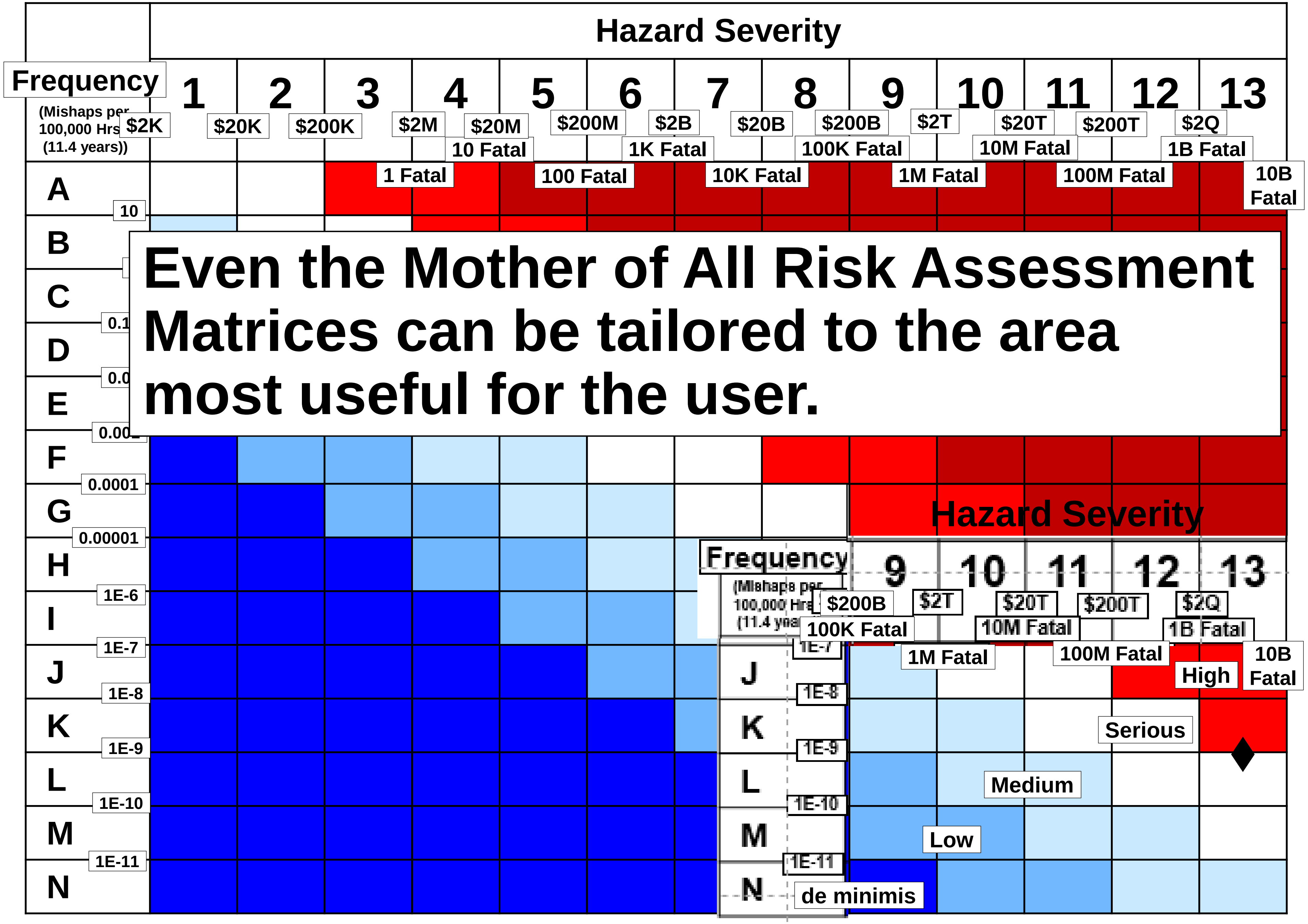
Severity		1	2	3	4	5
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities
A	>100					
B	>10					
C	>1					
D	>0.1					
E	>0.01					5E
F	>0.001					
G	>0.0001					

⑨ Easily tailored with reporting of risk consistent with other systems within the family of systems.

Mother of All Risk Assessment Matrices (Spaceship Earth)



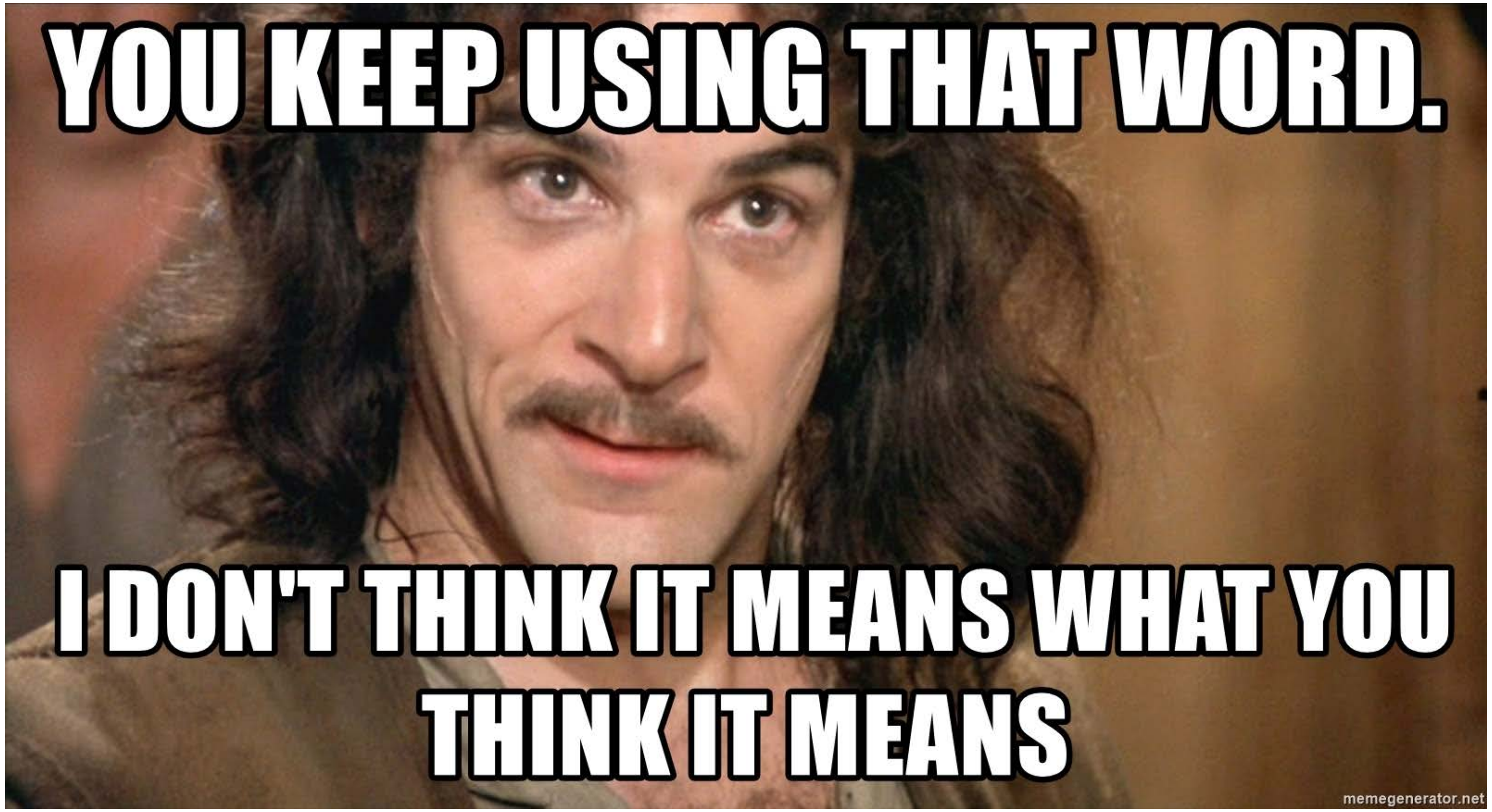
Mother of All Risk Assessment Matrices (Spaceship Earth)



Even the Mother of All Risk Assessment Matrices can be tailored to the area most useful for the user.

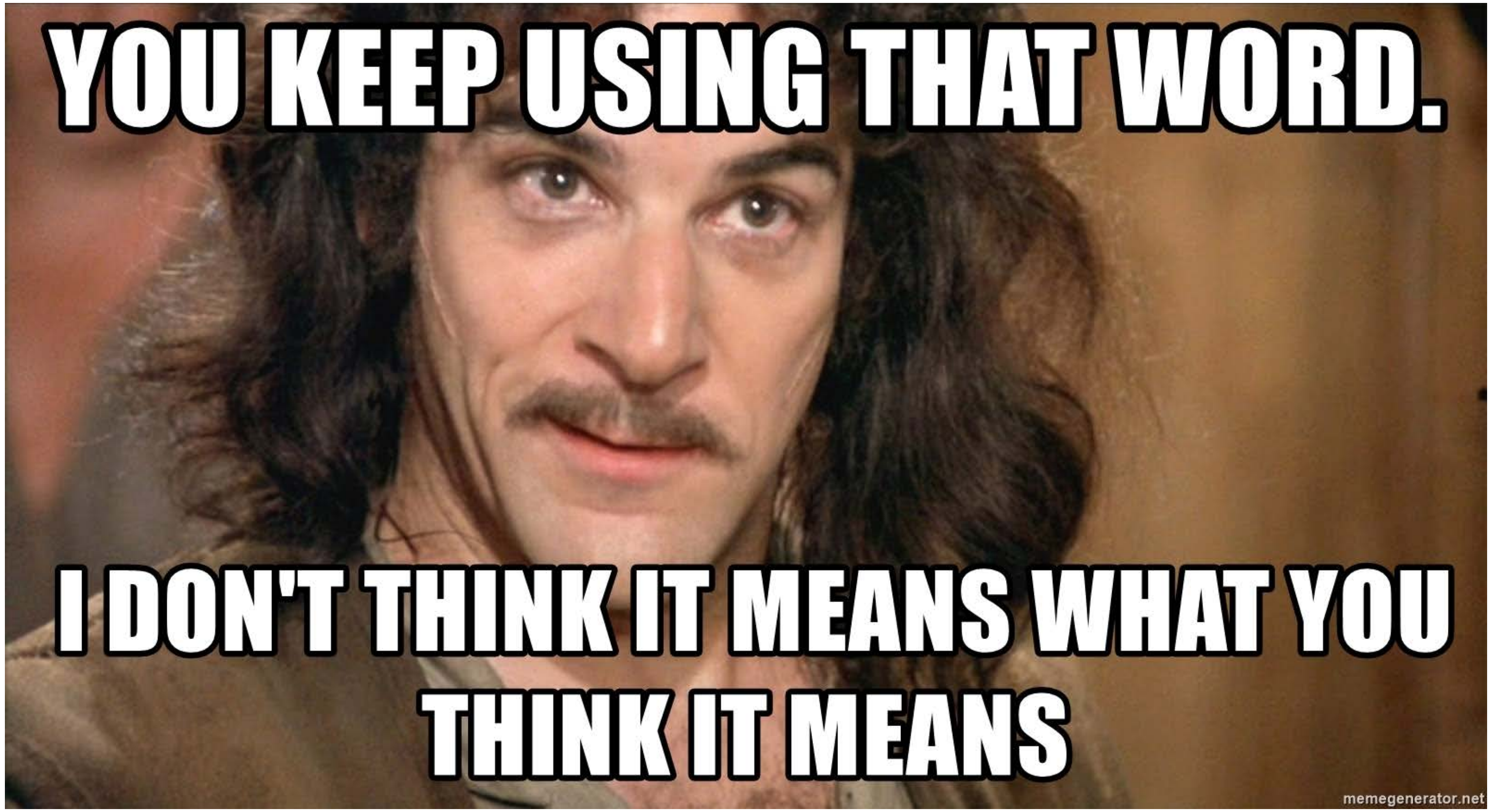
Additional Recommendation

- Eliminate one-word labels for Severity (Catastrophic, Critical, Marginal, Negligible) and Probability (Frequent, Probable, Occasional, Remote, Improbable)

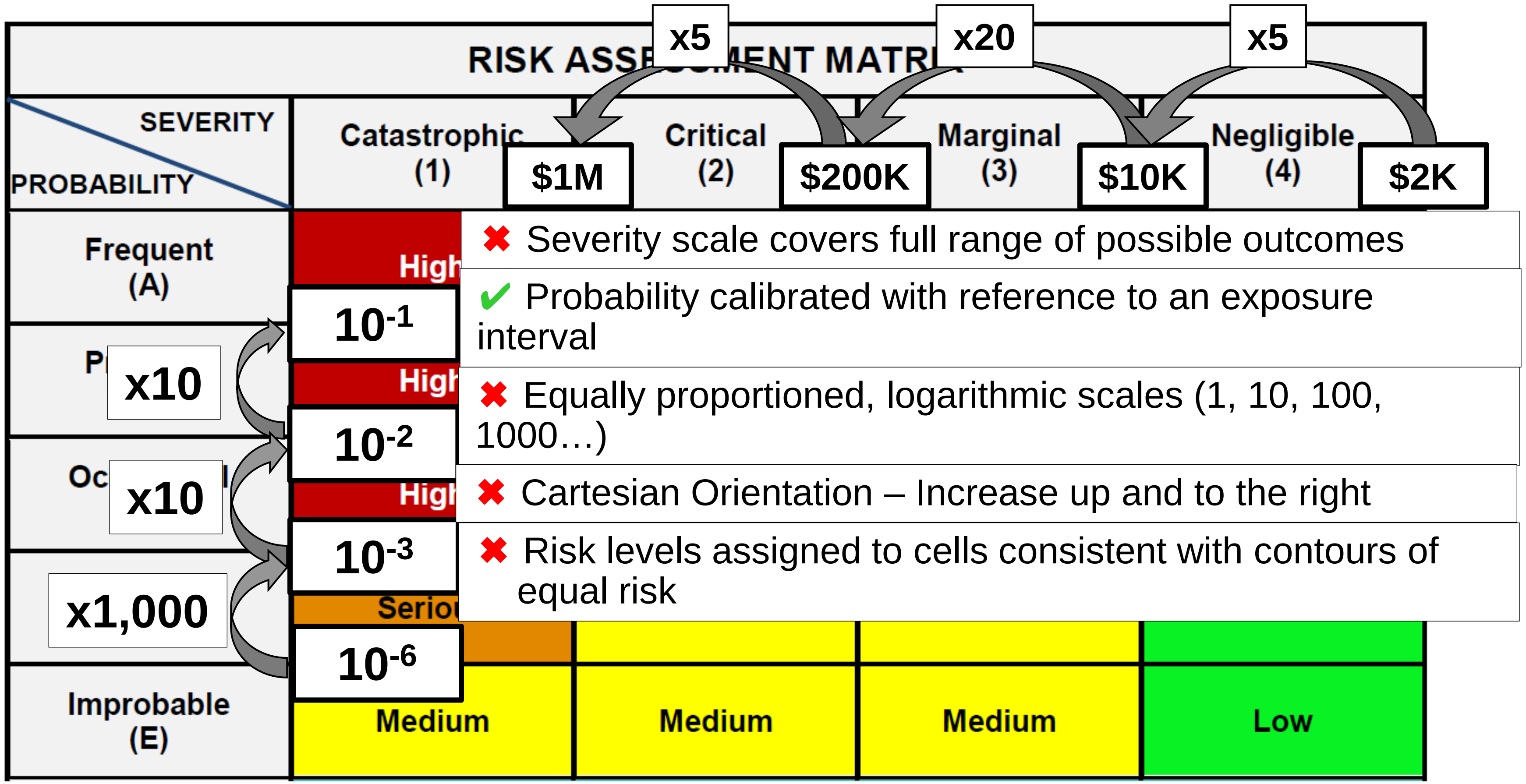


Additional Recommendation

- Just use Severity 1, Severity 2, Probability C, etc.

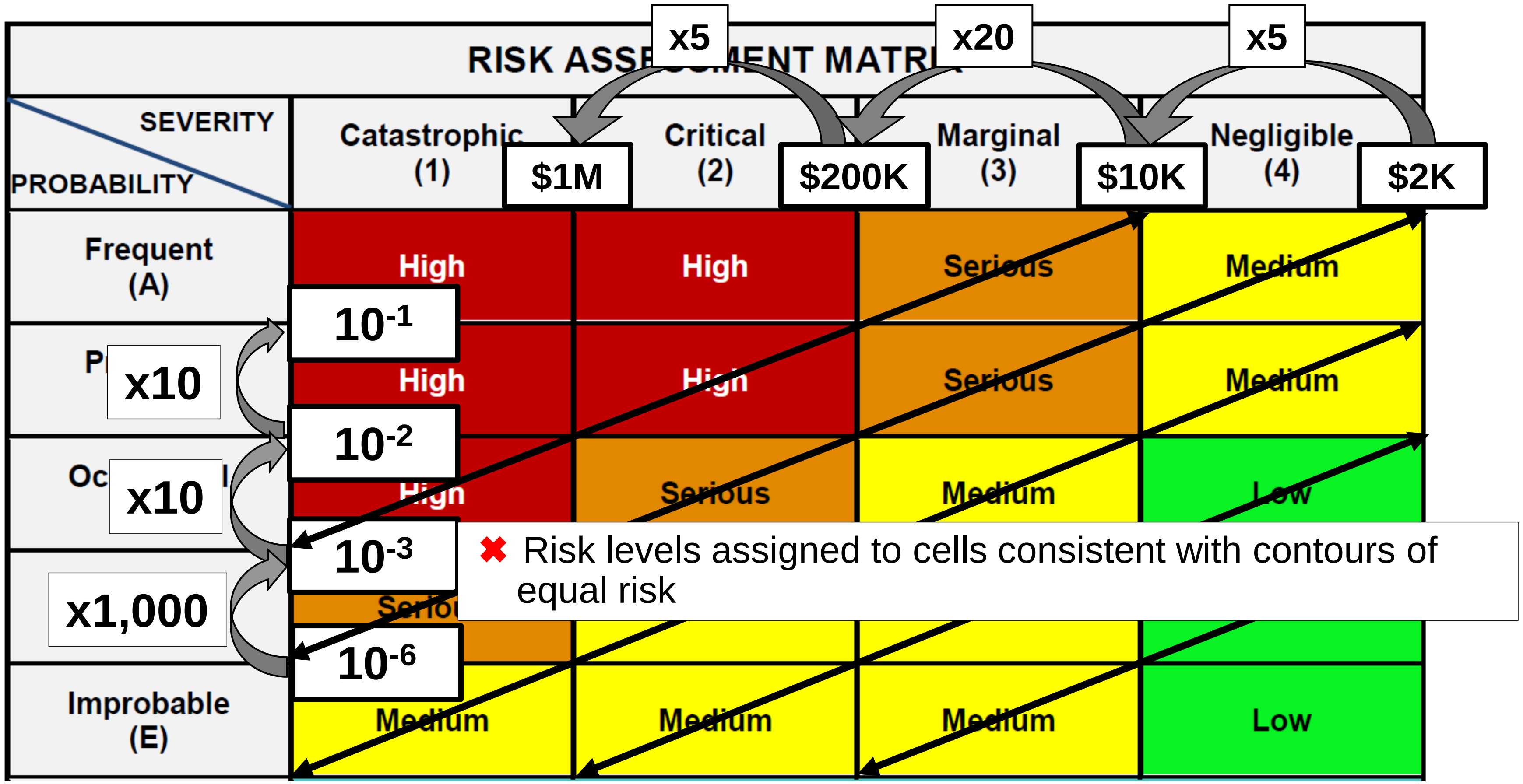


MIL-STD-882D Matrix



- ✖ Severity scale covers full range of possible outcomes
- ✔ Probability calibrated with reference to an exposure interval
- ✖ Equally proportioned, logarithmic scales (1, 10, 100, 1000…)
- ✖ Cartesian Orientation – Increase up and to the right
- ✖ Risk levels assigned to cells consistent with contours of equal risk

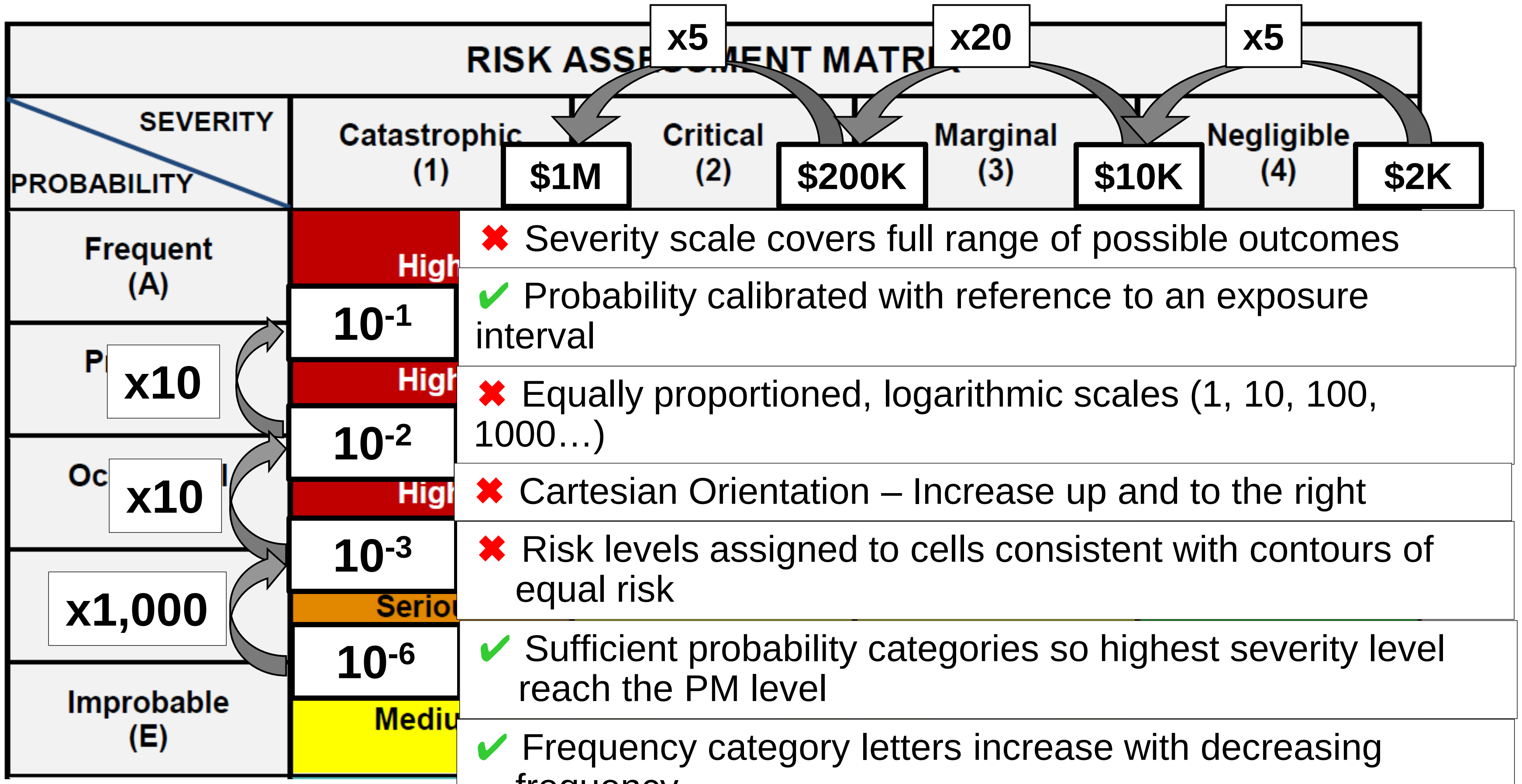
MIL-STD-882D Matrix



SEVERITY PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
P	High	High	Serious	Medium
Oc l	High	Serious	Medium	Low
	Seriou			
Improbable (E)	Medium	Medium	Medium	Low

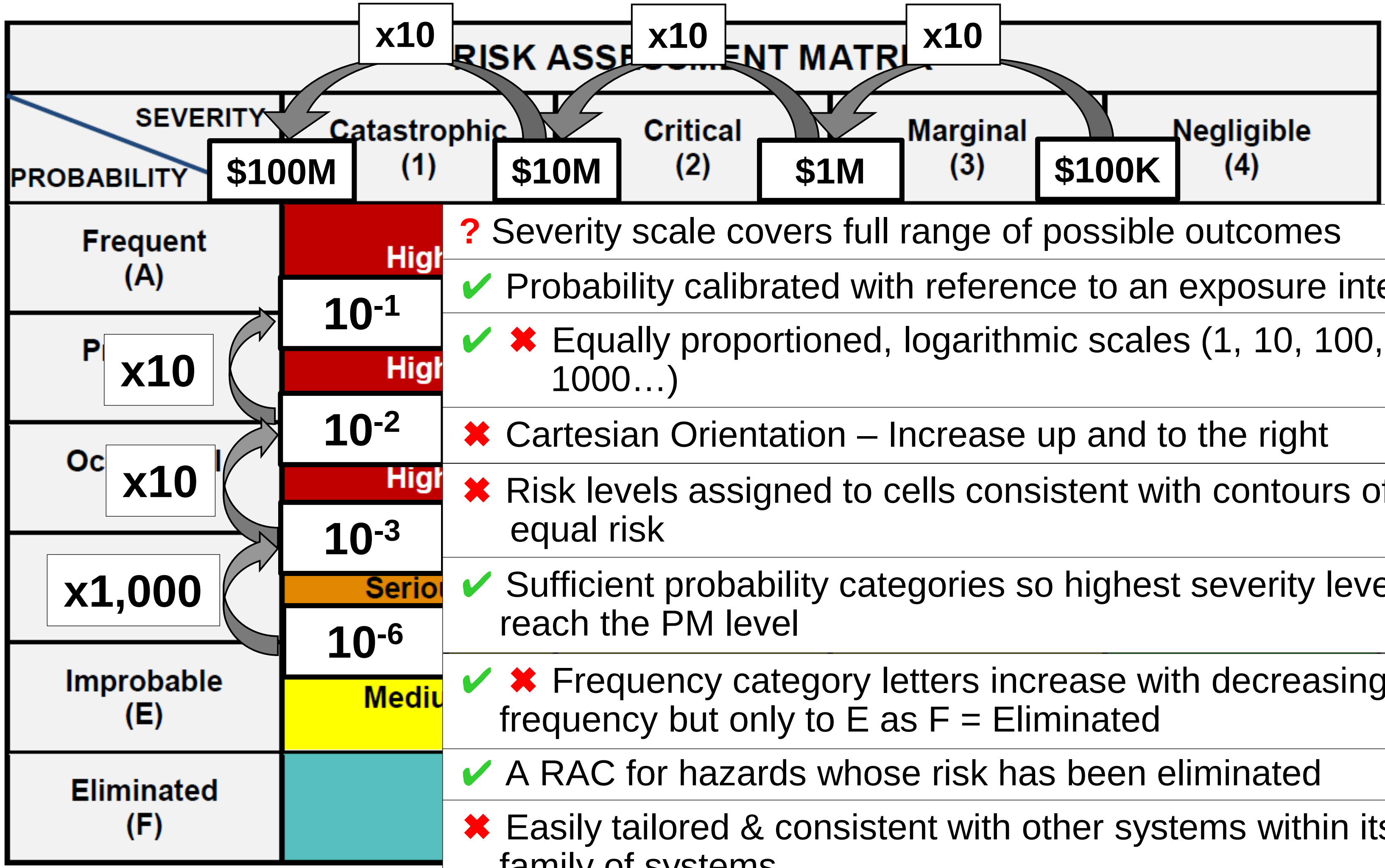
✖ Risk levels assigned to cells consistent with contours of equal risk

MIL-STD-882D Matrix



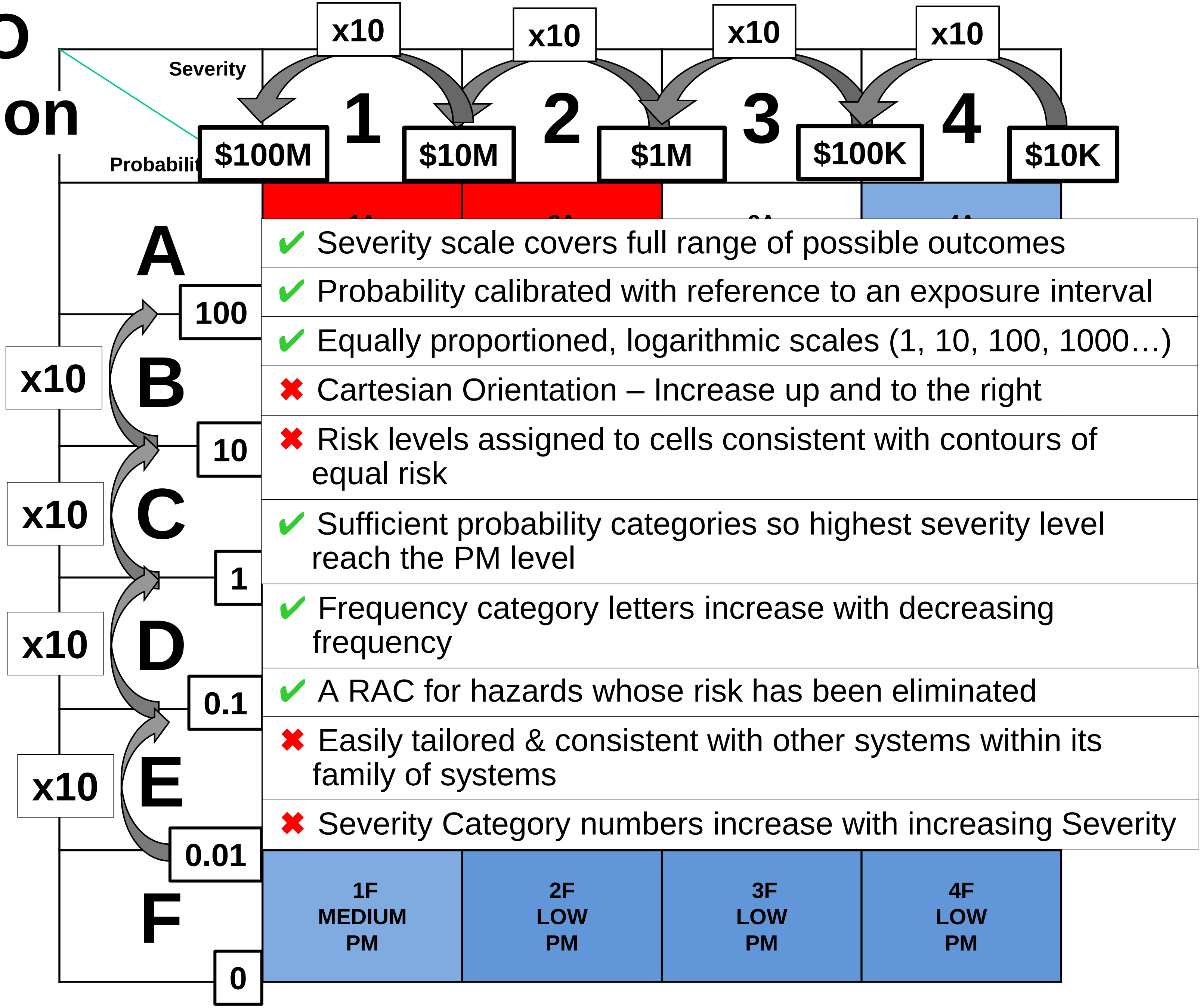
- ✖ Severity scale covers full range of possible outcomes
- ✔ Probability calibrated with reference to an exposure interval
- ✖ Equally proportioned, logarithmic scales (1, 10, 100, 1000…)
- ✖ Cartesian Orientation – Increase up and to the right
- ✖ Risk levels assigned to cells consistent with contours of equal risk
- ✔ Sufficient probability categories so highest severity level reach the PM level
- ✔ Frequency category letters increase with decreasing frequency
- ✖ A RAC for hazards whose risk has been eliminated
- ✖ Easily tailored & consistent with other systems within its family of systems
- ✖ Severity Category numbers increase with increasing Severity

MIL-STD-882E Matrix



- ? Severity scale covers full range of possible outcomes
- ✔ Probability calibrated with reference to an exposure interval
- ✔ ✖ Equally proportioned, logarithmic scales (1, 10, 100, 1000…)
- ✖ Cartesian Orientation – Increase up and to the right
- ✖ Risk levels assigned to cells consistent with contours of equal risk
- ✔ Sufficient probability categories so highest severity level reach the PM level
- ✔ ✖ Frequency category letters increase with decreasing frequency but only to E as F = Eliminated
- ✔ A RAC for hazards whose risk has been eliminated
- ✖ Easily tailored & consistent with other systems within its family of systems
- ✖ Severity Category numbers increase with increasing Severity

PEO Aviation

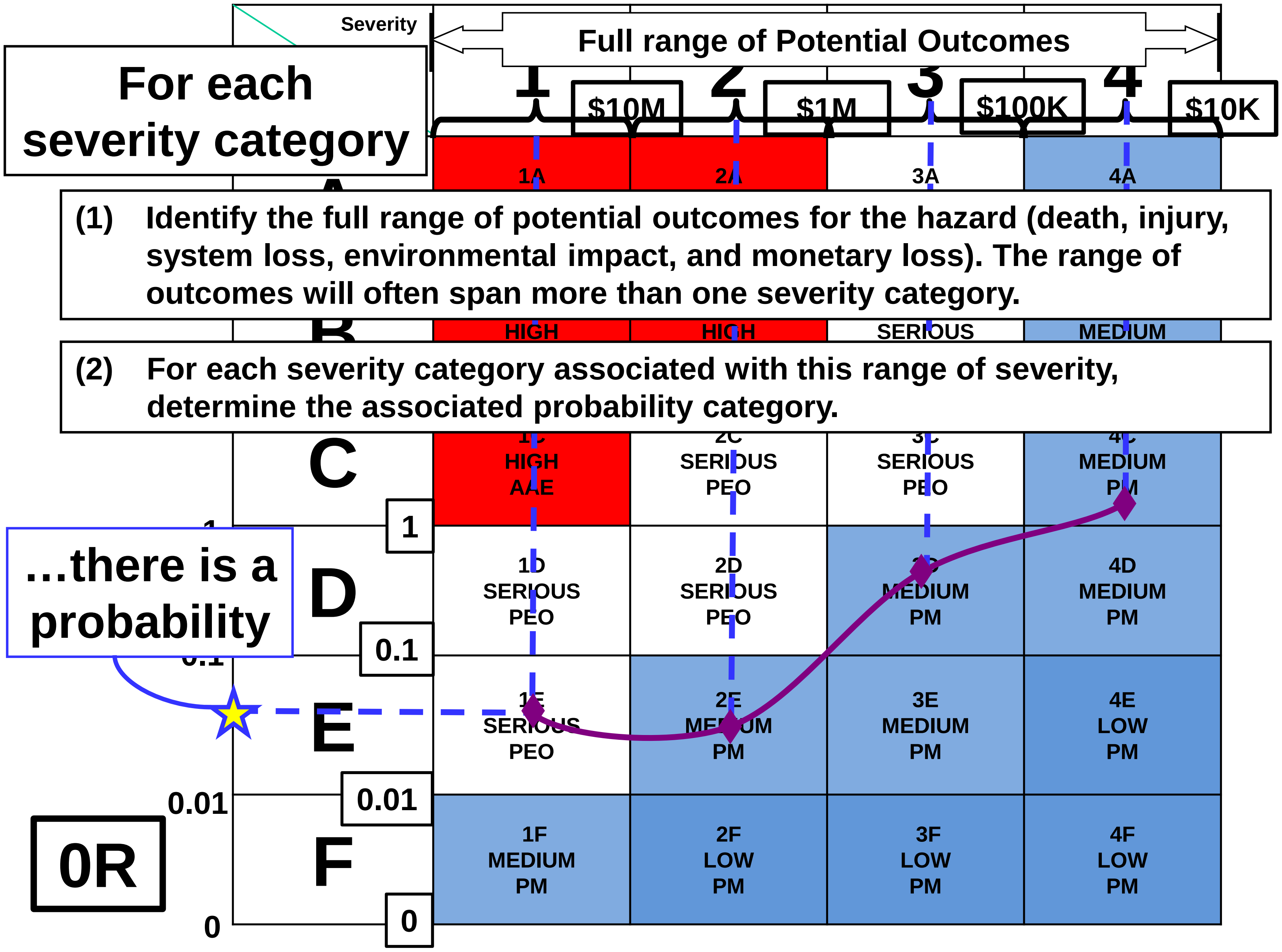


- ✔ Severity scale covers full range of possible outcomes
- ✔ Probability calibrated with reference to an exposure interval
- ✔ Equally proportioned, logarithmic scales (1, 10, 100, 1000…)
- ✖ Cartesian Orientation – Increase up and to the right
- ✖ Risk levels assigned to cells consistent with contours of equal risk
- ✔ Sufficient probability categories so highest severity level reach the PM level
- ✔ Frequency category letters increase with decreasing frequency
- ✔ A RAC for hazards whose risk has been eliminated
- ✖ Easily tailored & consistent with other systems within its family of systems
- ✖ Severity Category numbers increase with increasing Severity

0R

Topics for this Tutorial

- Purpose of a Hazard Risk Matrix
- Understanding the Attributes of a well-designed risk assessment matrix
- **How to Assign a Risk Assessment Code**
- Understanding Probability
- Building an Expanded Matrix
- Plotting Accidents on a Matrix
- Using Relative Risk Values
- Building Hazard Risk Profiles



For each severity category

(1) Identify the full range of potential outcomes for the hazard (death, injury, system loss, environmental impact, and monetary loss). The range of outcomes will often span more than one severity category.

(2) For each severity category associated with this range of severity, determine the associated probability category.

…there is a probability

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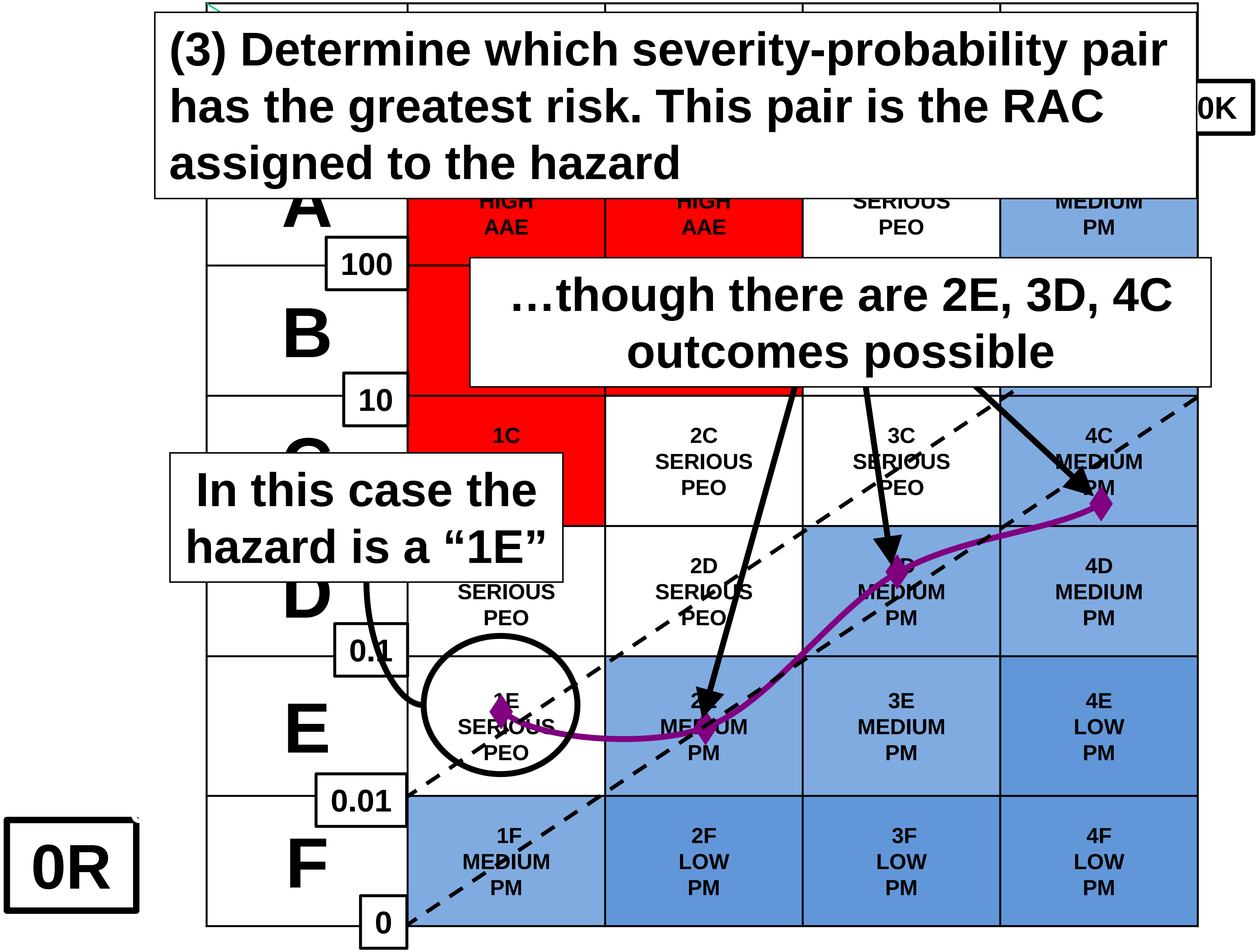
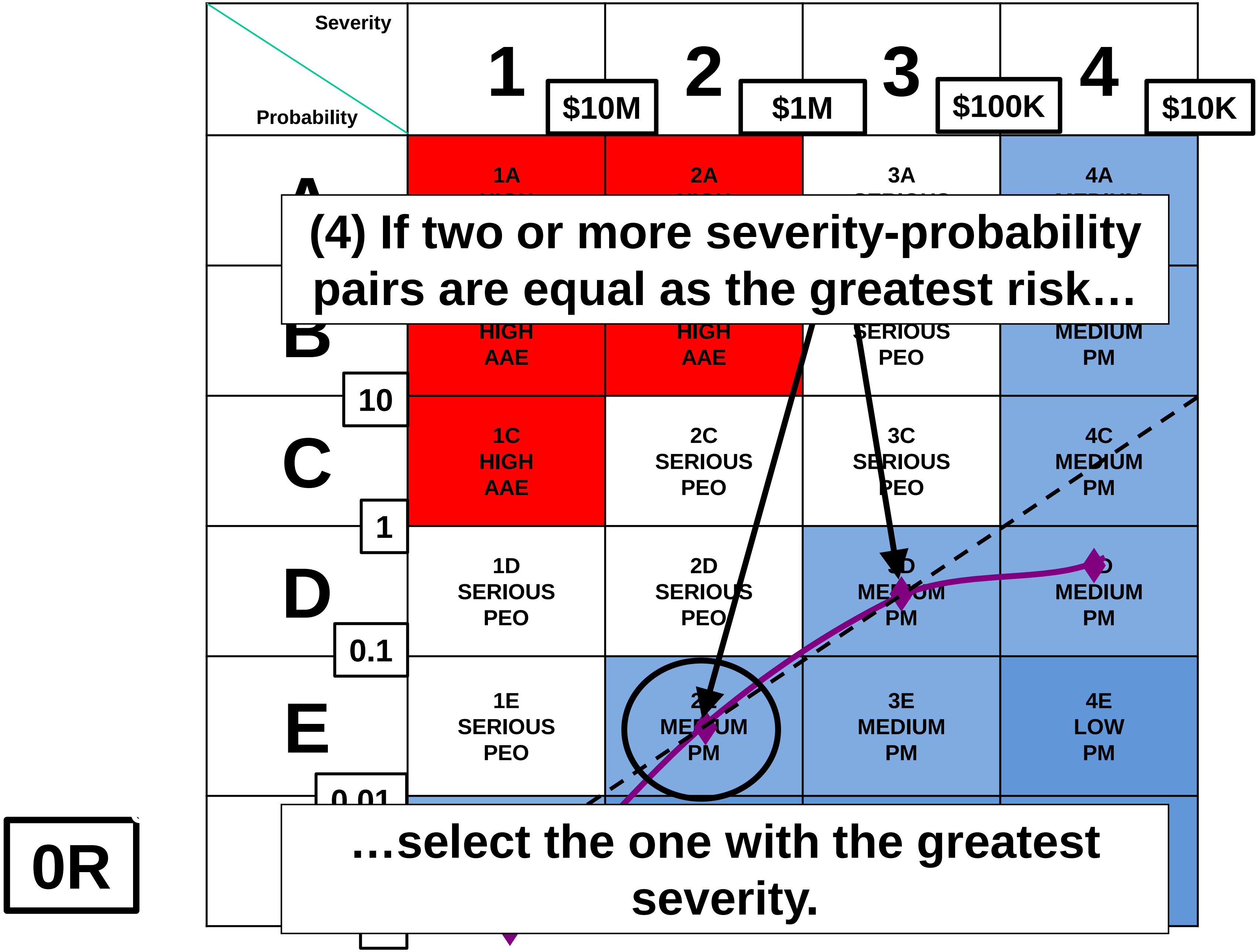


(3) Determine which severity-probability pair has the greatest risk. This pair is the RAC assigned to the hazard

…though there are 2E, 3D, 4C outcomes possible

In this case the hazard is a “1E”



(4) If two or more severity-probability pairs are equal as the greatest risk…

Severity / Probability	1 $10M	2 $1M	3 $100K	4 $10K
A	1A	2A	3A	4A
B 10	HIGH AAE	HIGH AAE	SERIOUS PEO	MEDIUM PM
C 1	1C HIGH AAE	2C SERIOUS PEO	3C SERIOUS PEO	4C MEDIUM PM
D 0.1	1D SERIOUS PEO	2D SERIOUS PEO	3D MEDIUM PM	4D MEDIUM PM
E 0.01	1E SERIOUS PEO	2E MEDIUM PM	3E MEDIUM PM	4E LOW PM

…select the one with the greatest severity.

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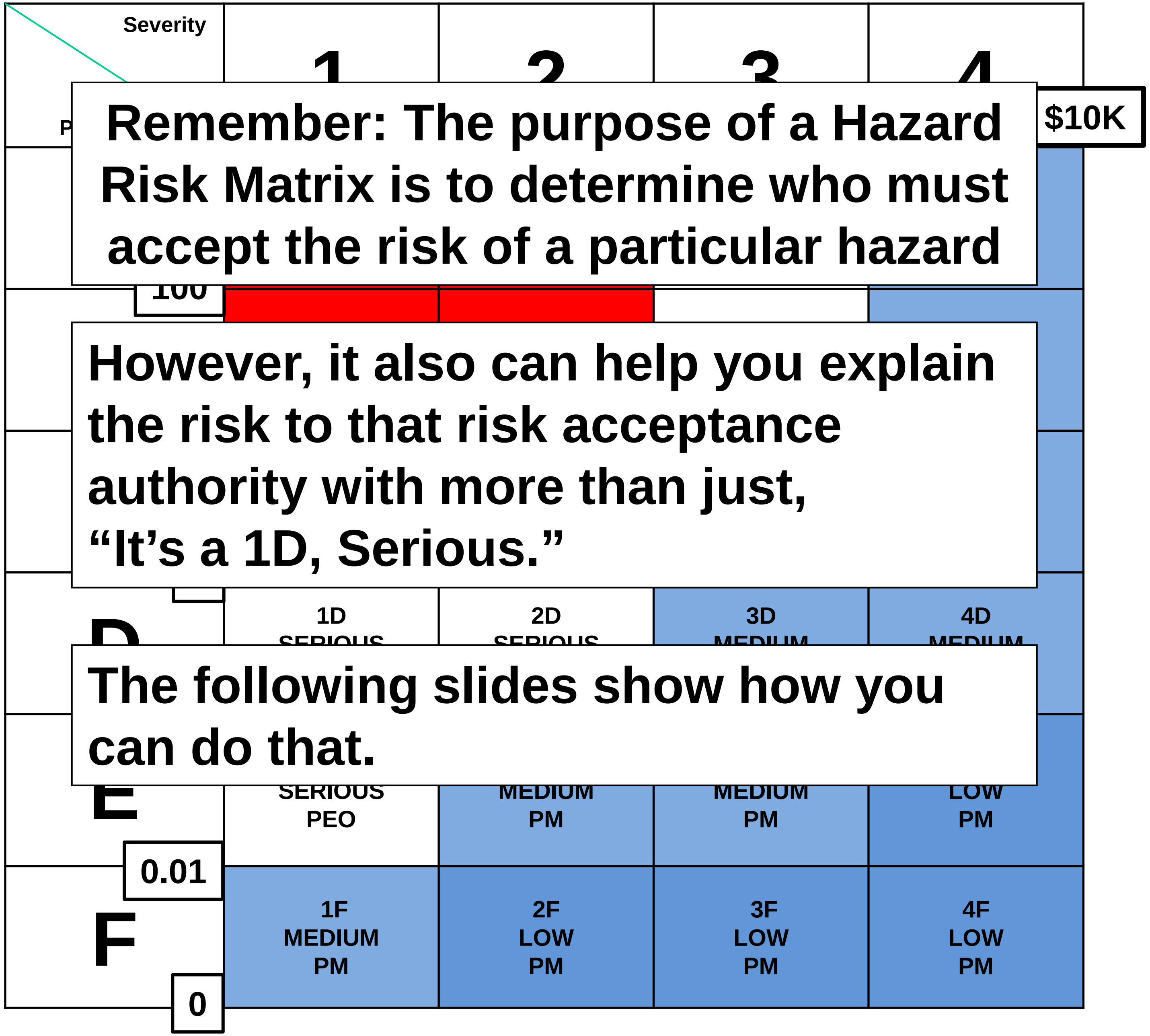

Remember: The purpose of a Hazard Risk Matrix is to determine who must accept the risk of a particular hazard

However, it also can help you explain the risk to that risk acceptance authority with more than just,
“It’s a 1D, Serious.”

The following slides show how you can do that.

0R

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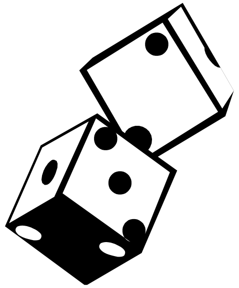
Understanding Probability

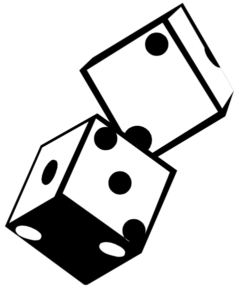


Probability:

“A number expressing the likelihood that a specific event will occur, expressed as the ratio of the number of actual occurrences to the number of possible occurrences.”

- The American Heritage® Dictionary of the English Language, Fourth Edition

Understanding Probability



Math Definition:

- **Repeat a random experiment "n" number of times.**
- **If a specific outcome has occurred "f" times in these n trials, the number "f" is the frequency of the outcome.**
- **The ratio f/n is the relative frequency of the outcome.**
- **A relative frequency is usually very unstable for small values of "n," but it tends to stabilize about some number "p" as "n" increases.**
- **The number "p" is the probability of the outcome.**

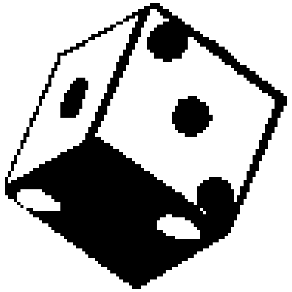
$$p = f / n$$

for very large values of n

Understanding Probability

Simple example:

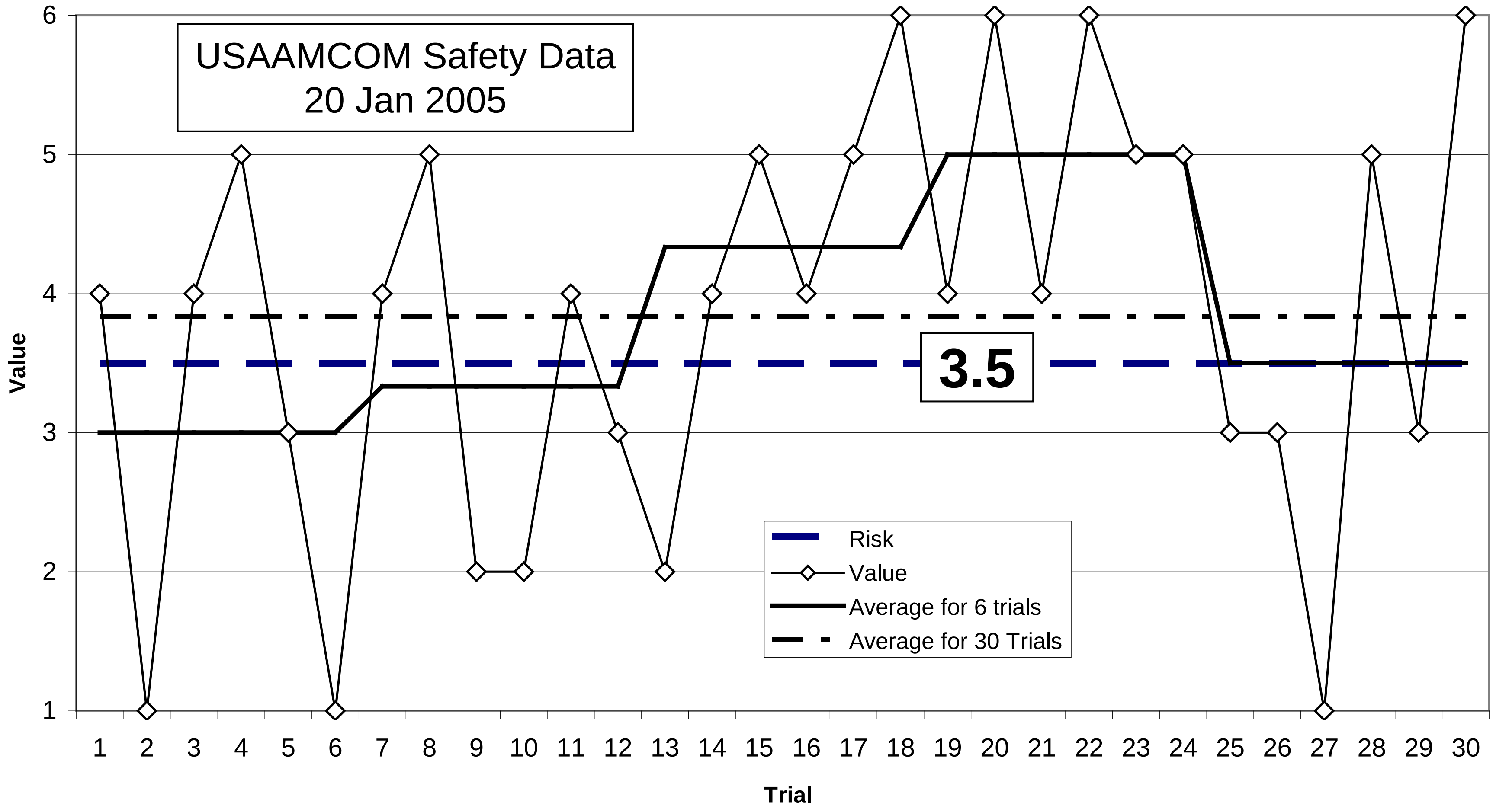
Probability of rolling a “3” with one die.



- Roll #1 - “5”, f/n = 0/1 = 0
- Roll #2 - “2”, f/n = 0/2 = 0
- Roll #3 - “3”, f/n = 1/3 = .333…
- Roll #4 - “4”, f/n = 1/4 = .25
- Roll #1,000: 163 “3”s, f/n = 163/1000 = .163
- Rolls approach infinity f/n = .166666….

Rolling Dice

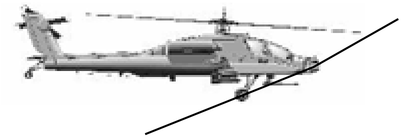
Roll a single die 30 times. The expected value of each roll is 3.5. What you actually get is somewhat different.



Understanding Probability

Hazard: Helicopter strikes wire; results in Class A mishap

Probability: 4.406E-06 occurrences per flight hour



- **1 Flight Hr, no mishap, rate = 0**
- **1,000 Flight Hrs, no mishap, rate = 0**
- **176,182 Flight Hrs, 1st mishap, rate = 5.676E-06 /flt hr**
- **274,539 Flight Hrs, 2nd mishap, rate = 7.285E-06 /flt hr**
- **700,462 Flt Hrs, 3rd mishap, rate = 4.283E-06 /flt hr**
- **10,000,000 Flt Hrs, 46 mishaps, rate = 4.600E-06 /flt hr**
- **1,000,000,000 Hrs, 4407 mishaps, rate = 4.407E-06 /flt hr**
- **Flight hours approach infinity, rate = 4.406E-06 /flt hr**

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PEO Aviation Risk Decision Authority Matrix

Severity Probability	1 $10M	2 $1M	3 $100K	4 $10K
A 100	1A HIGH AAE	2A HIGH AAE	3A SERIOUS PEO	4A MEDIUM PM
B 10	1B HIGH AAE	2B HIGH AAE	3B SERIOUS PEO	4B MEDIUM PM
C 1	1C HIGH AAE	2C SERIOUS PEO	3C SERIOUS PEO	4C MEDIUM PM
D 0.1	1D SERIOUS PEO	2D SERIOUS PEO	3D MEDIUM PM	4D MEDIUM PM
E 0.01	1E SERIOUS PEO	2E MEDIUM PM	3E MEDIUM PM	4E LOW PM
F 0	1F MEDIUM PM	2F LOW PM	3F LOW PM	4F LOW PM

0R

Applying Probability Classifications to a military helicopter

Fleet Size = 368 aircraft

Utilization = 240 hours/year

Life = 12 years/aircraft

Aircraft Life = 240 x 12
= 2,880 hours

Fleet Exposure Hours = 368 x 240 x 12
= 1,059,840 hours

Fleet Hours per Year = 368 x 240
= 88,320 hours

US Army PEO Aviation Enhanced Matrix

$$\frac{1{,}059{,}840 \; \cancel{\text{flt hrs}}}{1 \text{ fleet life}} \; X \; \frac{10 \text{ Events}}{100{,}000 \; \cancel{\text{flt hrs}}} = \frac{105.98 \text{ Events}}{1 \text{ Fleet Life}}$$

	Events per Flight	Flight Hours per	Events per 100,000	Events per	Years per	Event per Fleet	Fleet Life per
Probable B							
	10^{-4}	10,000	10	8.832	0.113	105.98	0.00944
Occasional **C**							
	10^{-5}	100,000	1	0.8832	1.13	10.598	0.0944
Remote **D**							
	10^{-6}	1,000,000	0.1	0.0883	11.3	1.0598	0.944
Improbable **E**							
	10^{-7}	10,000,000	0.01	0.00883	113	0.106	9.44
Very Improbable **F**							
	0		0	0		0	
Zero Risk **0R**							

Numbers greater than 1 are easier to comprehend

US Army PEO Aviation Enhanced Matrix

	Events per Flight Hour	Flight Hours per Event	Events per 100,000 Flt Hrs
Frequent **A**			
	10^{-3}	1,000	100
Probable **B**			
	10^{-4}	10,000	10
Occasional **C**			
	10^{-5}	100,000	1
Remote **D**			
	10^{-6}	1,000,000	0.1
Improbable **E**			
	10^{-7}	10,000,000	0.01
Very Improbable **F**			
	0		0
Zero Risk **0R**			

US Army PEO Aviation Enhanced Matrix

	Events per Flight Hour	Flight Hours per Event	Events per 100,000 Flt Hrs	Events per Year	Years per Event
Frequent **A**	10^{-3}	1,000	100	88.32	0.0113
Probable **B**	10^{-4}	10,000	10	8.832	0.113
Occasional **C**	10^{-5}	100,000	1	0.8832	1.13
Remote **D**	10^{-6}	1,000,000	0.1	0.0883	11.3
Improbable **E**	10^{-7}	10,000,000	0.01	0.00883	113
Very Improbable **F**	0		0	0	
Zero Risk **0R**					

US Army PEO Aviation Enhanced Matrix

	Events per Flight	Flight Hours per	Events per 100,000	Events per	Years per
Probable **B**					
	10^{-4}	10,000	10	8.832	0.113
Occasional **C**					
	10^{-5}	100,000	1	0.8832	1.13
Remote **D**					
	10^{-6}	1,000,000	0.1	0.0883	11.3
Improbable **E**					
	10^{-7}	10,000,000	0.01	0.00883	113
Very Improbable **F**					
	0		0	0	
Zero Risk **0R**					

$$\frac{88{,}320\ \cancel{\text{flt hrs}}}{\text{Year}} \times \frac{10\ \text{Events}}{100{,}000\ \cancel{\text{flt hrs}}} = \frac{8.832\ \text{Events}}{\text{Year}}$$

Numbers greater than 1 are easier to comprehend

US Army PEO Aviation Enhanced Matrix

Frequent **A**
Probable **B**
Occasional **C**
Remote **D**
Improbable **E**
Very Improbable **F**
Zero Risk **0R**

Events per Flight Hour	Flight Hours per Event	Events per 100,000 Flt Hrs	Events per Year	Years per Event	Event per Fleet Life	Fleet Life per Event
10^{-3}	1,000	100	88.32	0.0113	1,060	0.000944
10^{-4}	10,000	10	8.832	0.113	105.98	0.00944
10^{-5}	100,000	1	0.8832	1.13	10.598	0.0944
10^{-6}	1,000,000	0.1	0.0883	11.3	1.0598	0.944
10^{-7}	10,000,000	0.01	0.00883	113	0.106	9.44
0		0	0		0	

US Army PEO Aviation Enhanced Matrix

	Events per Flight	Flight Hours per	Events per 100,000	Events per	Years per	Event per Fleet	Fleet Life per
Occasional **C**	10^{-4}	10,000	10	8.832	0.113	105.98	0.00944
Remote **D**	10^{-5}	100,000	1	0.8832	1.13	10.598	0.0944
Improbable **E**	10^{-6}	1,000,000	0.1	0.0883	11.3	1.0598	0.944
Very Improbable **F**	10^{-7}	10,000,000	0.01	0.00883	113	0.106	9.44
Zero Risk **0R**	0		0	0		0	

$$\frac{1{,}059{,}840\ \cancel{\text{flt hrs}}}{1\ \text{fleet life}}\ \text{X}\ \frac{10\ \text{Events}}{100{,}000\ \cancel{\text{flt hrs}}} = \frac{105.98\ \text{Events}}{1\ \text{Fleet Life}}$$

US Army PEO Aviation Enhanced Matrix

	Events per Flight Hour	Flight Hours per Event	Events per 100,000 Flt Hrs	Events per Year	Years per Event	Event per Fleet Life	Fleet Life per Event
Frequent **A**	10^{-3}	1,000	100	88.32	0.0113	1,060	0.000944
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Improbable **E**	10^{-7}	10,000,000	0.01	0.00883	113	0.106	9.44
Very Improbable **F**	0		0	0		0	
Zero Risk **0R**							

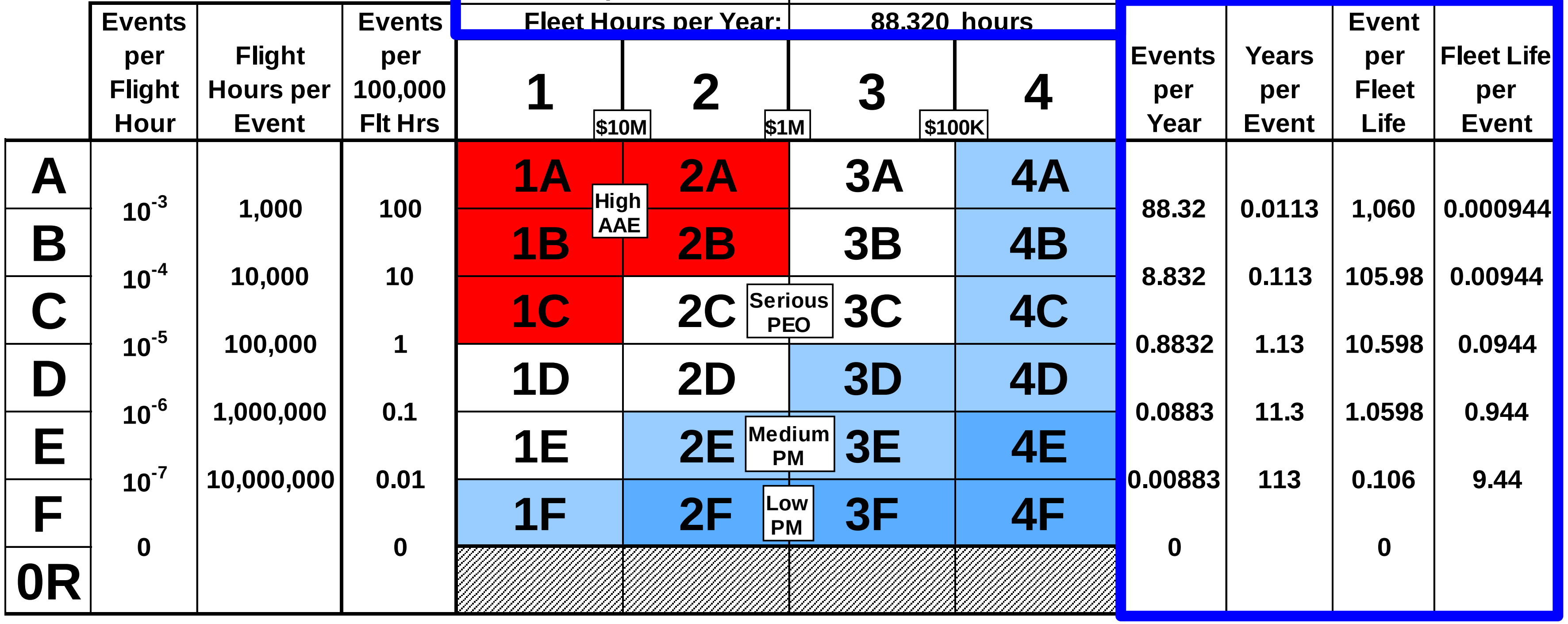
Numbers greater than 1 are easier to comprehend

US Army PEO Aviation Enhanced Matrix

☐ Input
☐ Calculated

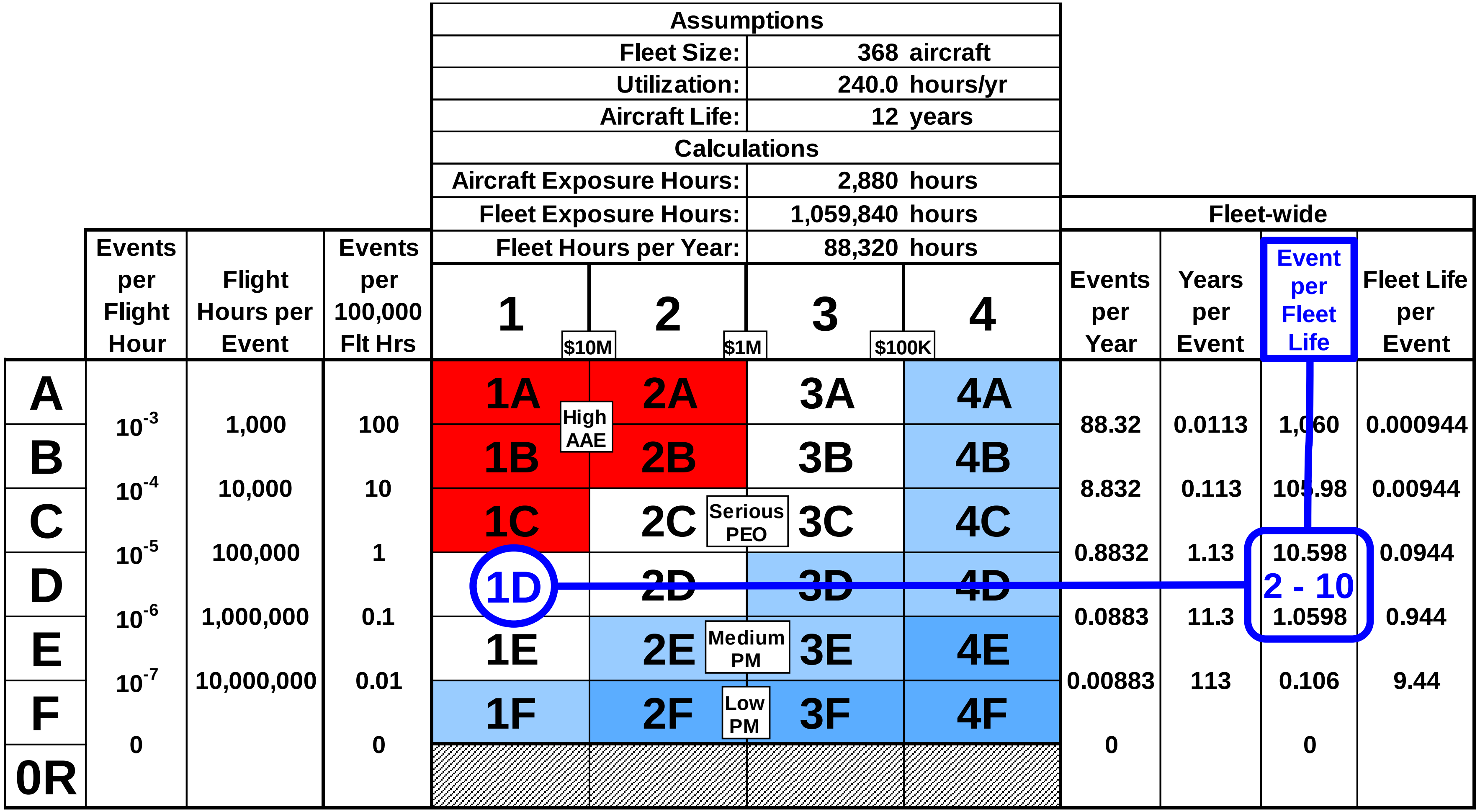
Assumptions	
Fleet Size:	368 aircraft
Utilization:	240.0 hours/yr
Aircraft Life:	12 years

Calculations	
Aircraft Exposure Hours:	2,880 hours
Fleet Exposure Hours:	1,059,840 hours
Fleet Hours per Year:	88,320 hours



								Fleet-wide			
	Events per Flight Hour	Flight Hours per Event	Events per 100,000 Flt Hrs	1	2	3	4	Events per Year	Years per Event	Event per Fleet Life	Fleet Life per Event
				$10M	$1M	$100K					
A				1A	2A	3A	4A				
	10^{-3}	1,000	100	High AAE				88.32	0.0113	1,060	0.000944
B				1B	2B	3B	4B				
	10^{-4}	10,000	10					8.832	0.113	105.98	0.00944
C				1C	2C Serious PEO	3C	4C				
	10^{-5}	100,000	1					0.8832	1.13	10.598	0.0944
D				1D	2D	3D	4D				
	10^{-6}	1,000,000	0.1					0.0883	11.3	1.0598	0.944
E				1E	2E Medium PM	3E	4E				
	10^{-7}	10,000,000	0.01					0.00883	113	0.106	9.44
F				1F	2F Low PM	3F	4F				
	0		0					0		0	
0R											

Consequences of Risk Acceptance

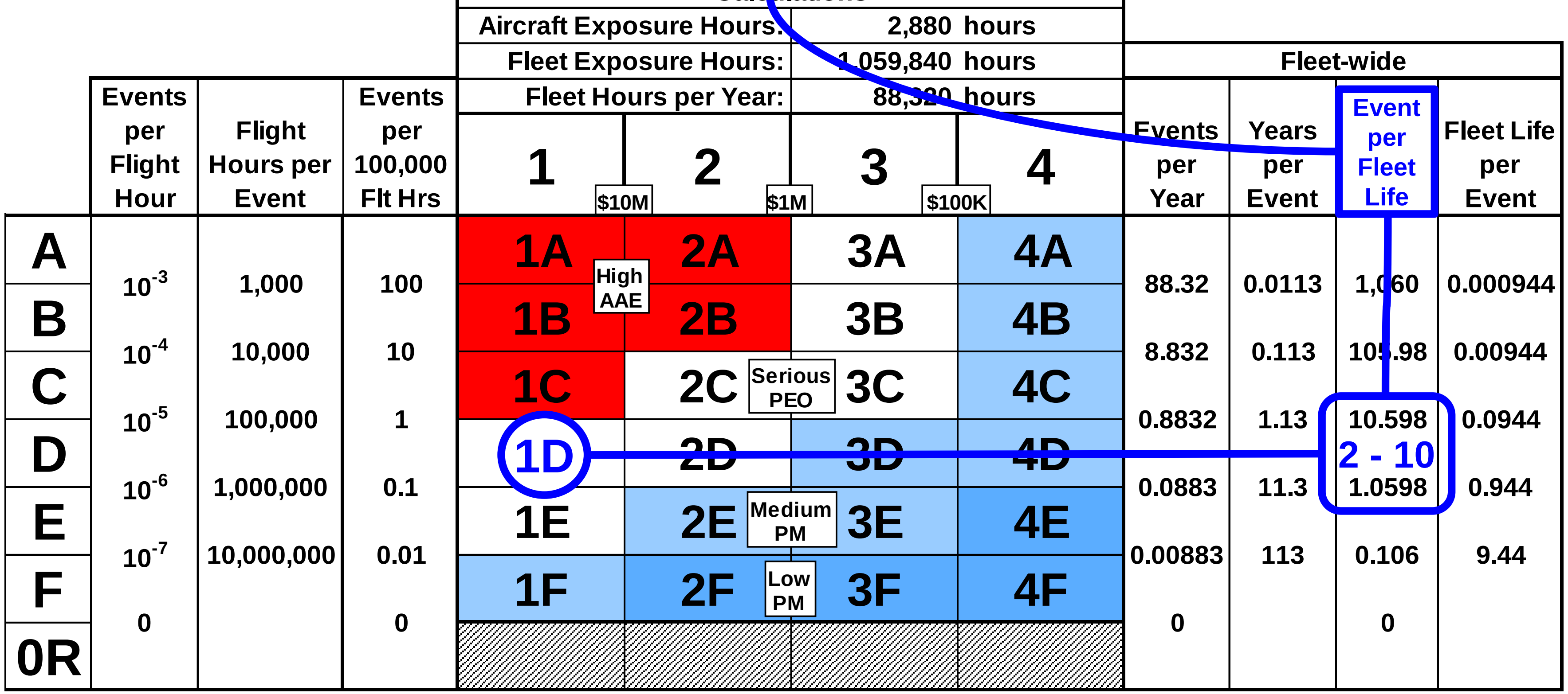


Assumptions	
Fleet Size:	368 aircraft
Utilization:	240.0 hours/yr
Aircraft Life:	12 years
Calculations	
Aircraft Exposure Hours:	2,880 hours
Fleet Exposure Hours:	1,059,840 hours
Fleet Hours per Year:	88,320 hours

	Events per Flight Hour	Flight Hours per Event	Events per 100,000 Flt Hrs	1	2	3	4	Fleet-wide			
				$10M	$1M	$100K		Events per Year	Years per Event	Event per Fleet Life	Fleet Life per Event
A				1A	2A	3A	4A				
	10^{-3}	1,000	100	High AAE				88.32	0.0113	1,060	0.000944
B				1B	2B	3B	4B				
	10^{-4}	10,000	10					8.832	0.113	105.98	0.00944
C				1C	2C Serious PEO	3C	4C				
	10^{-5}	100,000	1					0.8832	1.13	10.598	0.0944
D				1D	2D	3D	4D			2 - 10	
	10^{-6}	1,000,000	0.1					0.0883	11.3	1.0598	0.944
E				1E	2E Medium PM	3E	4E				
	10^{-7}	10,000,000	0.01					0.00883	113	0.106	9.44
F				1F	2F Low PM	3F	4F				
	0		0					0		0	
0R				▨	▨	▨	▨				

Consequences of Risk Acceptance

Consequences of Risk Acceptance:
On the order of 2 to 10 Class A accidents due to this hazard over the remaining life cycle of the aircraft.



Aircraft Exposure Hours:	2,880 hours
Fleet Exposure Hours:	1,059,840 hours
Fleet Hours per Year:	88,320 hours

	Events per Flight Hour	Flight Hours per Event	Events per 100,000 Flt Hrs	1 $10M	2 $1M	3 $100K	4	Fleet-wide Events per Year	Years per Event	Event per Fleet Life	Fleet Life per Event
A				1A	2A	3A	4A				
	10^{-3}	1,000	100	High AAE				88.32	0.0113	1,060	0.000944
B				1B	2B	3B	4B				
	10^{-4}	10,000	10					8.832	0.113	105.98	0.00944
C				1C	2C Serious PEO	3C	4C				
	10^{-5}	100,000	1					0.8832	1.13	10.598	0.0944
D				1D	2D	3D	4D			2 - 10	
	10^{-6}	1,000,000	0.1					0.0883	11.3	1.0598	0.944
E				1E	2E Medium PM	3E	4E				
	10^{-7}	10,000,000	0.01					0.00883	113	0.106	9.44
F				1F	2F Low PM	3F	4F				
	0		0					0		0	
0R				▨	▨	▨	▨				

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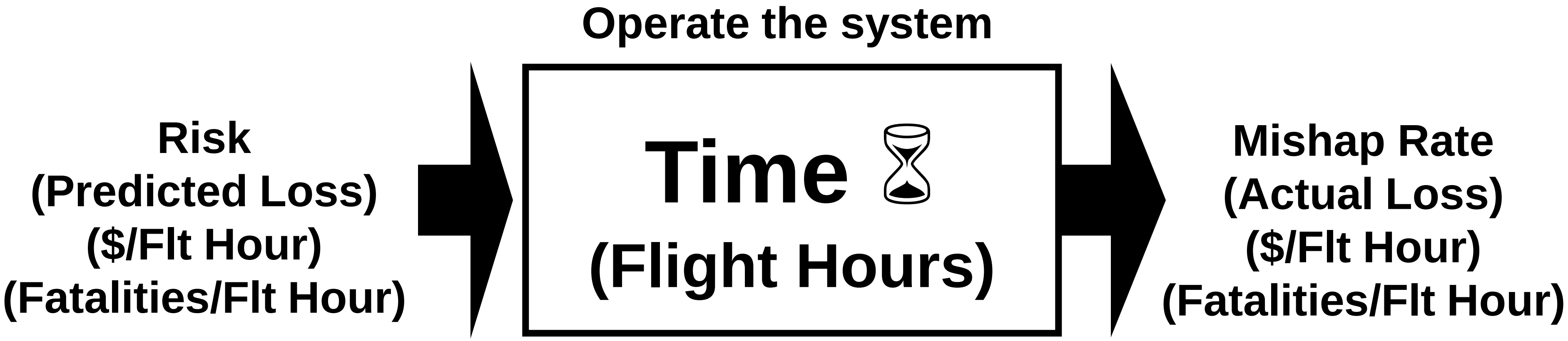
Mishap Risk & Mishap Loss

Mishap Risk over Time results in Mishap Loss



Operate the system

Risk
(Predicted Loss)
($/Flt Hour)
(Fatalities/Flt Hour)

Time ⌛
(Flight Hours)

Mishap Rate
(Actual Loss)
($/Flt Hour)
(Fatalities/Flt Hour)

Mishap History

Based on this relationship between mishap risk and mishap loss, we can plot mishap histories on a risk matrix as follows:

$$\text{Severity} = \frac{\text{Total Cost from Class A mishaps}}{\text{Total Number of Class A mishaps}}$$

$$= \frac{\$361{,}671{,}038}{59} = \$\ 6{,}130{,}018$$

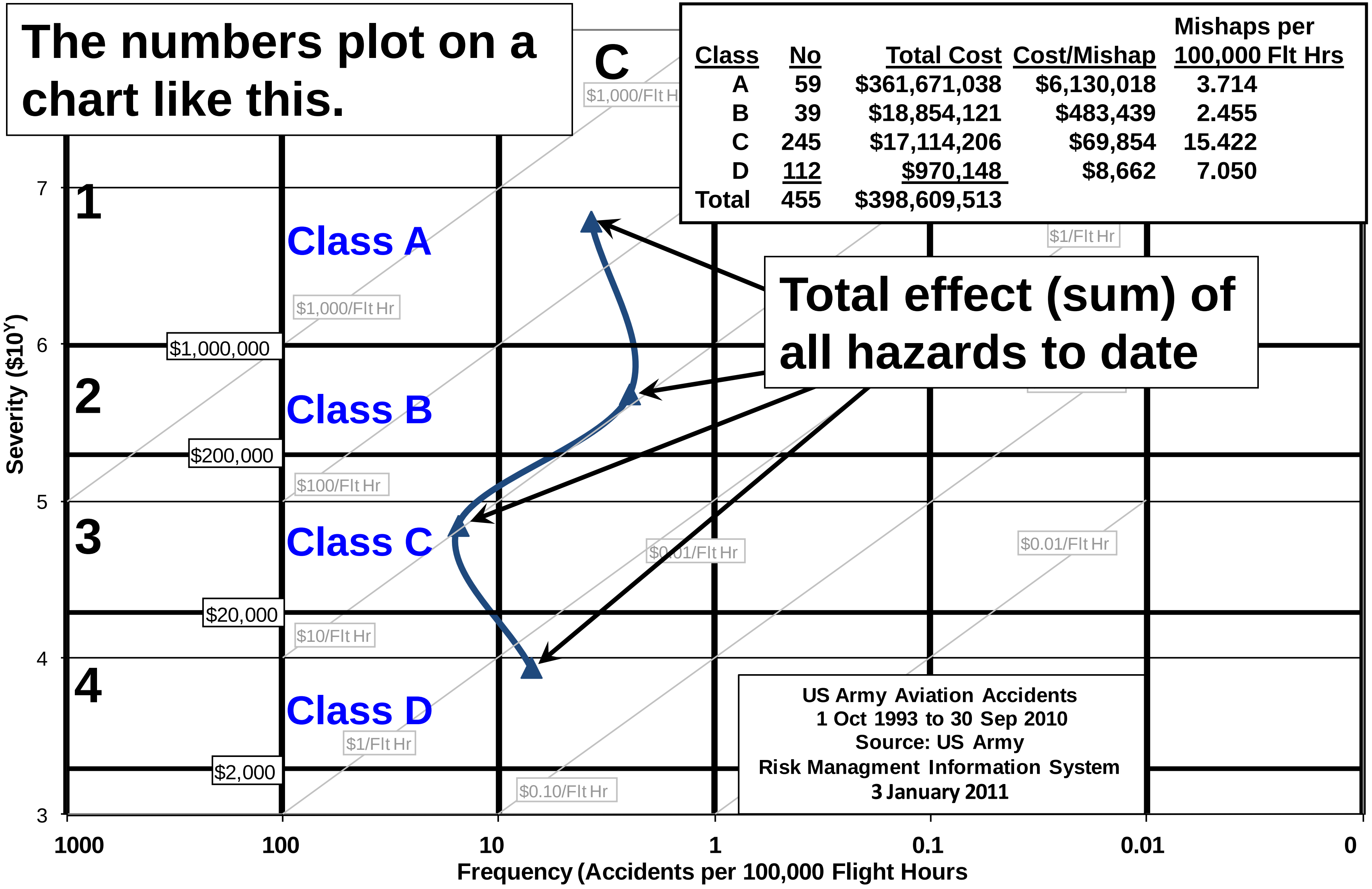
$$\text{Probability} = \frac{\text{Total Number of Class A mishaps}}{\text{Total Hours Flown}}$$

$$= \frac{59}{1{,}588{,}597} = 3.714 \text{ mishaps / 100,000 Flt Hrs}$$

Mishap History

Class	No	Total Cost	Cost/Mishap	Mishaps per 100,000 Flt Hrs
A	59	$361,671,038	$6,130,018	3.714
B	39	$18,854,121	$483,439	2.455
C	245	$17,114,206	$69,854	15.422
D	112	$970,148	$8,662	7.050
Total	455	$398,609,513		

Mishaps



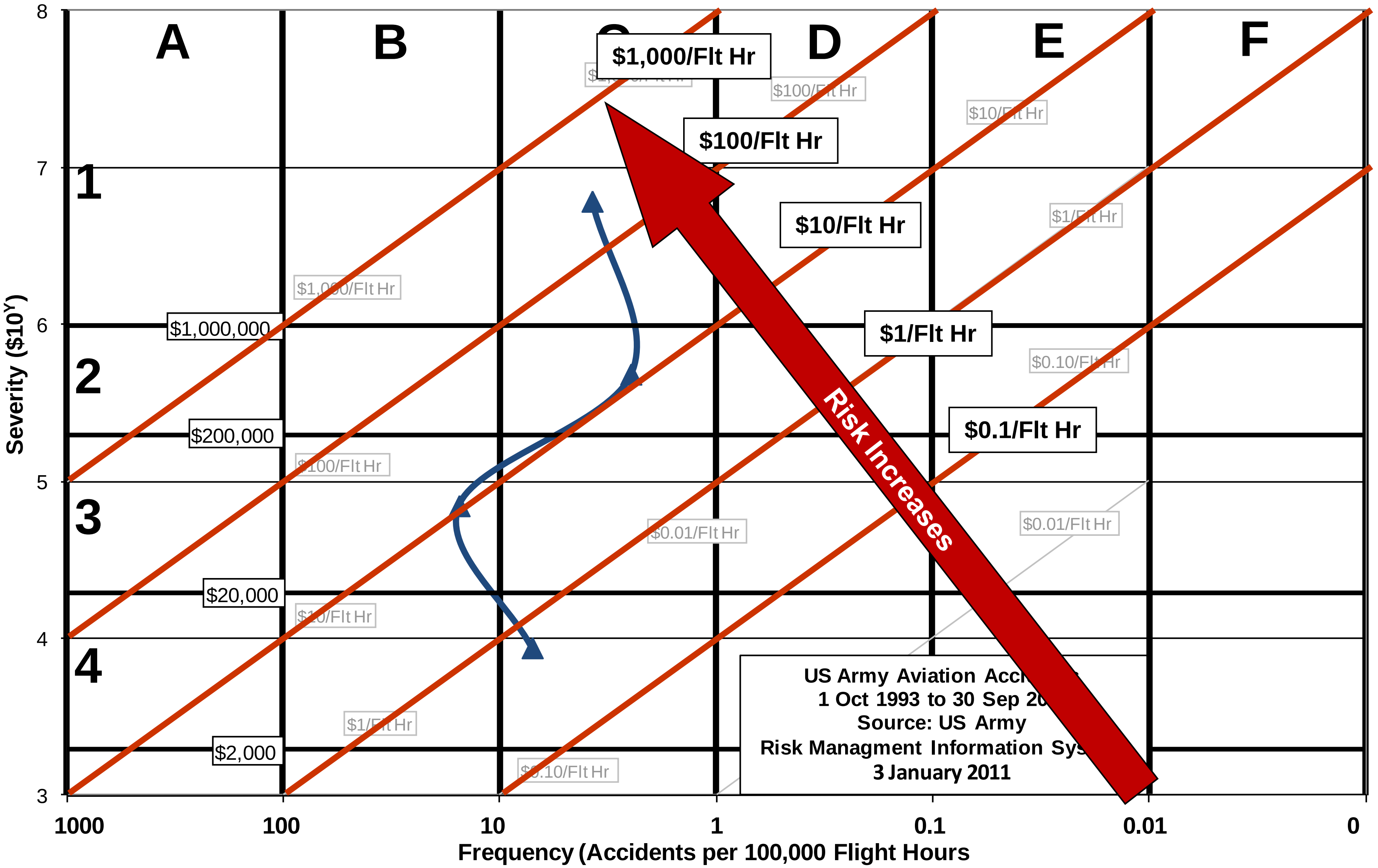
The numbers plot on a chart like this.

Class	No	Total Cost	Cost/Mishap	Mishaps per 100,000 Flt Hrs
A	59	$361,671,038	$6,130,018	3.714
B	39	$18,854,121	$483,439	2.455
C	245	$17,114,206	$69,854	15.422
D	112	$970,148	$8,662	7.050
Total	455	$398,609,513		

Total effect (sum) of all hazards to date

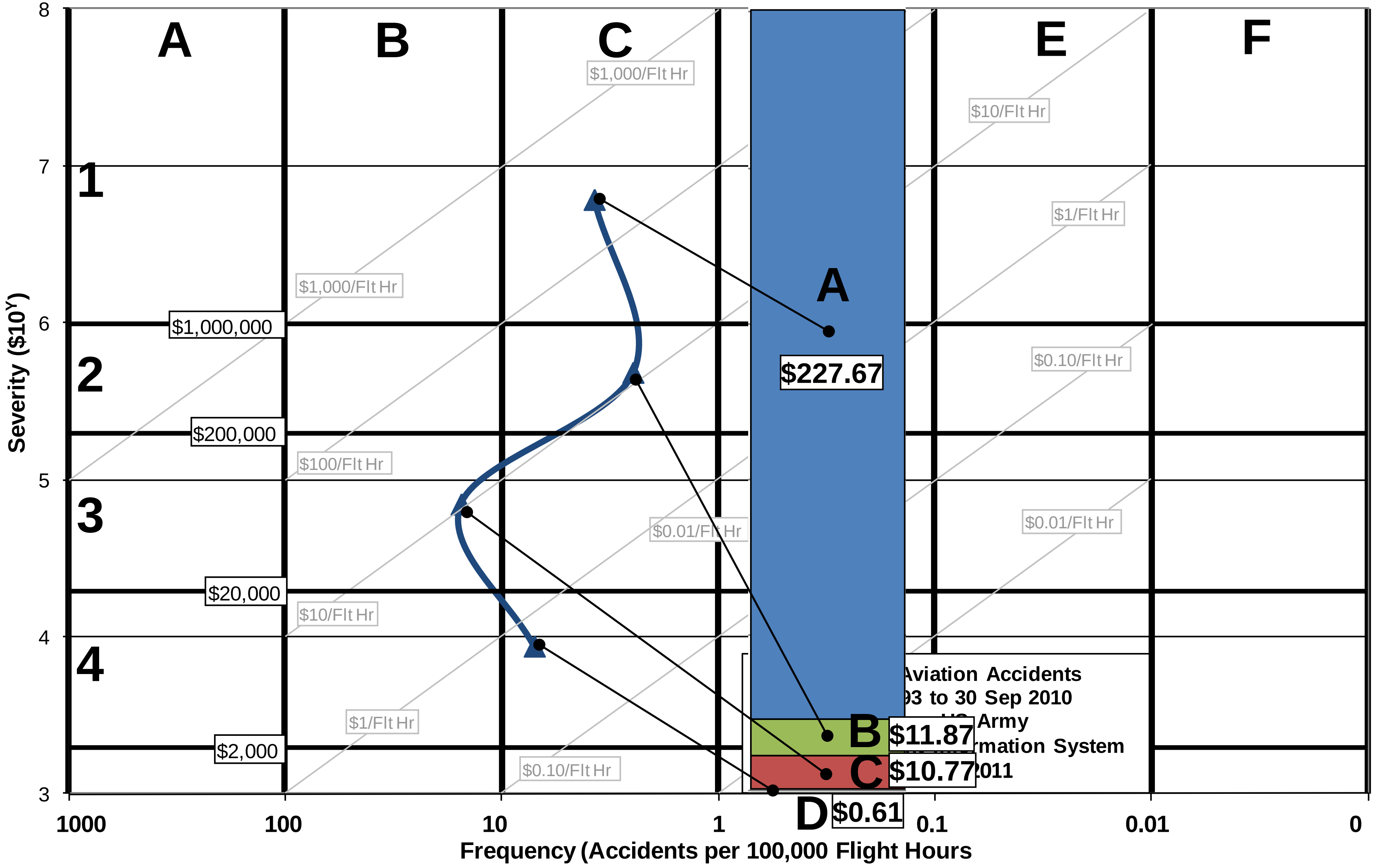
US Army Aviation Accidents
1 Oct 1993 to 30 Sep 2010
Source: US Army
Risk Managment Information System
3 January 2011

Mishaps

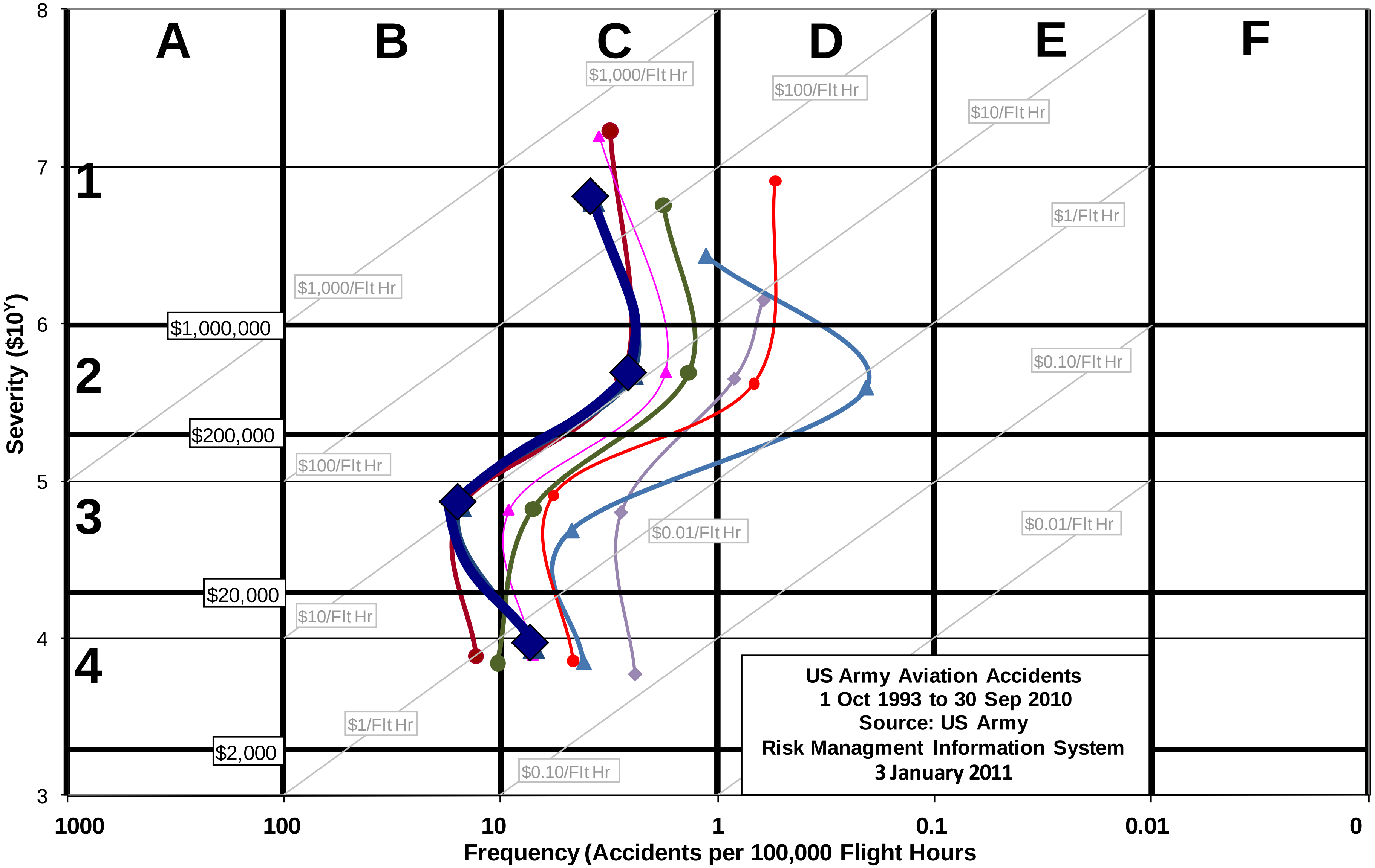


US Army Aviation Acci
1 Oct 1993 to 30 Sep 20
Source: US Army
Risk Managment Information Sys
3 January 2011

Mishaps

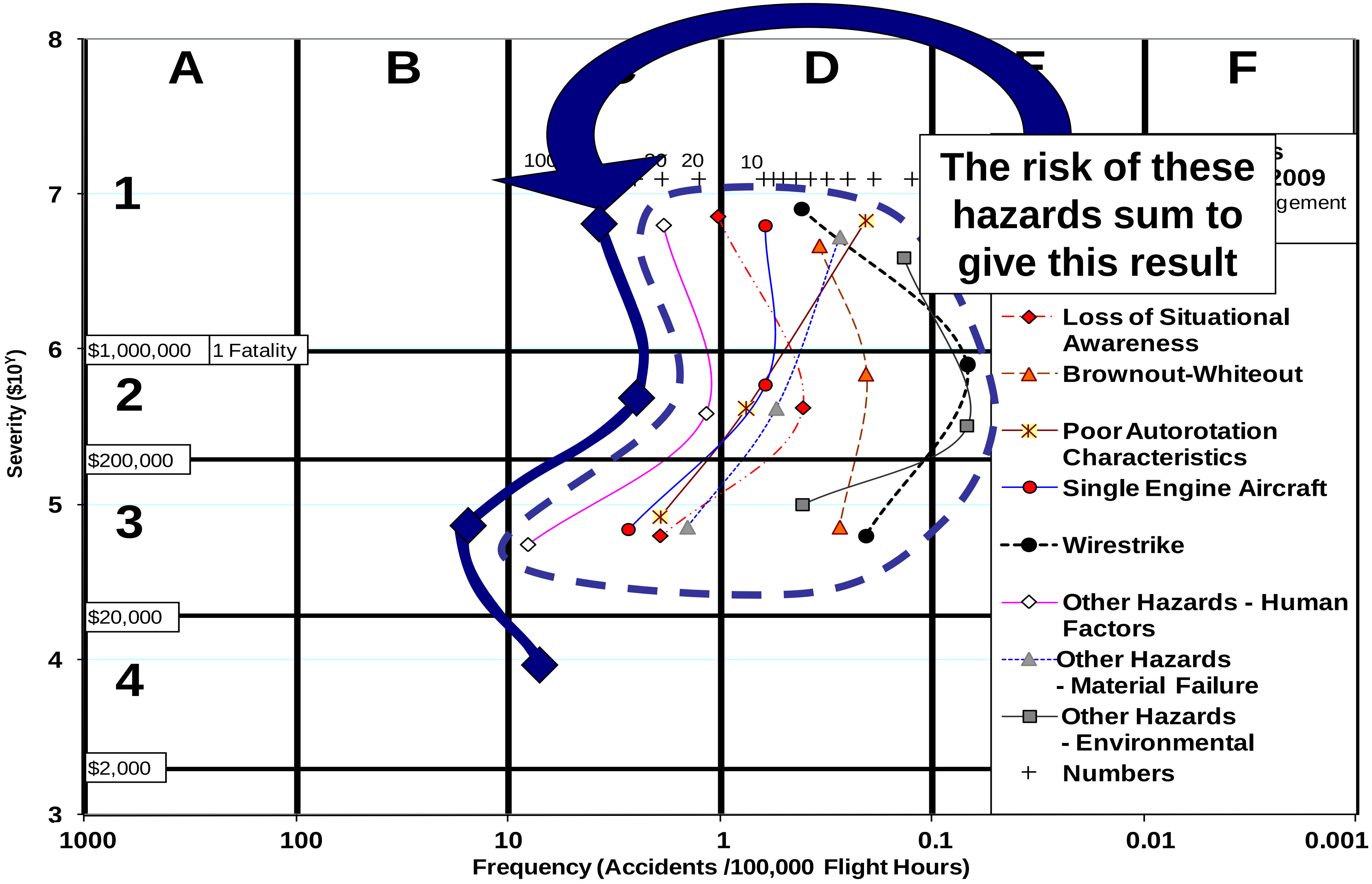

A
B
C
E
F
1
2
3
4
8
7
6
5
4
3
Severity ($10ʸ)
$1,000,000
$200,000
$20,000
$2,000
$1,000/Flt Hr
$1,000/Flt Hr
$100/Flt Hr
$10/Flt Hr
$1/Flt Hr
$0.10/Flt Hr
$0.01/Flt Hr
$10/Flt Hr
$1/Flt Hr
$0.10/Flt Hr
$0.01/Flt Hr
A
$227.67
B
$11.87
C
$10.77
D
$0.61
Aviation Accidents
93 to 30 Sep 2010
U.S. Army
rmation System
2011
1000
100
10
1
0.1
0.01
0
Frequency (Accidents per 100,000 Flight Hours

US Army Aviation Mishaps



US Army Aviation Accidents
1 Oct 1993 to 30 Sep 2010
Source: US Army
Risk Managment Information System
3 January 2011

US Army Aviation Mishaps

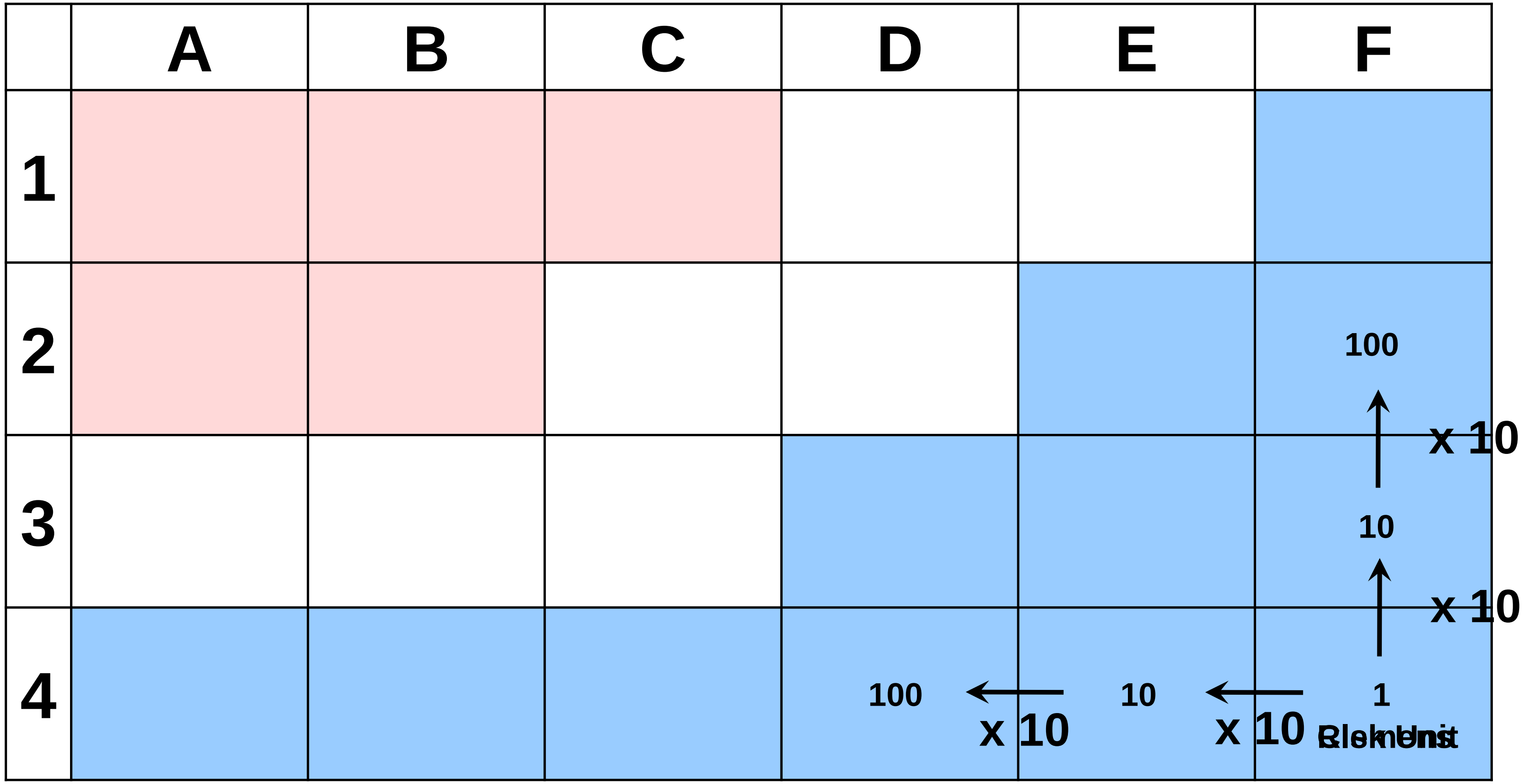


The risk of these hazards sum to give this result

Topics for this Tutorial

- Purpose of a Hazard Risk Matrix
- Understanding the Attributes of a well-designed risk assessment matrix
- How to Assign a Risk Assessment Code
- Understanding Probability
- Building an Expanded Matrix
- Plotting Accidents on a Matrix
- **Using Relative Risk Values**
- Building Hazard Risk Profiles

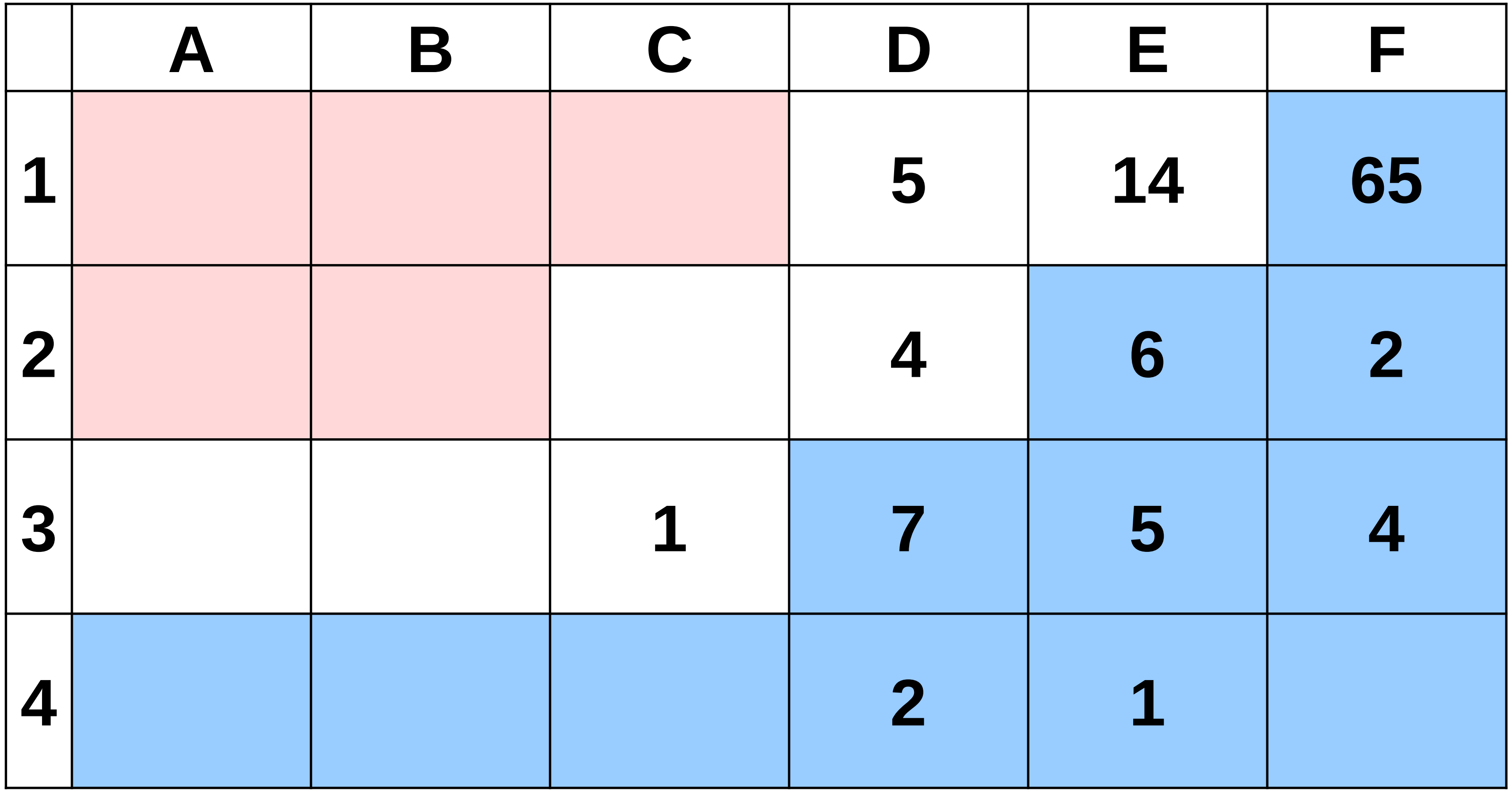
Matrix Relative Risk Values
(Risk Units)(Clemens)



Matrix Relative Risk Values
(Clemens)

	A	B	C	D	E	F
1	100,000,000	10,000,000	1,000,000	100,000	10,000	1,000
2	10,000,000	1,000,000	100,000	10,000	1,000	100
3	1,000,000	100,000	10,000	1,000	100	10
4	100,000	10,000	1,000	100	10	1

Helo A Hazard Distribution



	A	B	C	D	E	F
1				5	14	65
2				4	6	2
3			1	7	5	4
4				2	1	

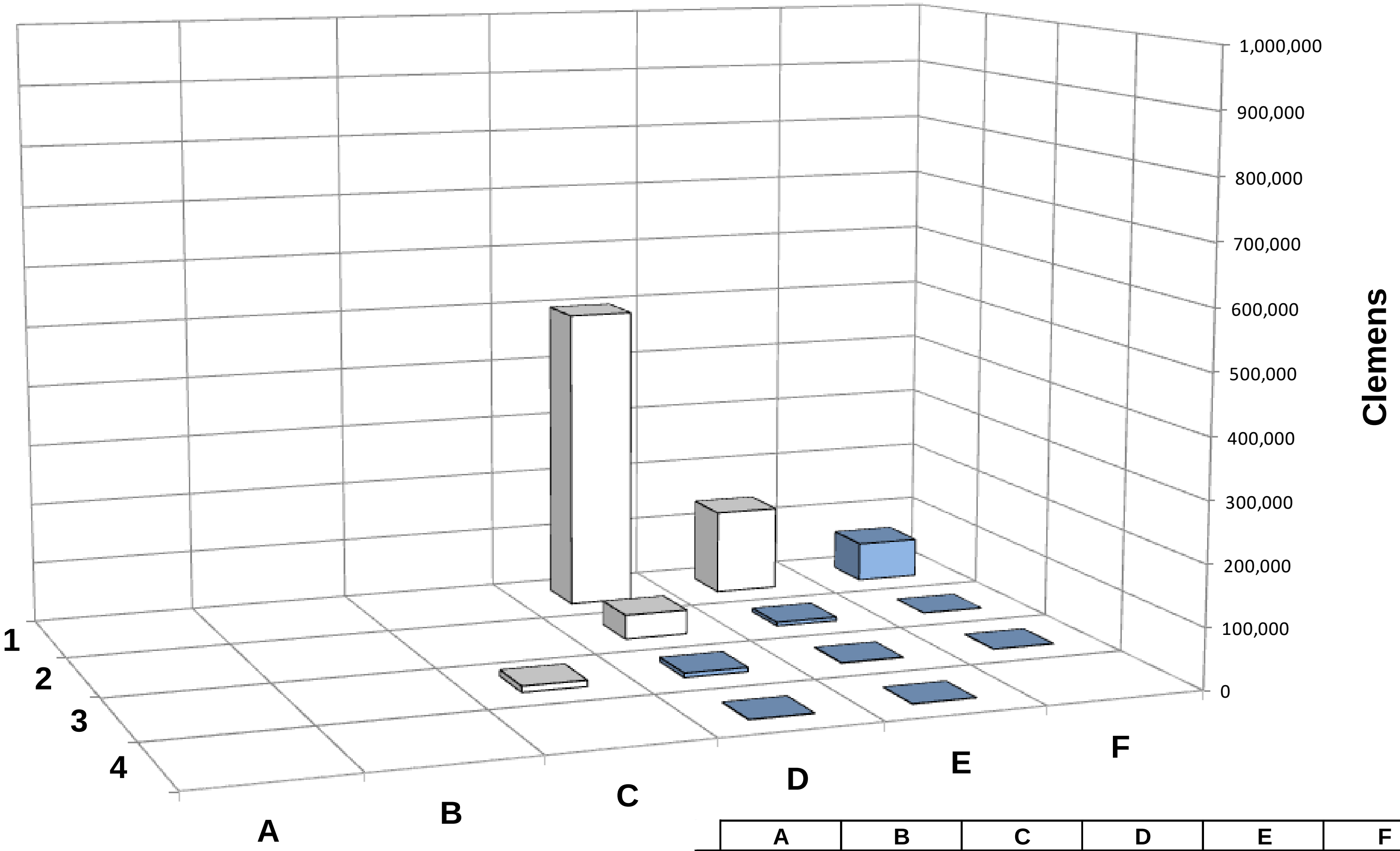
Helo A Matrix
Relative Values (Clemens)

	A	B	C	D	E	F
1				5 x 100,000 = 500,000	14 x 10,000 = 140,000	65 x 1,000 = 65,000
2				4 x 10,000 = 40,000	6 x 1,000 = 6,000	2 x 100 = 200
3			1 x 10,000 = 10,000	7 x 1,000 = 7,000	5 x 100 = 500	4 x 10 = 40
4				2 x 100 = 200	1 x 10 = 10	

Helo A Matrix
Relative Values (Clemens)

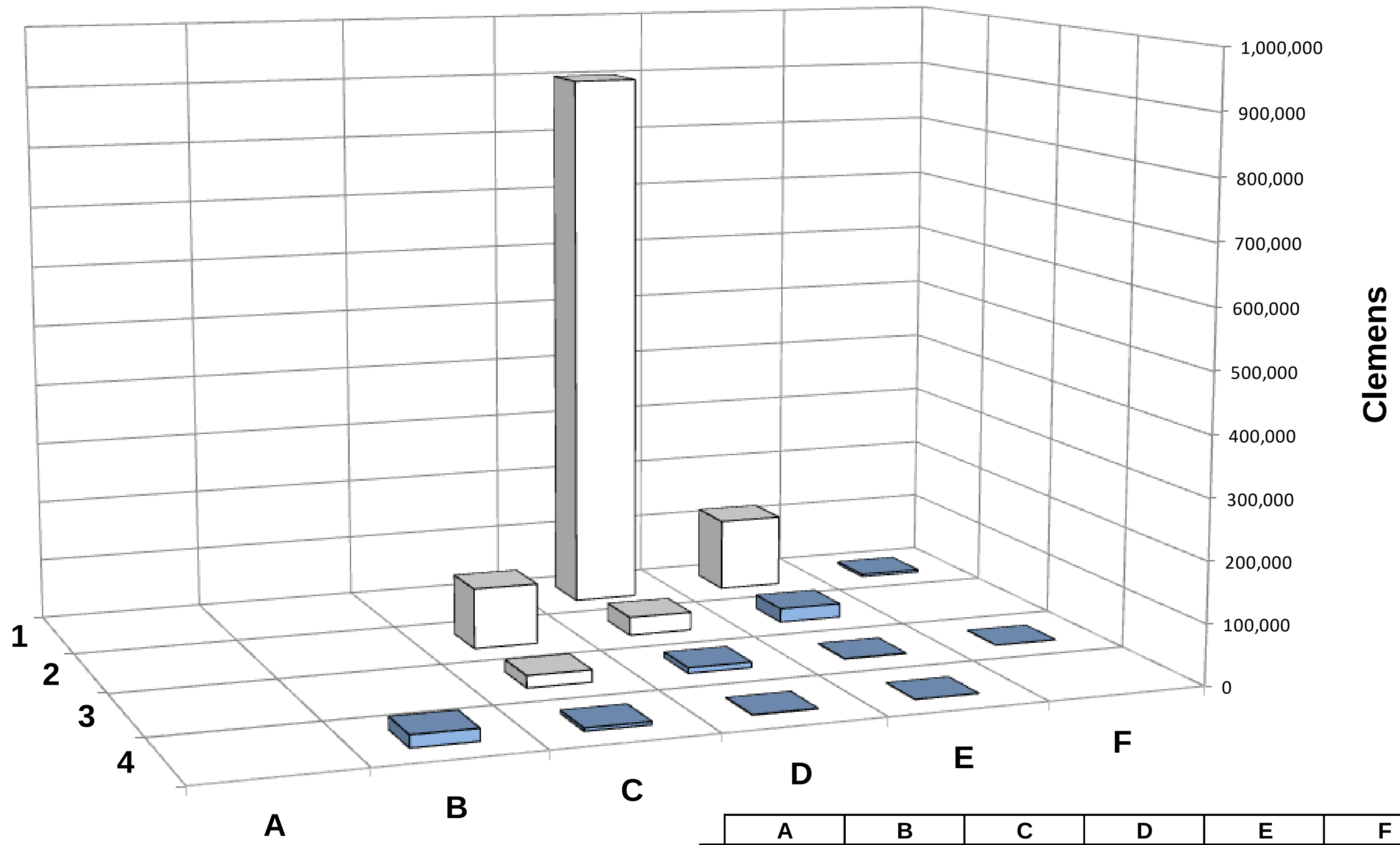
	A	B	C	D	E	F
1				500,000	140,000	65,000
2				40,000	6,000	200
3			10,000	7,000	500	40
4				200	10	

Helicopter A



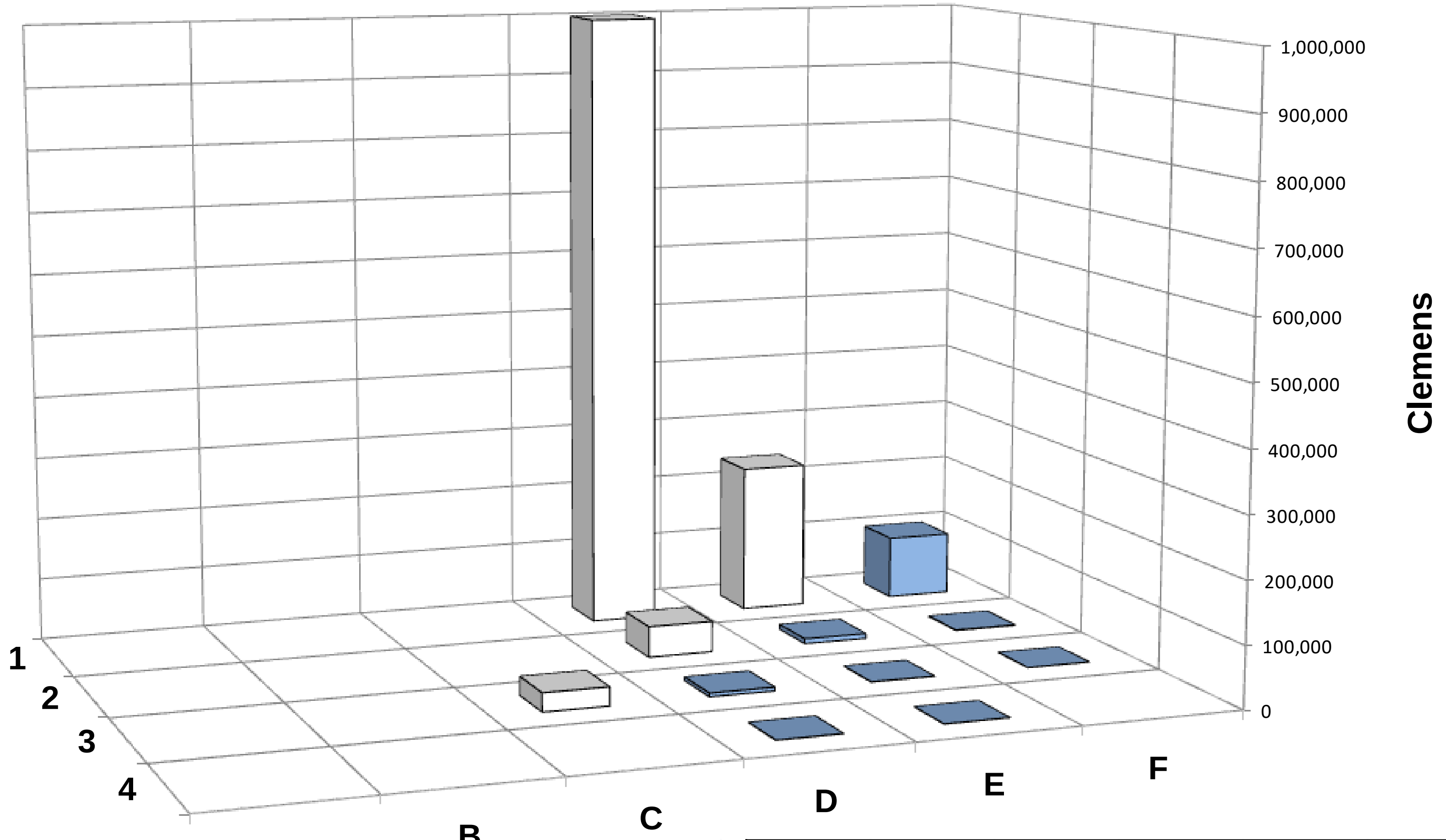
	A	B	C	D	E	F
1	🟥	🟥	🟥	5	14	65
2	🟥	🟥		4	6	2
3			1	7	5	4
4				2	1	

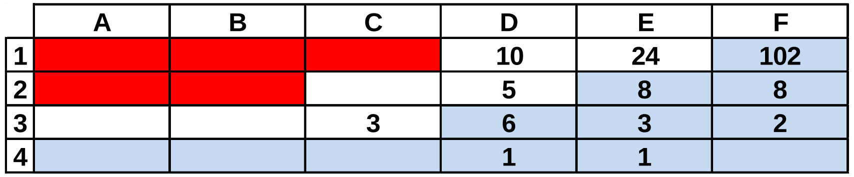
Helicopter B



	A	B	C	D	E	F
1	🟥	🟥	🟥	9	12	4
2	🟥	🟥	1	3	23	
3			2	9	6	1
4		2	5	5	2	

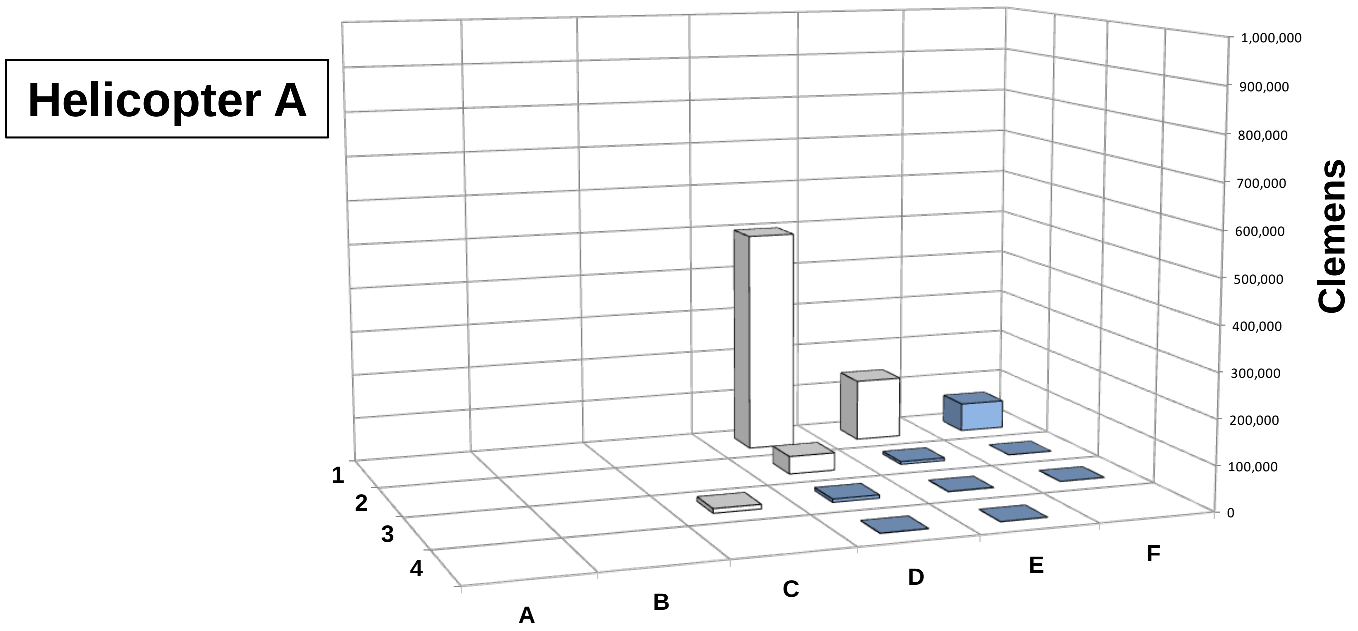
Helicopter C

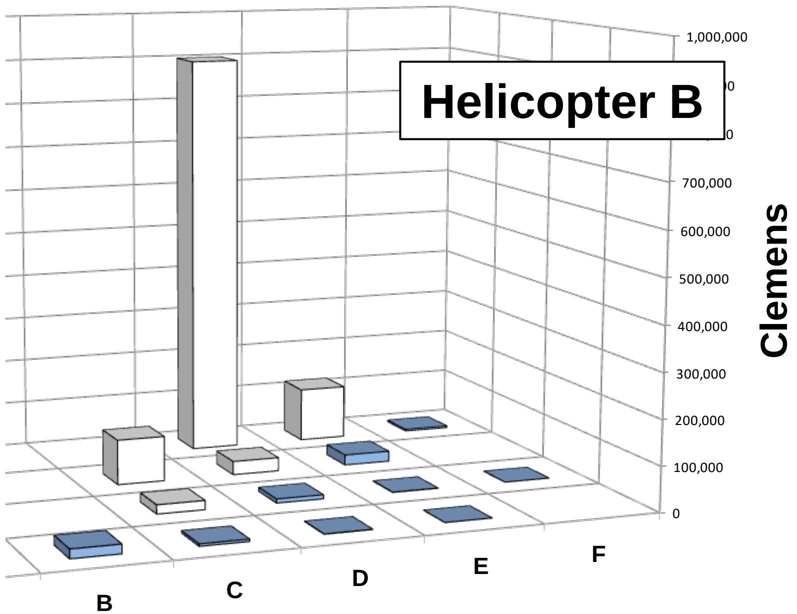


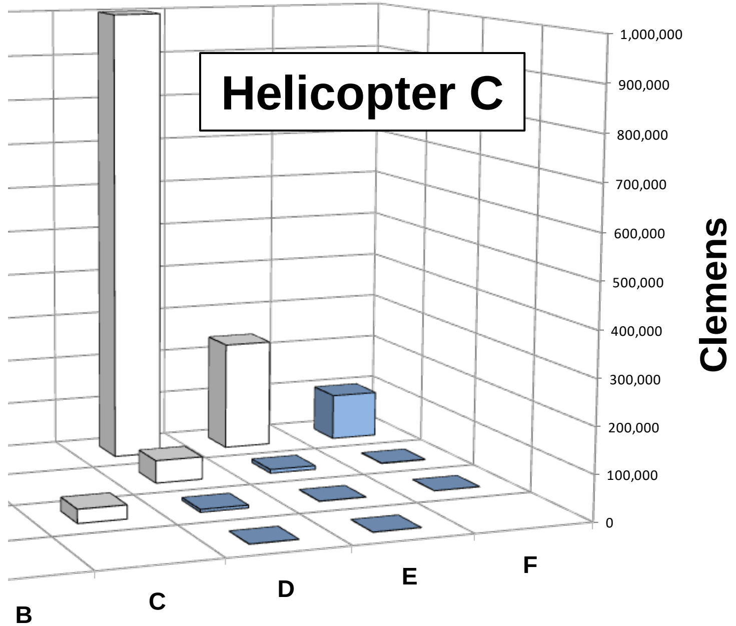


	A	B	C	D	E	F
1	🟥	🟥	🟥	10	24	102
2	🟥	🟥		5	8	8
3			3	6	3	2
4				1	1	

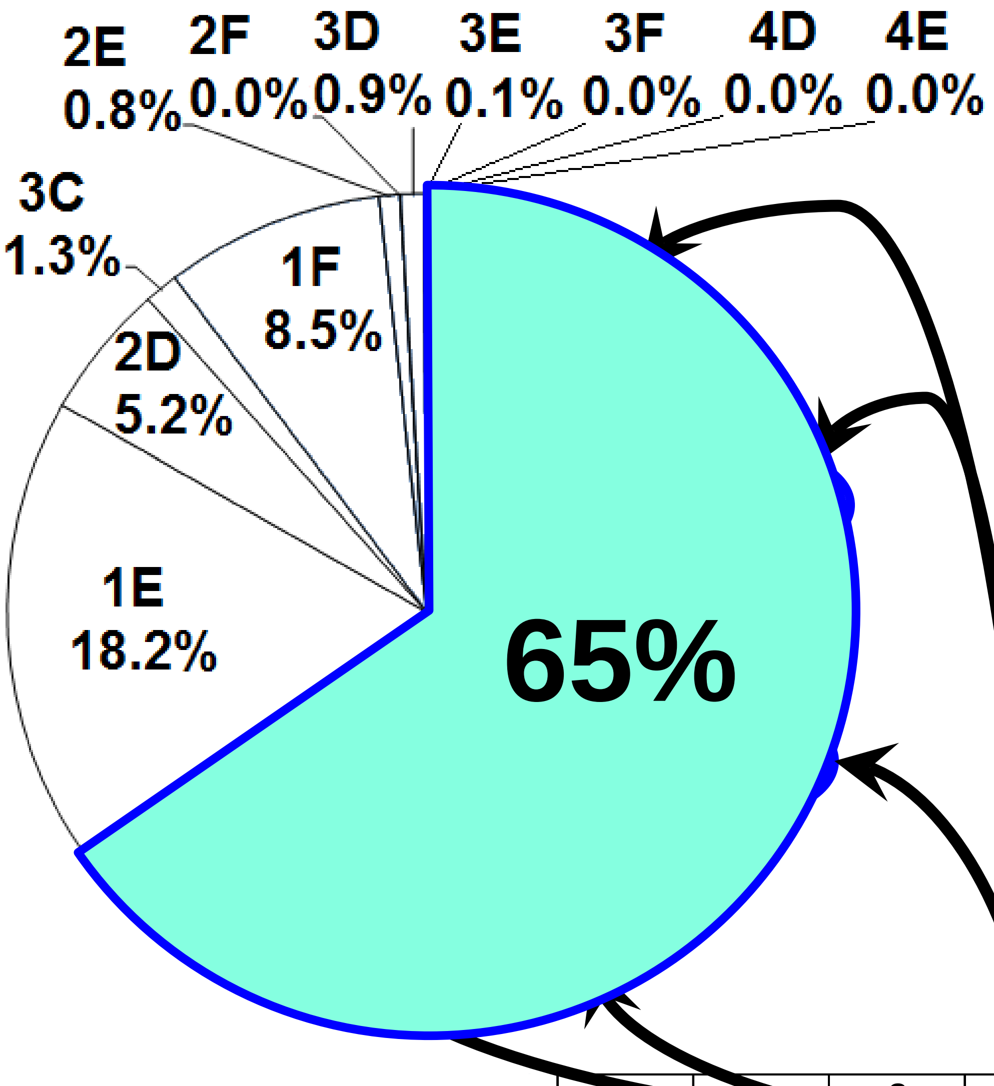
Side by Side Relative Risk by RAC





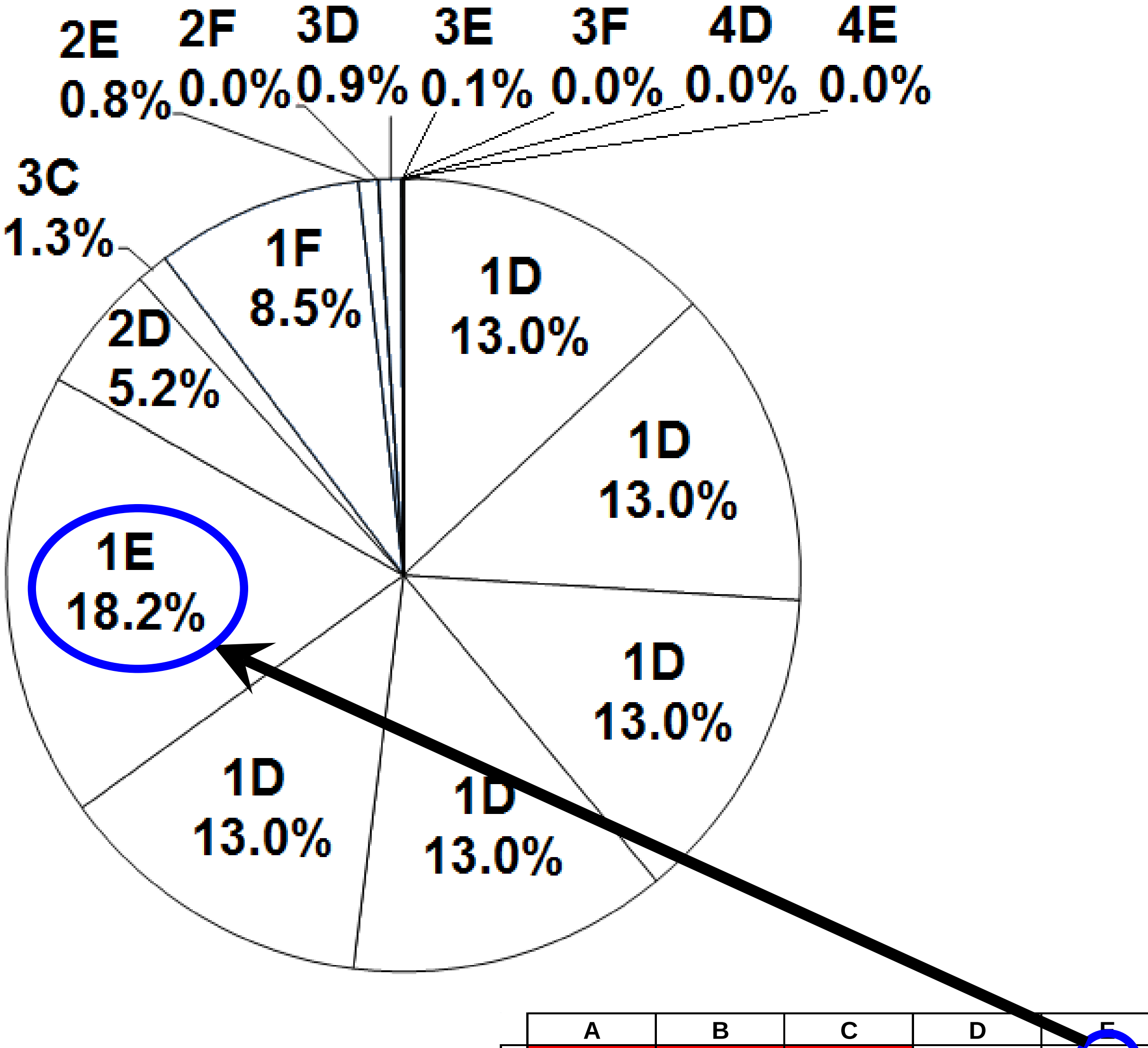


Risk Pie Chart by RAC



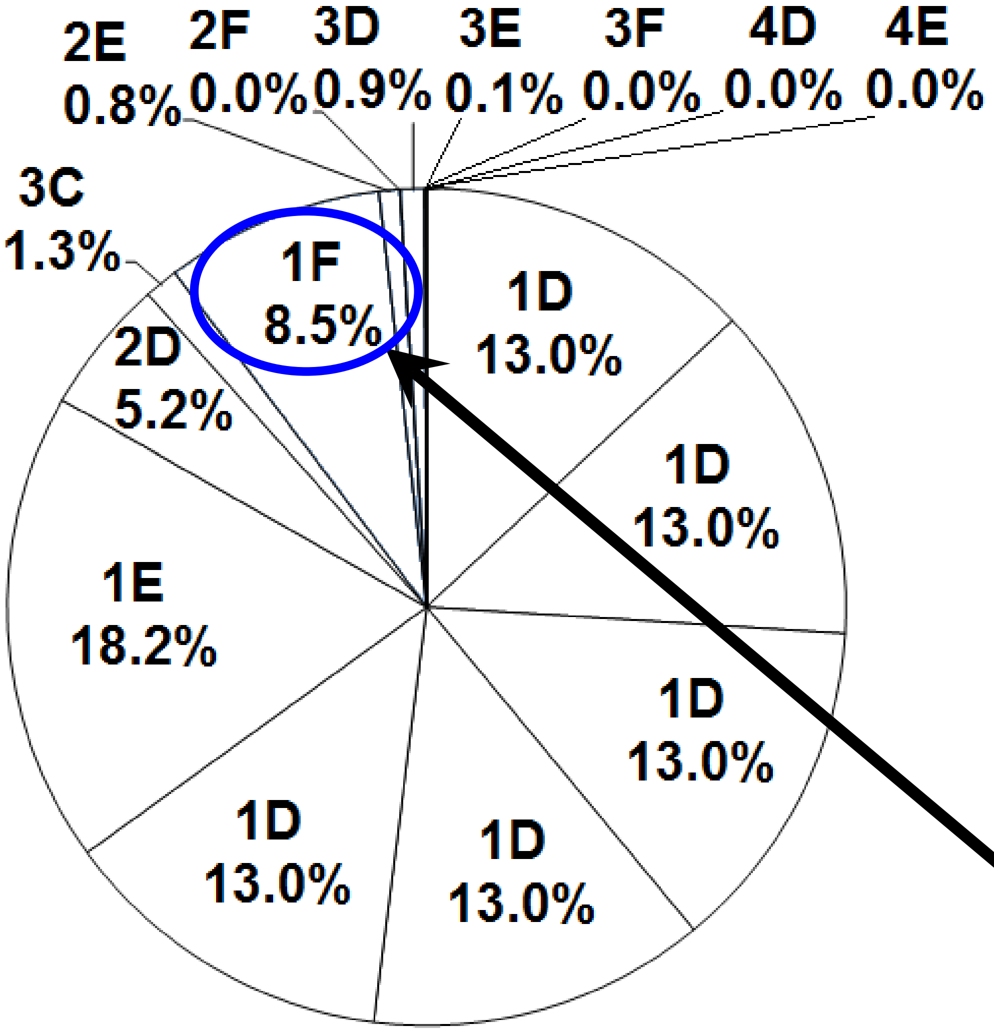
	A	B	C	D	E	F
1				5	14	65
2				4	6	2
3			1	7	5	4
4				2	1	

Risk Pie Chart by RAC



	A	B	C	D	E	F
1	🟥	🟥	🟥	5	14	65
2	🟥	🟥		4	6	2
3			1	7	5	4
4				2	1	

Risk Pie Chart by RAC

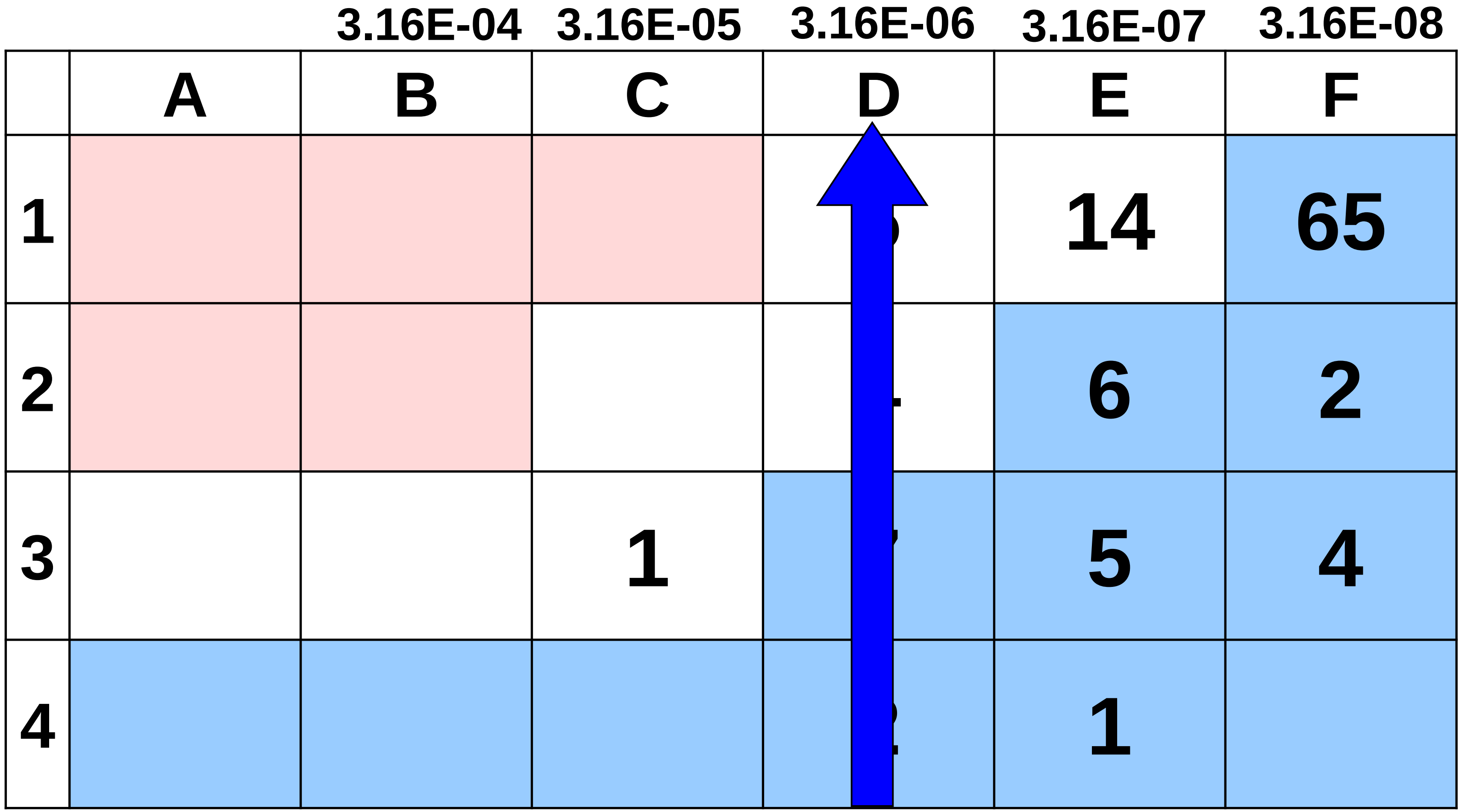


	A	B	C	D	E	F
1	🟥	🟥	🟥	5	14	65
2	🟥	🟥		4	6	2
3			1	7	5	4
4				2	1	

Topics for this Tutorial

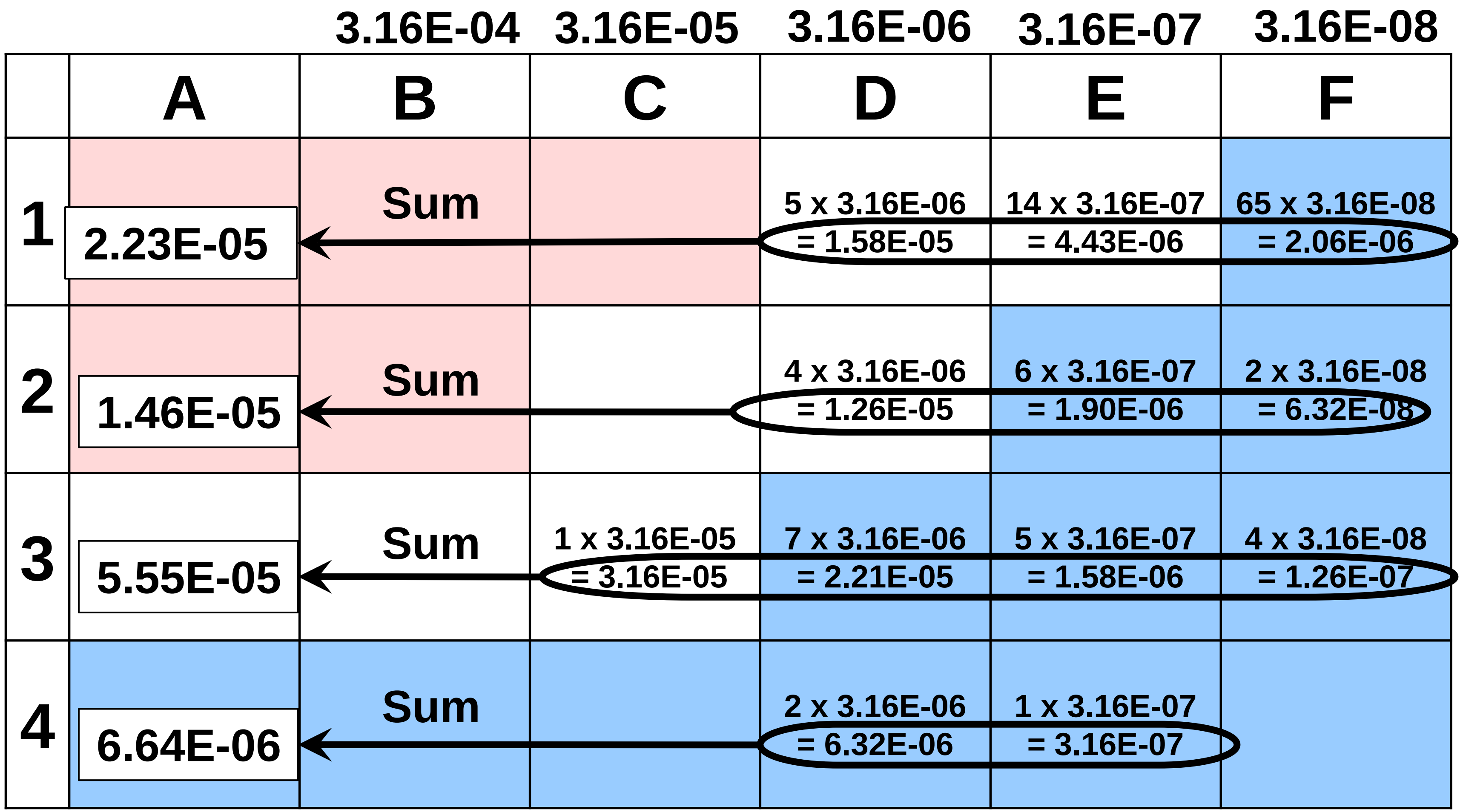
- Purpose of a Hazard Risk Matrix
- Understanding the Attributes of a well-designed risk assessment matrix
- How to Assign a Risk Assessment Code
- Understanding Probability
- Building an Expanded Matrix
- Plotting Accidents on a Matrix
- Using Relative Risk Values
- **Building Hazard Risk Profiles**

Hazard Risk Profile



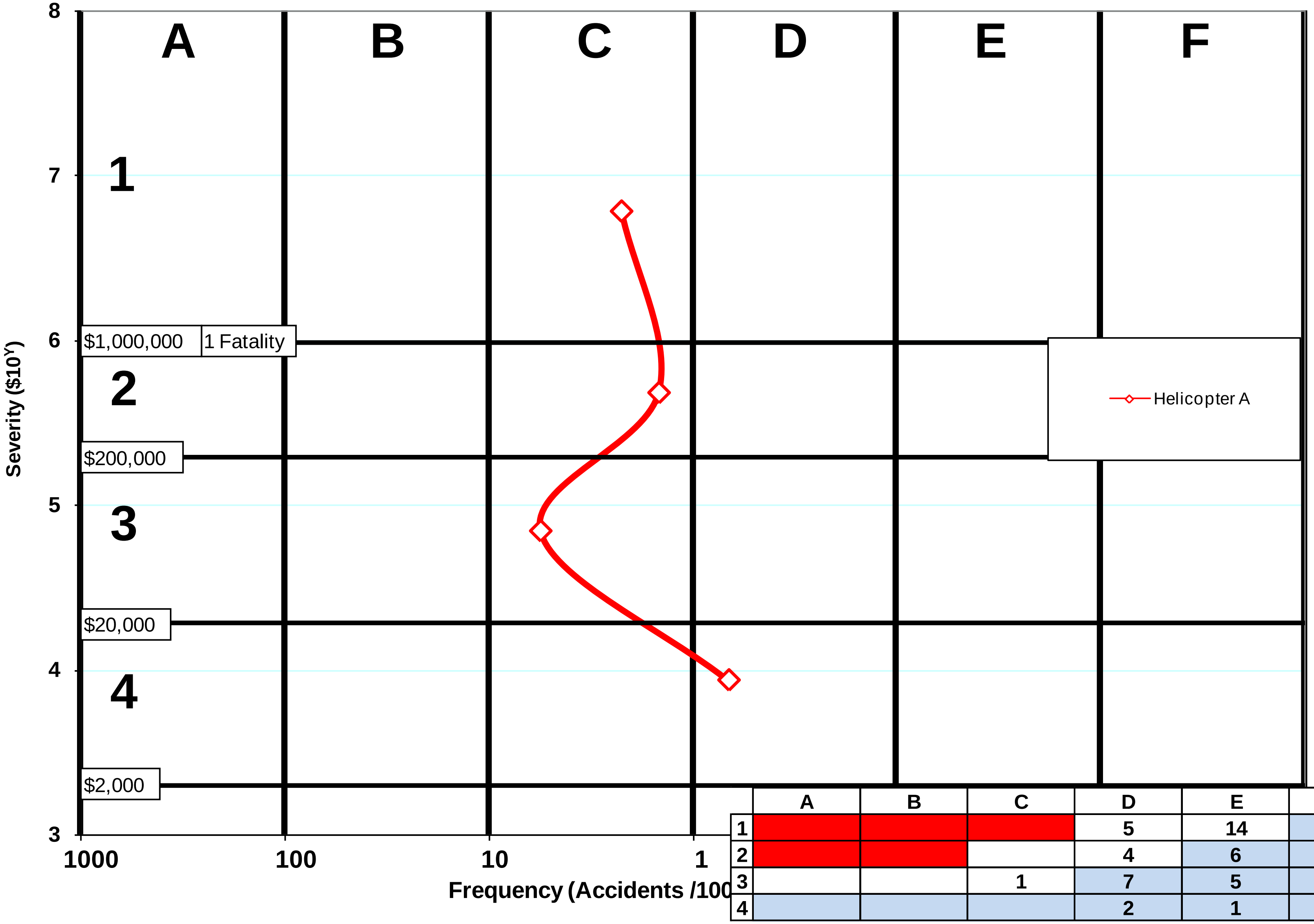
		3.16E-04	3.16E-05	3.16E-06	3.16E-07	3.16E-08
	A	B	C	D	E	F
1				[illegible]	14	65
2				1	6	2
3			1	7	5	4
4				2	1	

Hazard Risk Profile



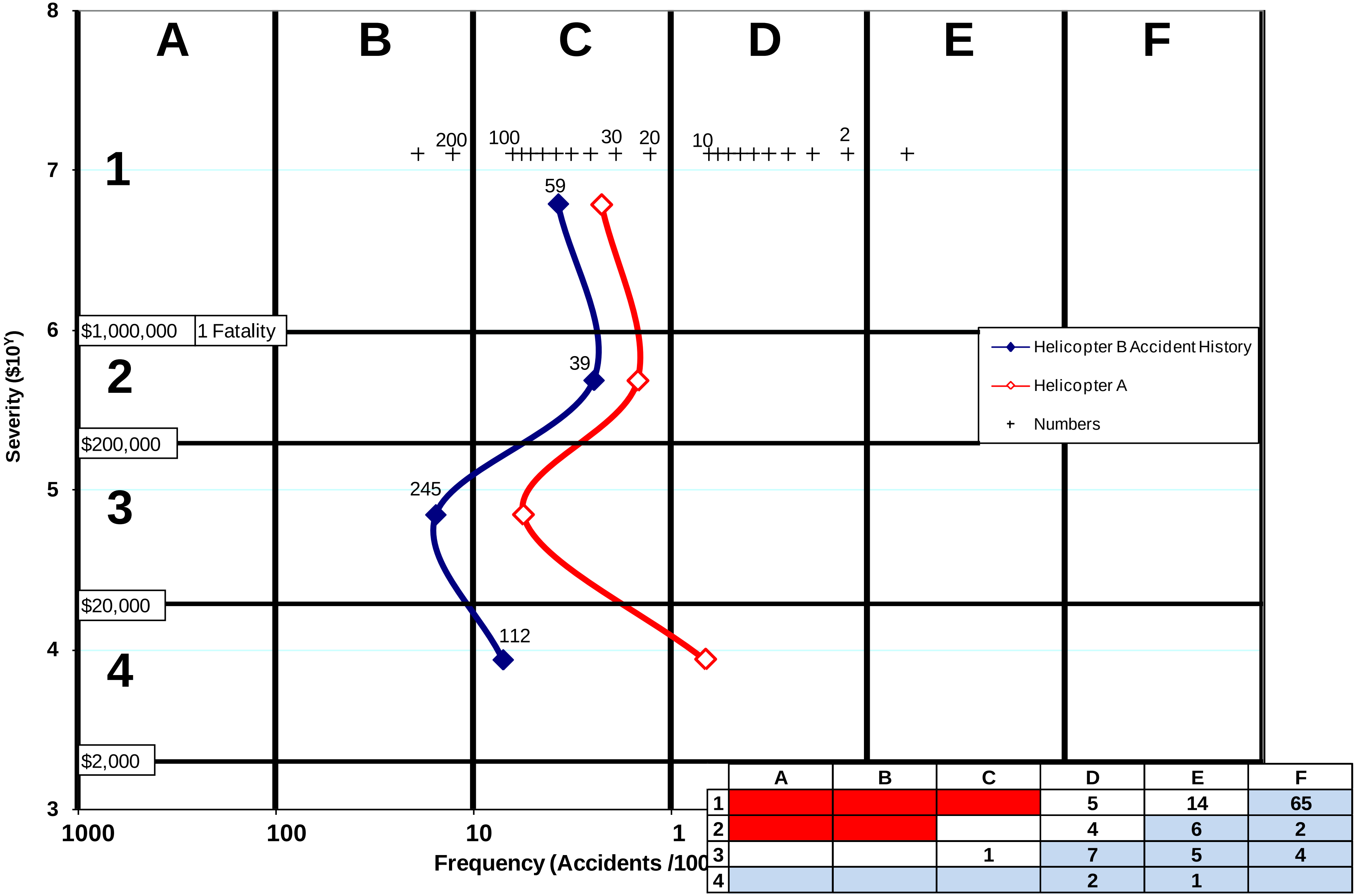
		3.16E-04	3.16E-05	3.16E-06	3.16E-07	3.16E-08
	A	**B**	**C**	**D**	**E**	**F**
1	2.23E-05	Sum		5 x 3.16E-06 = 1.58E-05	14 x 3.16E-07 = 4.43E-06	65 x 3.16E-08 = 2.06E-06
2	1.46E-05	Sum		4 x 3.16E-06 = 1.26E-05	6 x 3.16E-07 = 1.90E-06	2 x 3.16E-08 = 6.32E-08
3	5.55E-05	Sum	1 x 3.16E-05 = 3.16E-05	7 x 3.16E-06 = 2.21E-05	5 x 3.16E-07 = 1.58E-06	4 x 3.16E-08 = 1.26E-07
4	6.64E-06	Sum		2 x 3.16E-06 = 6.32E-06	1 x 3.16E-07 = 3.16E-07	

Hazard Risk Profile



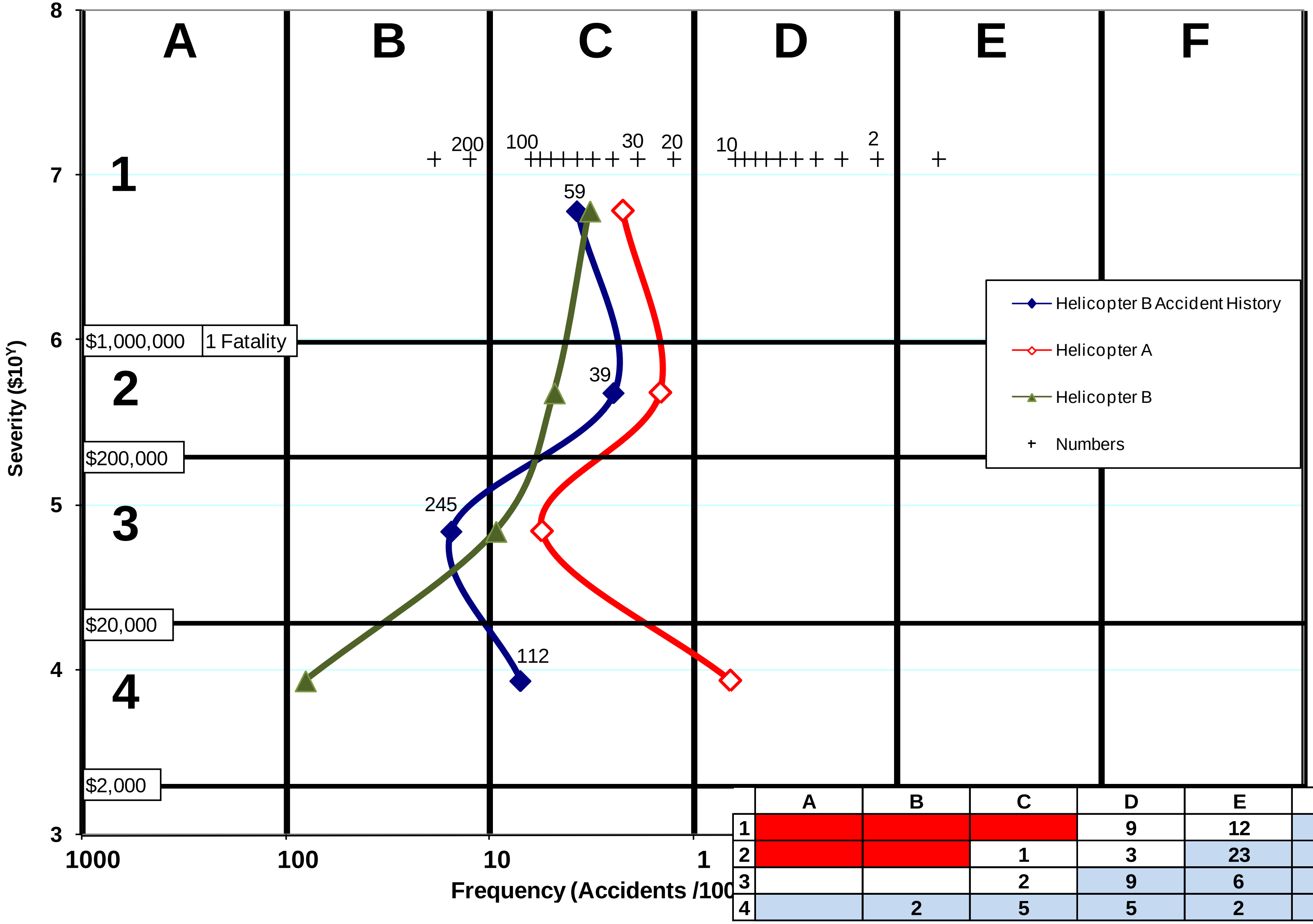
	A	B	C	D	E	F
1	🟥	🟥	🟥	5	14	65
2	🟥	🟥		4	6	2
3			1	7	5	4
4	🟦	🟦	🟦	2	1	🟦

Comparing Hazard Profile to Accident History



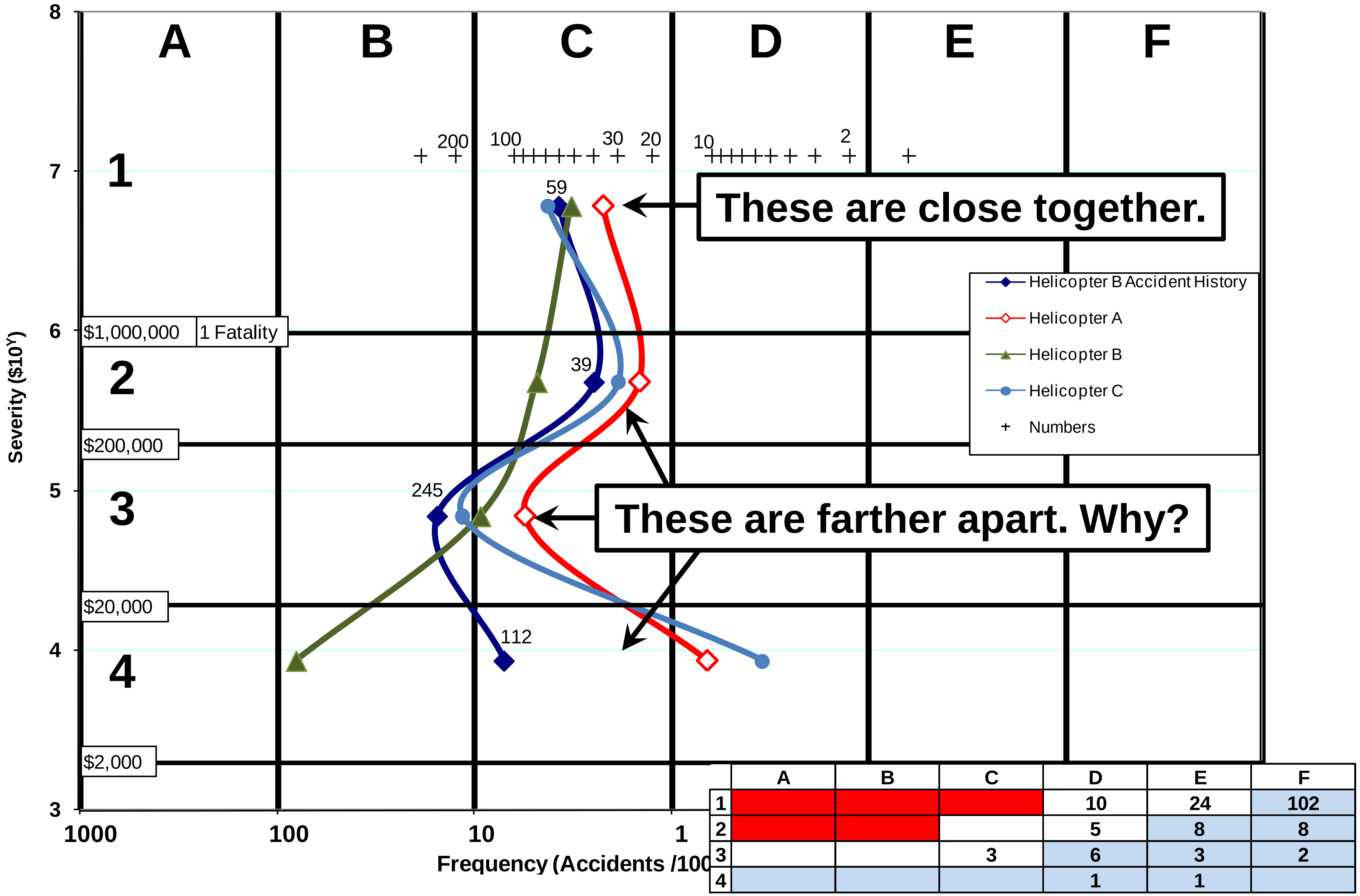
	A	B	C	D	E	F
1	🟥	🟥	🟥	5	14	65
2	🟥	🟥		4	6	2
3			1	7	5	4
4	🟦	🟦	🟦	2	1	🟦

Comparing Hazard Profile to Accident History



	A	B	C	D	E	F
1	🟥	🟥	🟥	9	12	4
2	🟥	🟥	1	3	23	
3			2	9	6	1
4		2	5	5	2	

Comparing Hazard Profile to Accident History

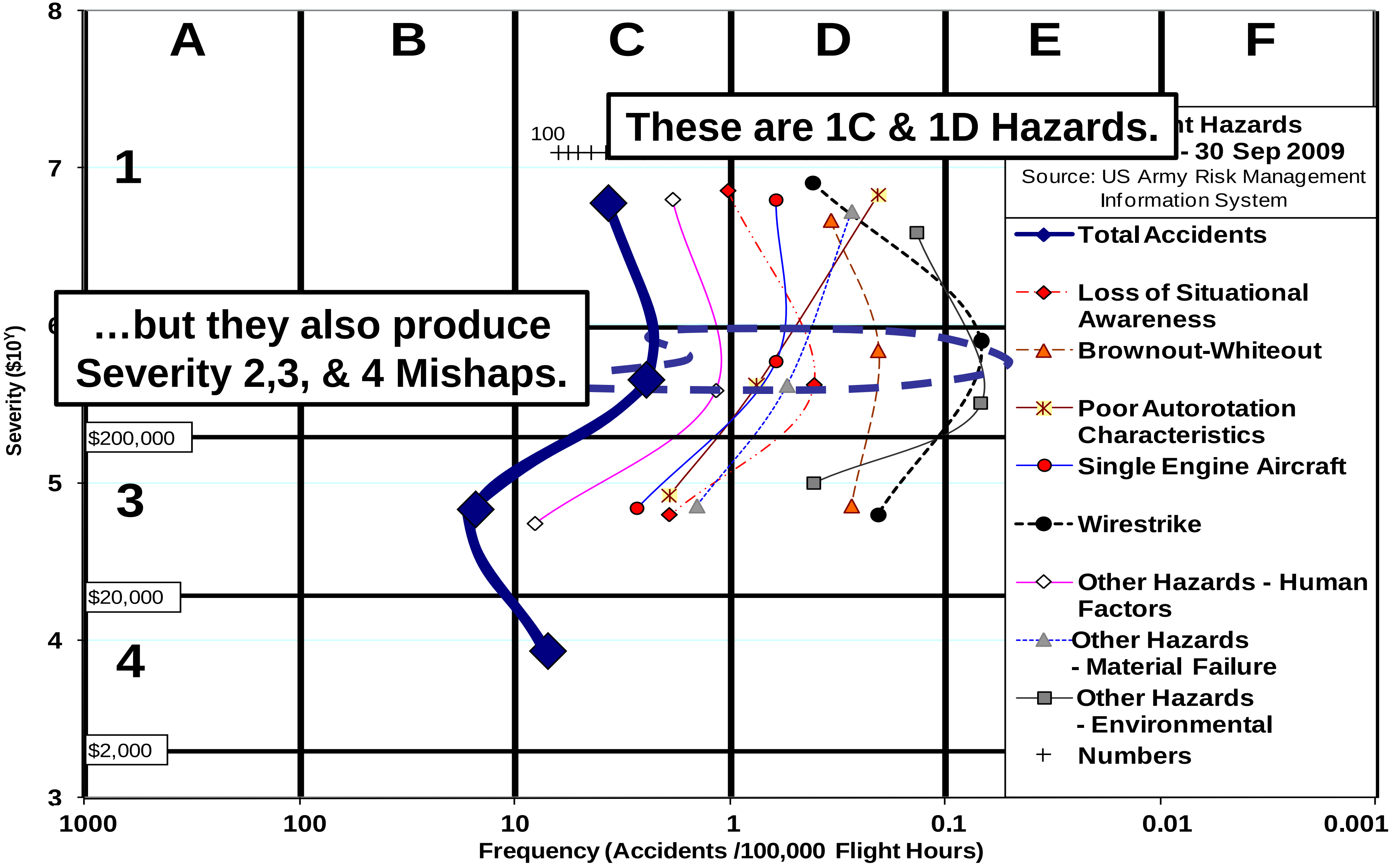


These are close together.

These are farther apart. Why?

	A	B	C	D	E	F
1	🟥	🟥	🟥	10	24	102
2	🟥	🟥		5	8	8
3			3	6	3	2
4				1	1	

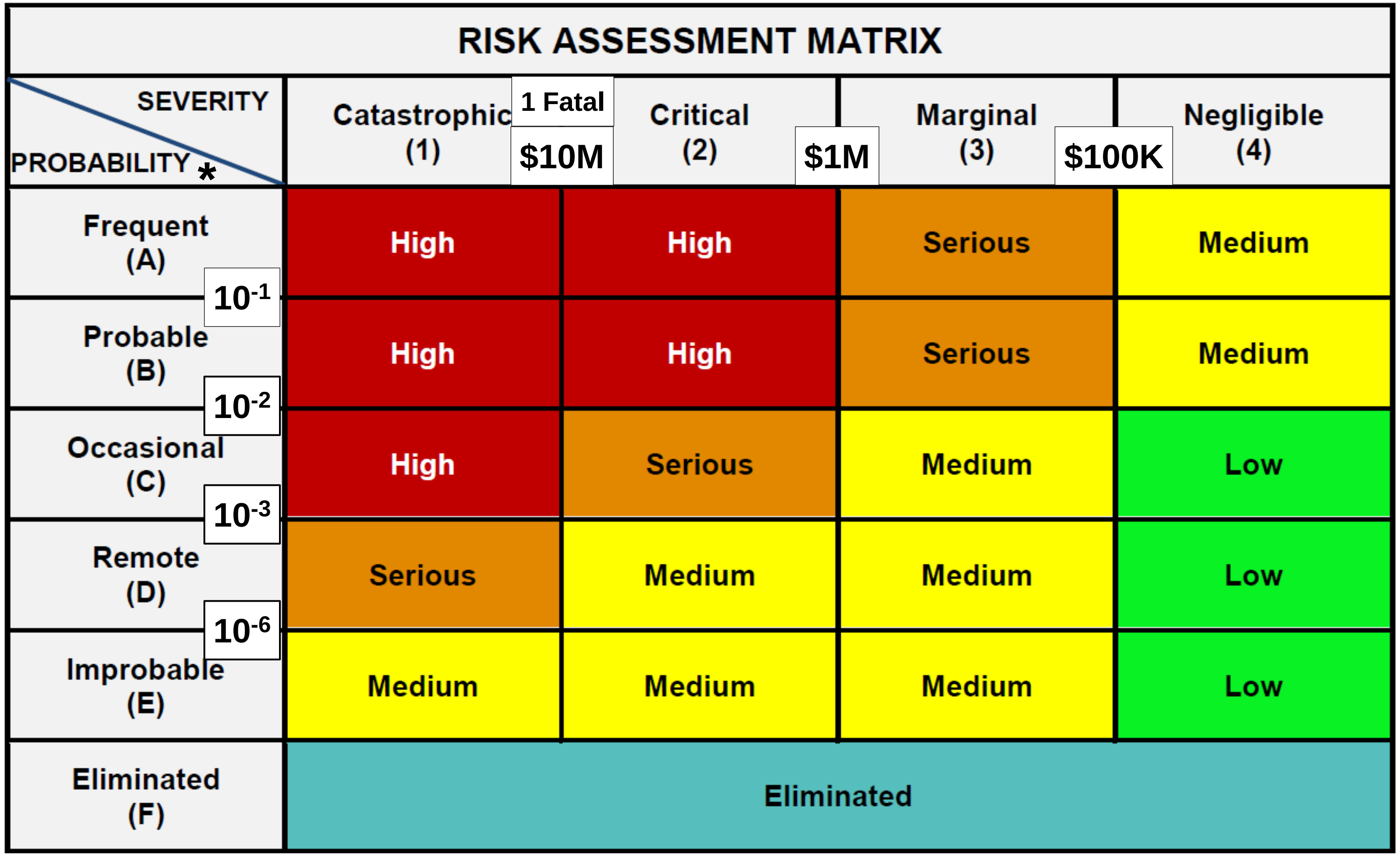
US Army Aviation Mishaps



These are 1C & 1D Hazards.

…but they also produce Severity 2,3, & 4 Mishaps.

Missile Risk Matrix



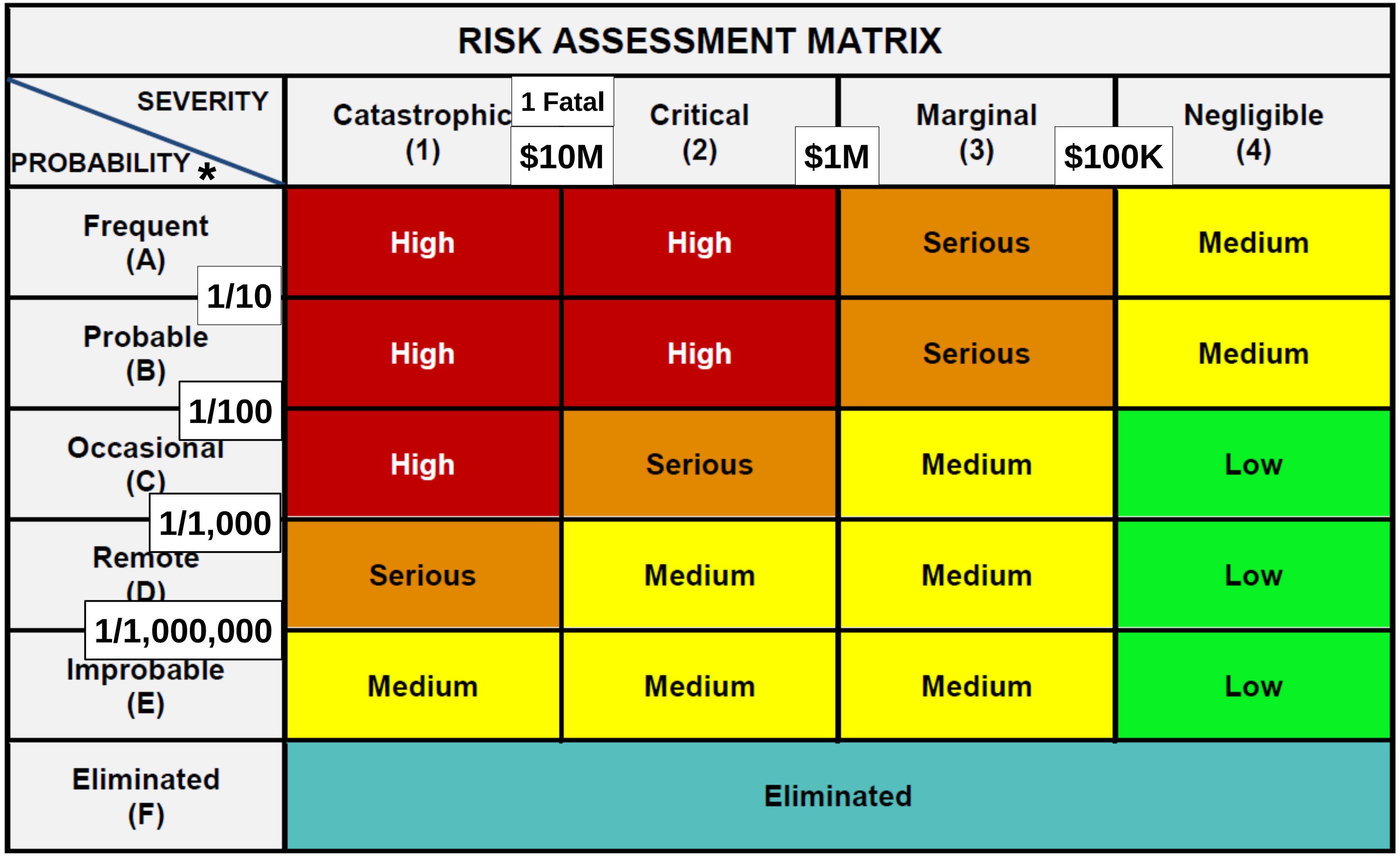
RISK ASSESSMENT MATRIX

SEVERITY / PROBABILITY *	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

1 Fatal
$10M
$1M
$100K

10^{-1}
10^{-2}
10^{-3}
10^{-6}

Missile Hazard Risk Matrix



RISK ASSESSMENT MATRIX				
SEVERITY PROBABILITY *	Catastrophic (1) 1 Fatal $10M	Critical (2) $1M	Marginal (3) $100K	Negligible (4)
Frequent (A) 1/10	High	High	Serious	Medium
Probable (B) 1/100	High	High	Serious	Medium
Occasional (C) 1/1,000	High	Serious	Medium	Low
Remote (D) 1/1,000,000	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Back of the Envelope Calculation

40,000 Shishkebab Missiles

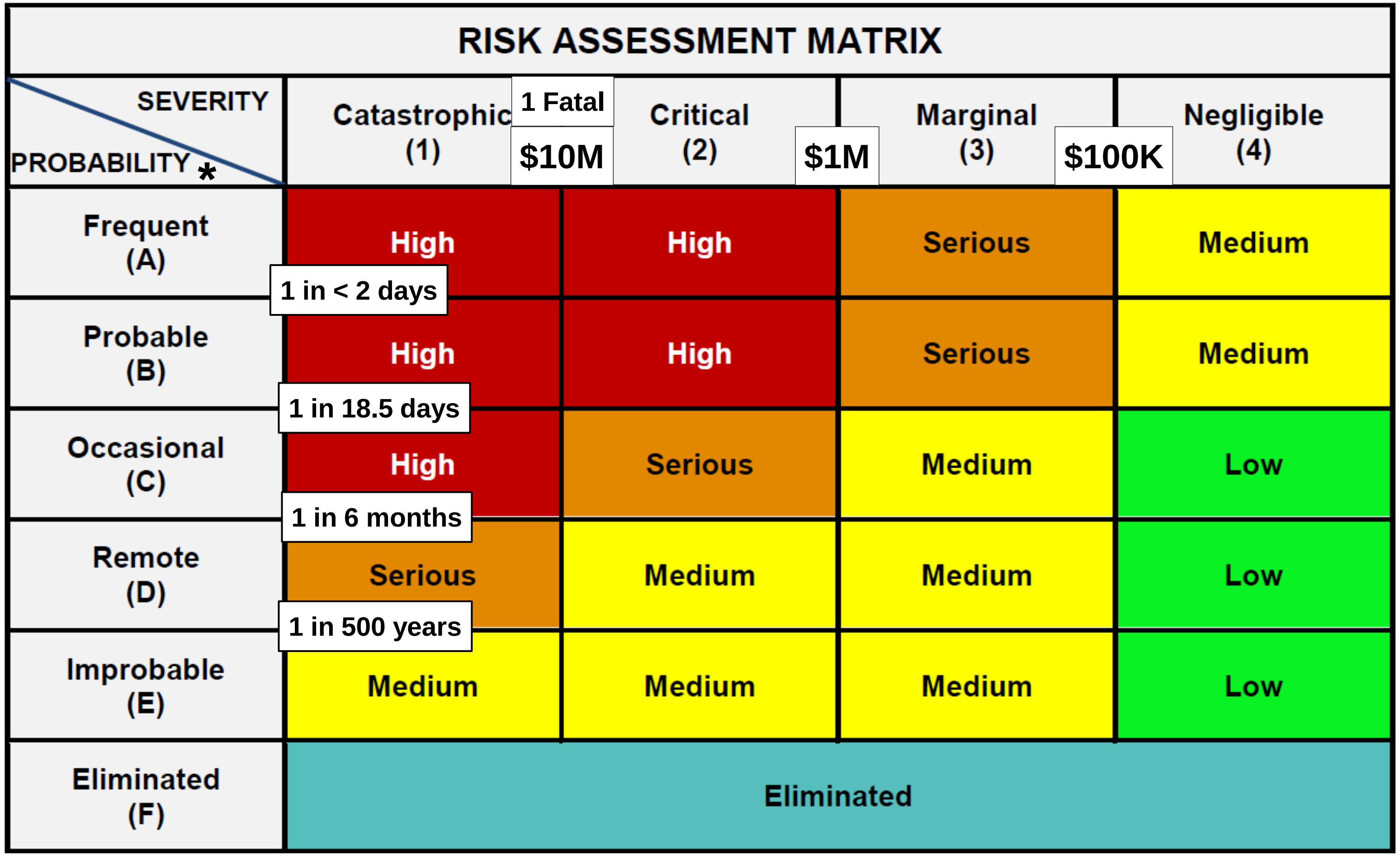
Delivered over 20 years

Assume all fired

1 accident in 1,000,000 firings

$$\frac{\textbf{1 accident}}{\textbf{1,000,000 }\cancel{\textbf{firings}}} \text{ X } \frac{\textbf{40,000 }\cancel{\textbf{firings}}}{\textbf{20 years}} = \frac{\textbf{1 accident}}{\textbf{500 years}}$$

Missile Hazard Risk Matrix



RISK ASSESSMENT MATRIX

SEVERITY PROBABILITY *	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

1 Fatal

$10M

$1M

$100K

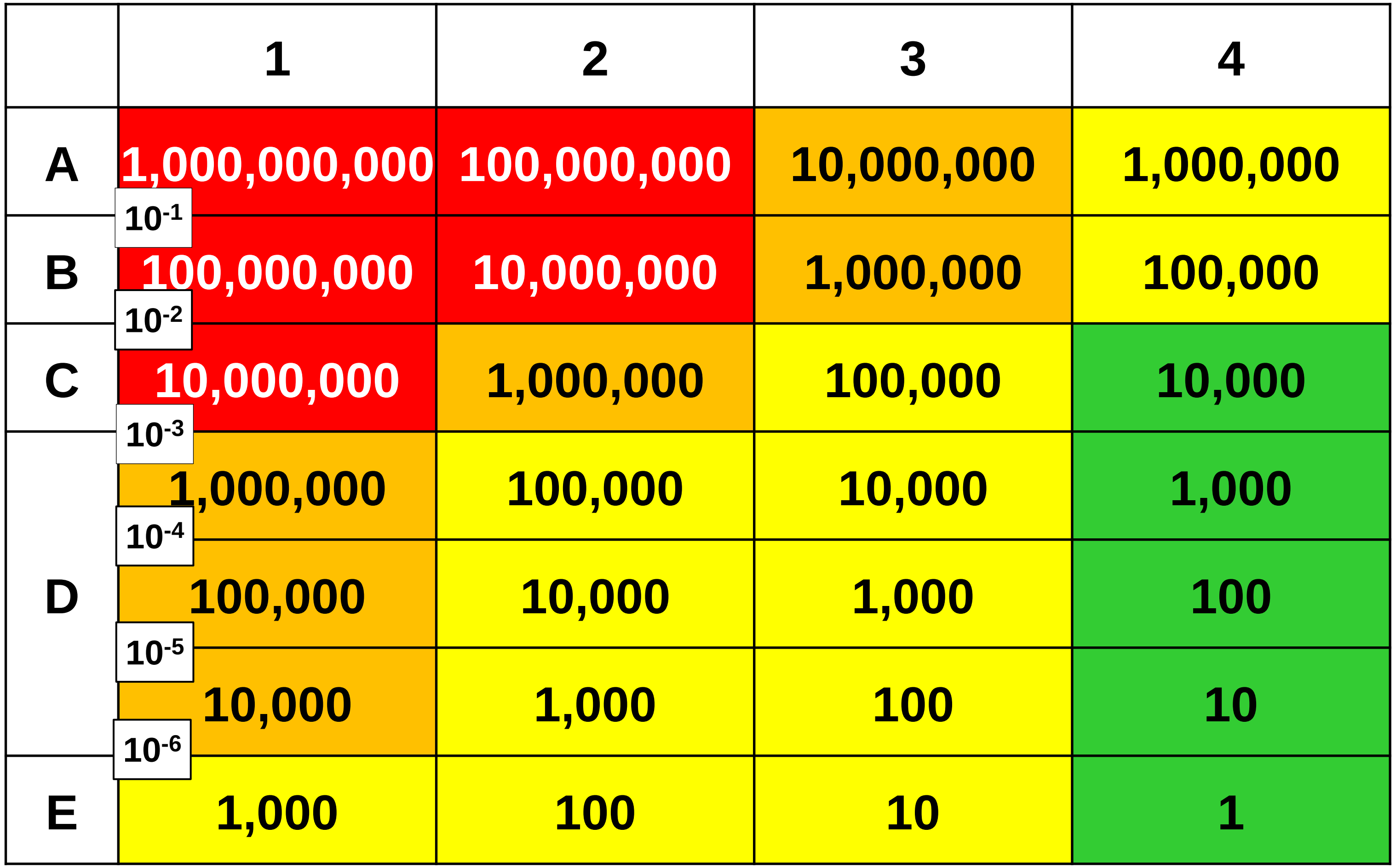
1 in < 2 days

1 in 18.5 days

1 in 6 months

1 in 500 years

Matrix Relative Risk Values

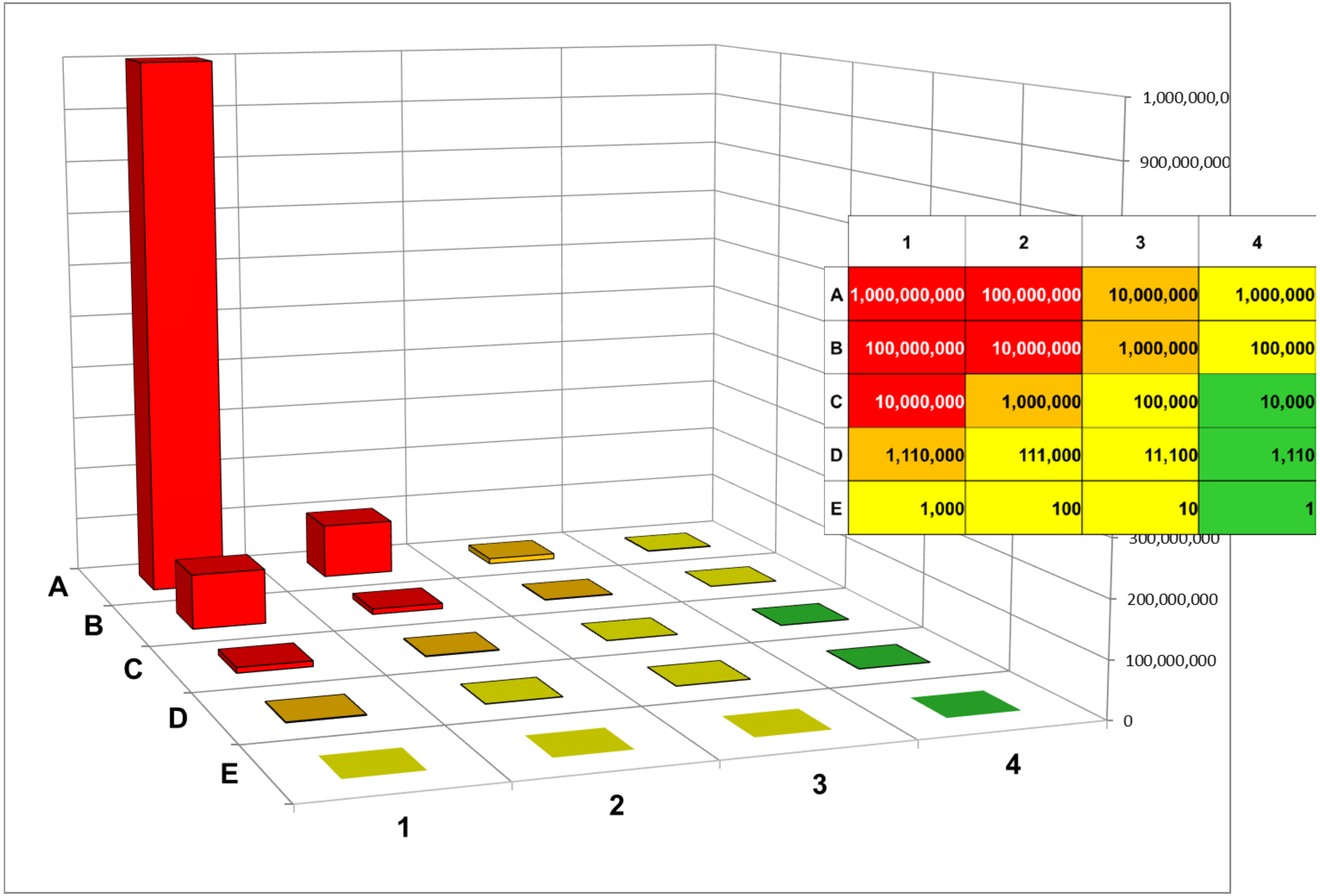


	1	2	3	4
A	1,000,000,000	100,000,000	10,000,000	1,000,000
10^{-1}				
B	100,000,000	10,000,000	1,000,000	100,000
10^{-2}				
C	10,000,000	1,000,000	100,000	10,000
10^{-3}				
D	1,000,000	100,000	10,000	1,000
10^{-4}				
	100,000	10,000	1,000	100
10^{-5}				
	10,000	1,000	100	10
10^{-6}				
E	1,000	100	10	1

Matrix Relative Risk Values

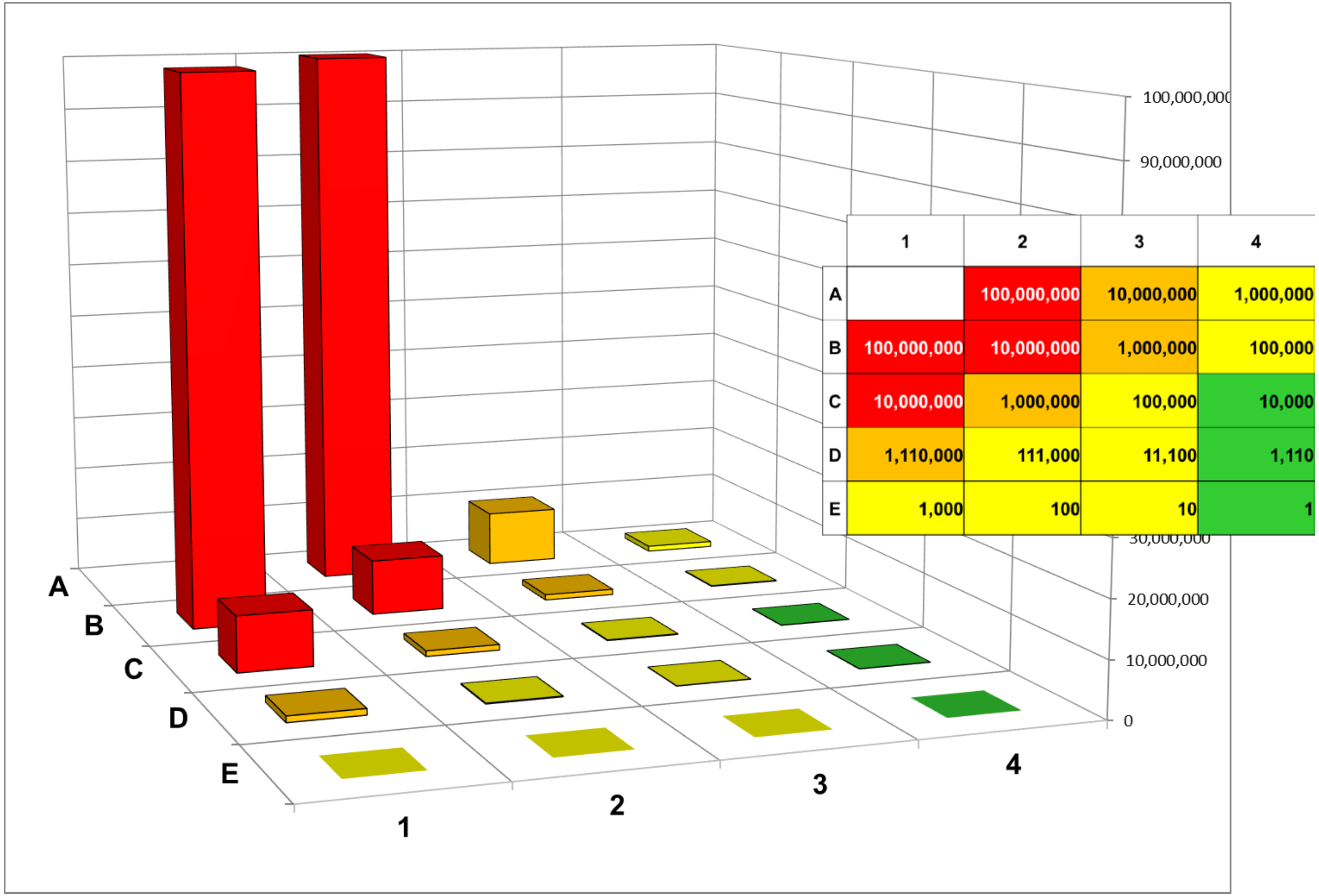
	1	2	3	4
A	1,000,000,000	100,000,000	10,000,000	1,000,000
10^{-1}				
B	100,000,000	10,000,000	1,000,000	100,000
10^{-2}				
C	10,000,000	1,000,000	100,000	10,000
10^{-3}				
D	1,110,000	111,000	11,100	1,110
10^{-6}				
E	1,000	100	10	1

Matrix Relative Risk Values



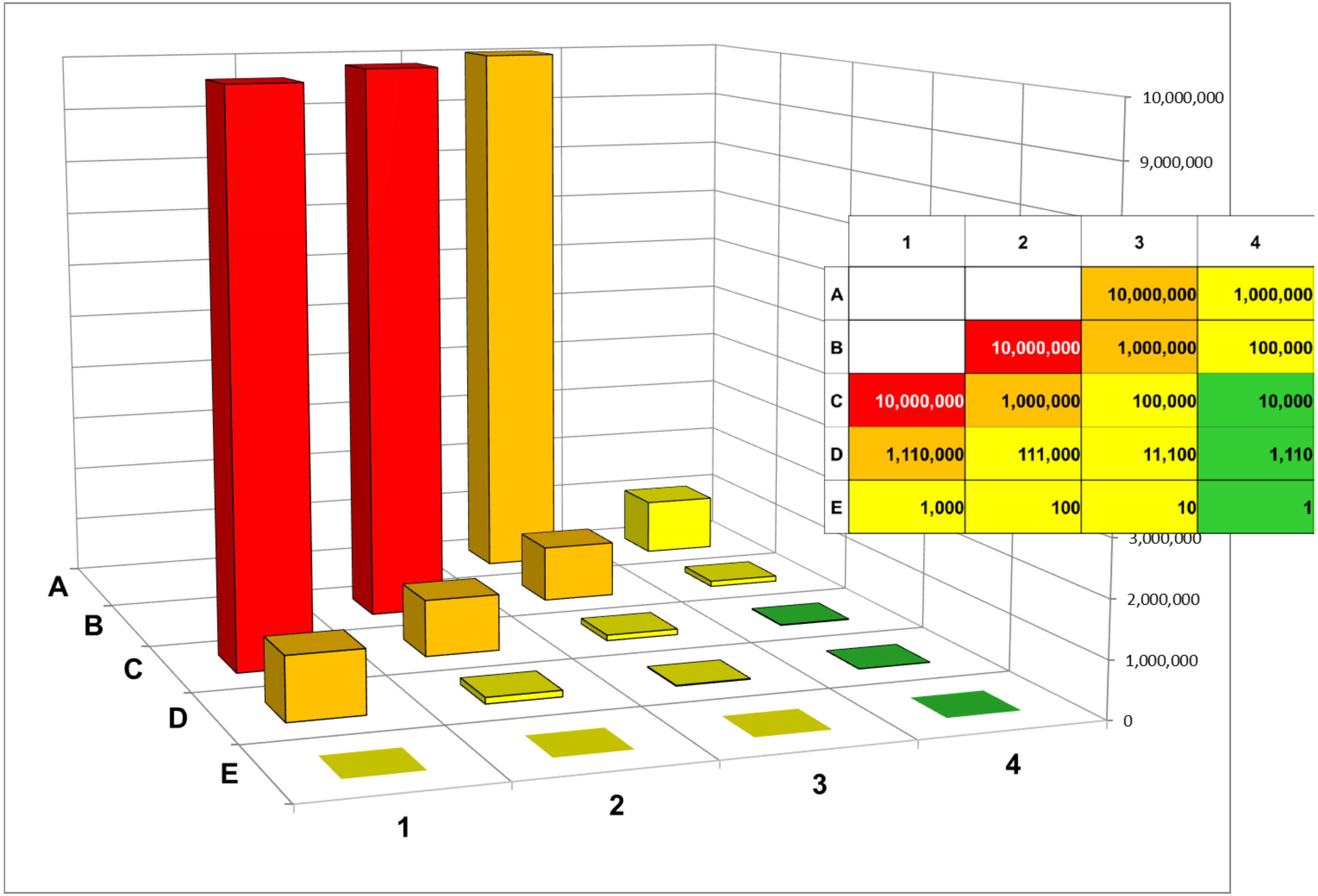
	1	2	3	4
A	1,000,000,000	100,000,000	10,000,000	1,000,000
B	100,000,000	10,000,000	1,000,000	100,000
C	10,000,000	1,000,000	100,000	10,000
D	1,110,000	111,000	11,100	1,110
E	1,000	100	10	1

Matrix Relative Risk Values



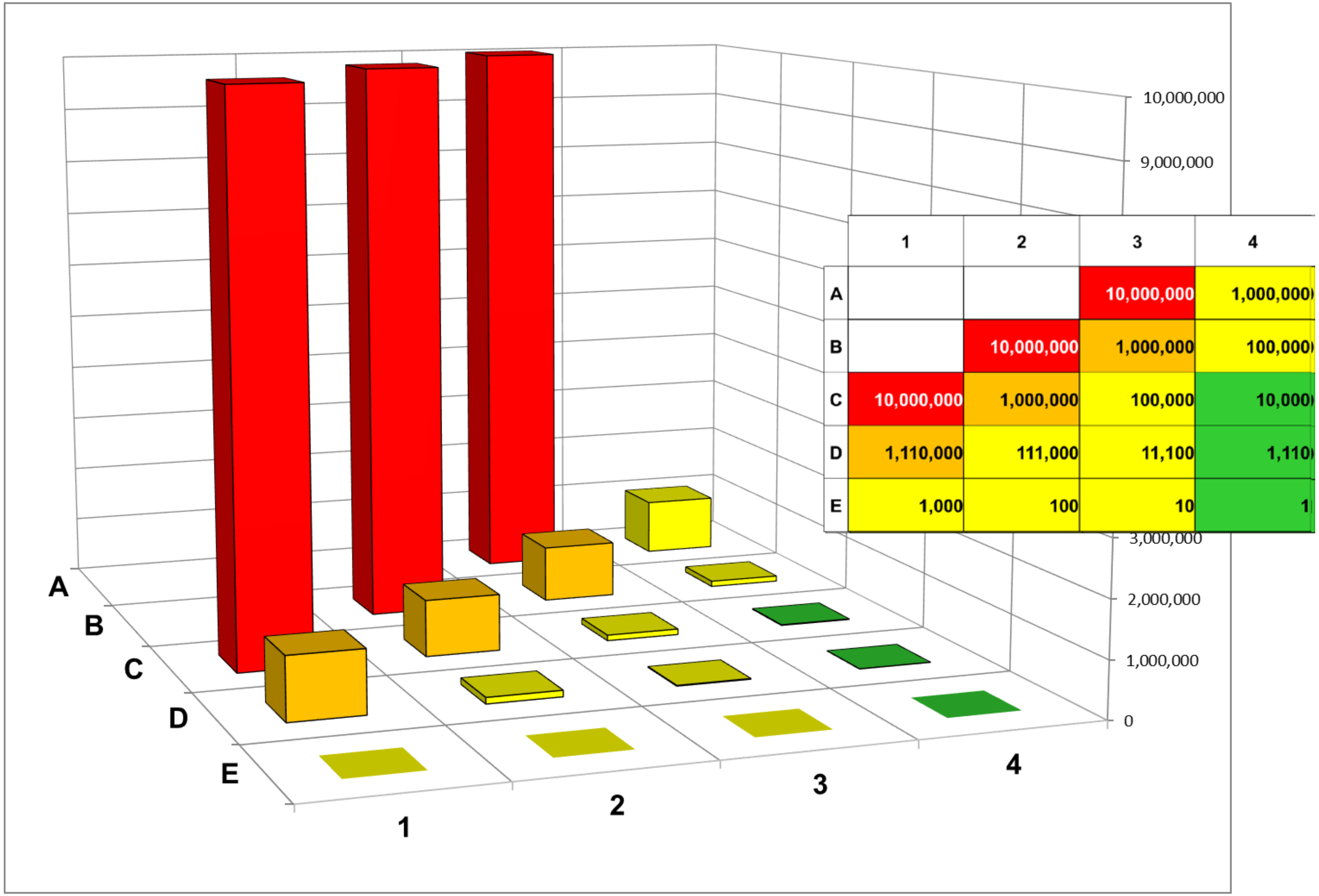
	1	2	3	4
A		100,000,000	10,000,000	1,000,000
B	100,000,000	10,000,000	1,000,000	100,000
C	10,000,000	1,000,000	100,000	10,000
D	1,110,000	111,000	11,100	1,110
E	1,000	100	10	1

Matrix Relative Risk Values



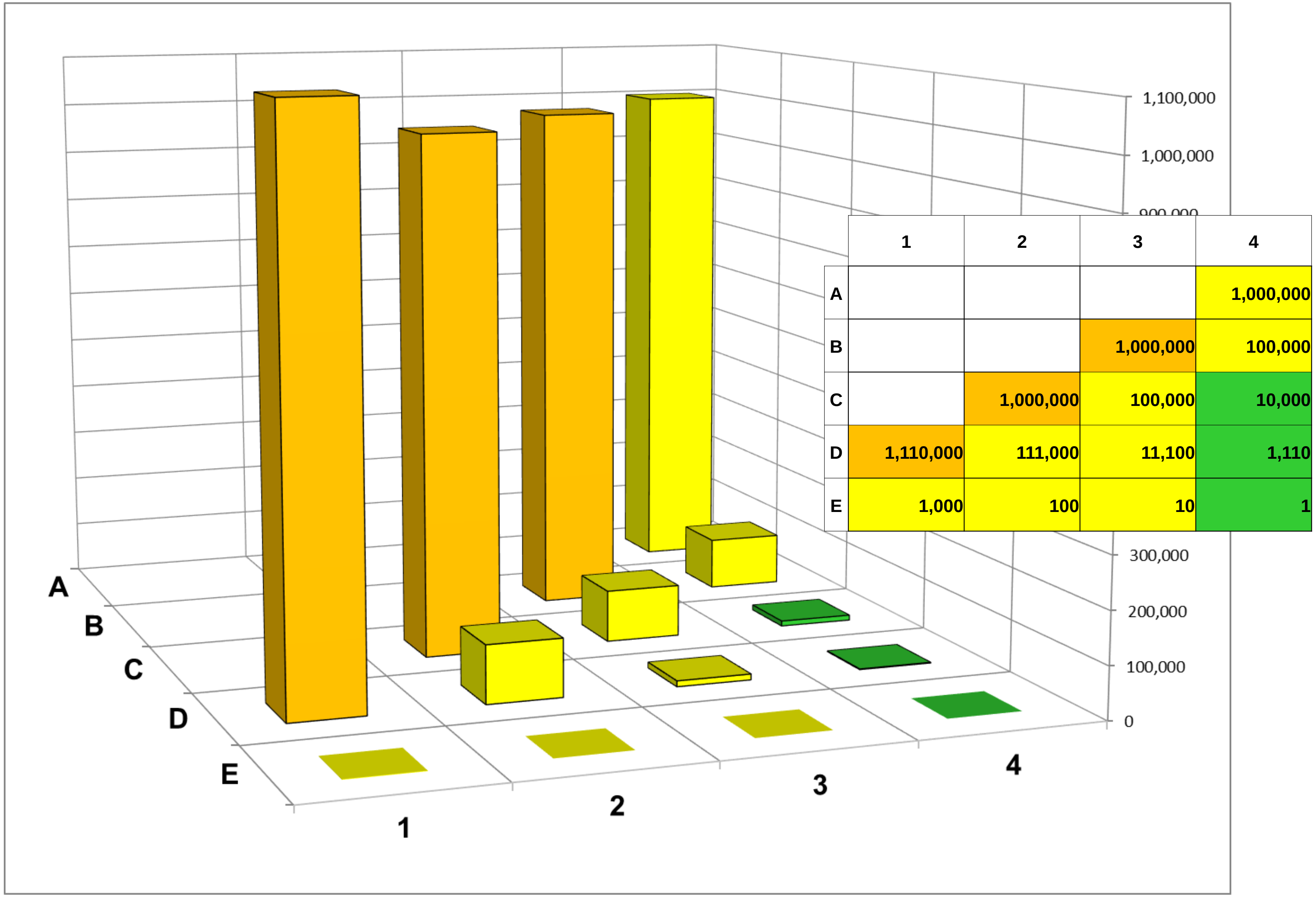
	1	2	3	4
A			10,000,000	1,000,000
B		10,000,000	1,000,000	100,000
C	10,000,000	1,000,000	100,000	10,000
D	1,110,000	111,000	11,100	1,110
E	1,000	100	10	1

Matrix Relative Risk Values



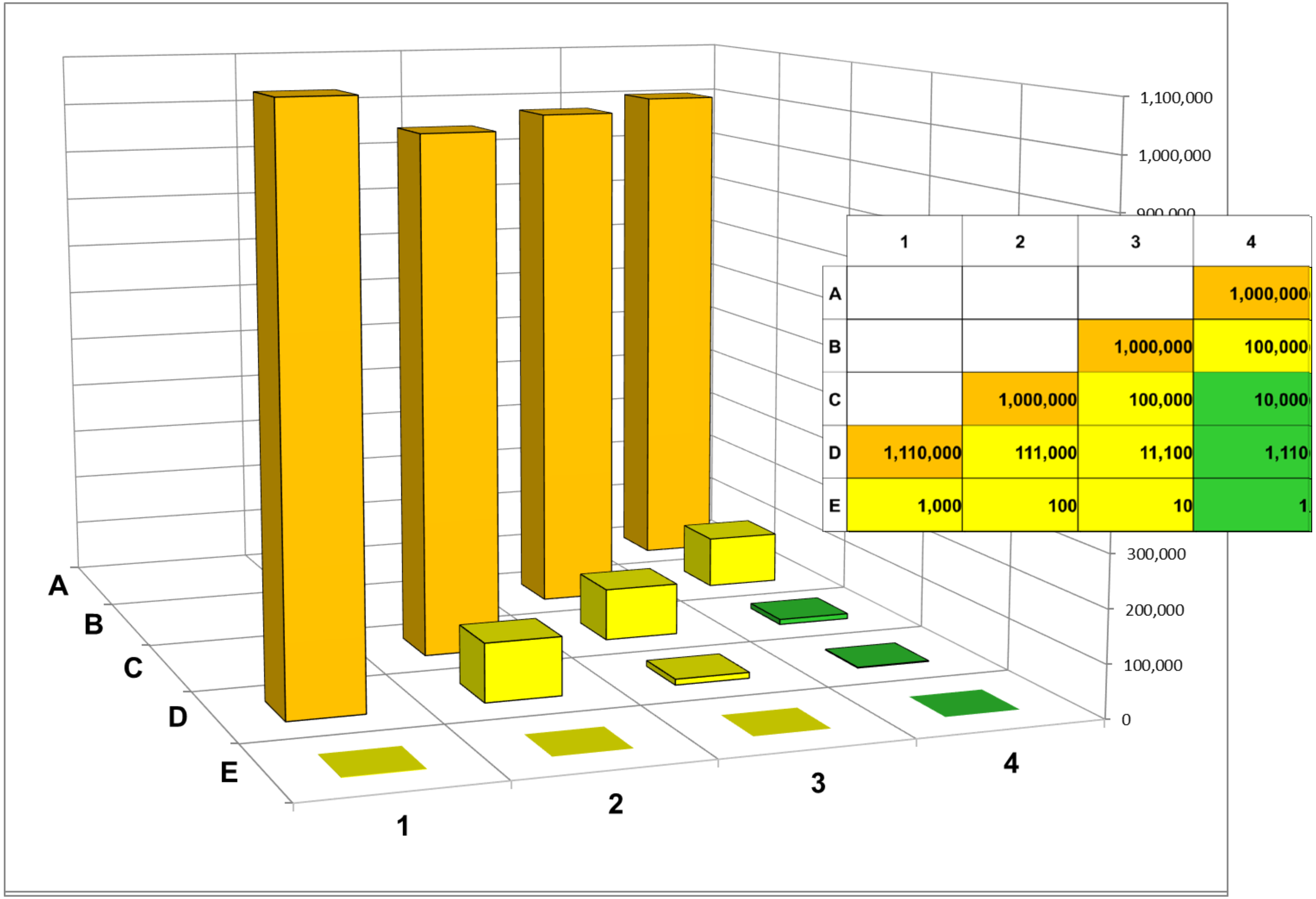
	1	2	3	4
A			10,000,000	1,000,000
B		10,000,000	1,000,000	100,000
C	10,000,000	1,000,000	100,000	10,000
D	1,110,000	111,000	11,100	1,110
E	1,000	100	10	1

Matrix Relative Risk Values



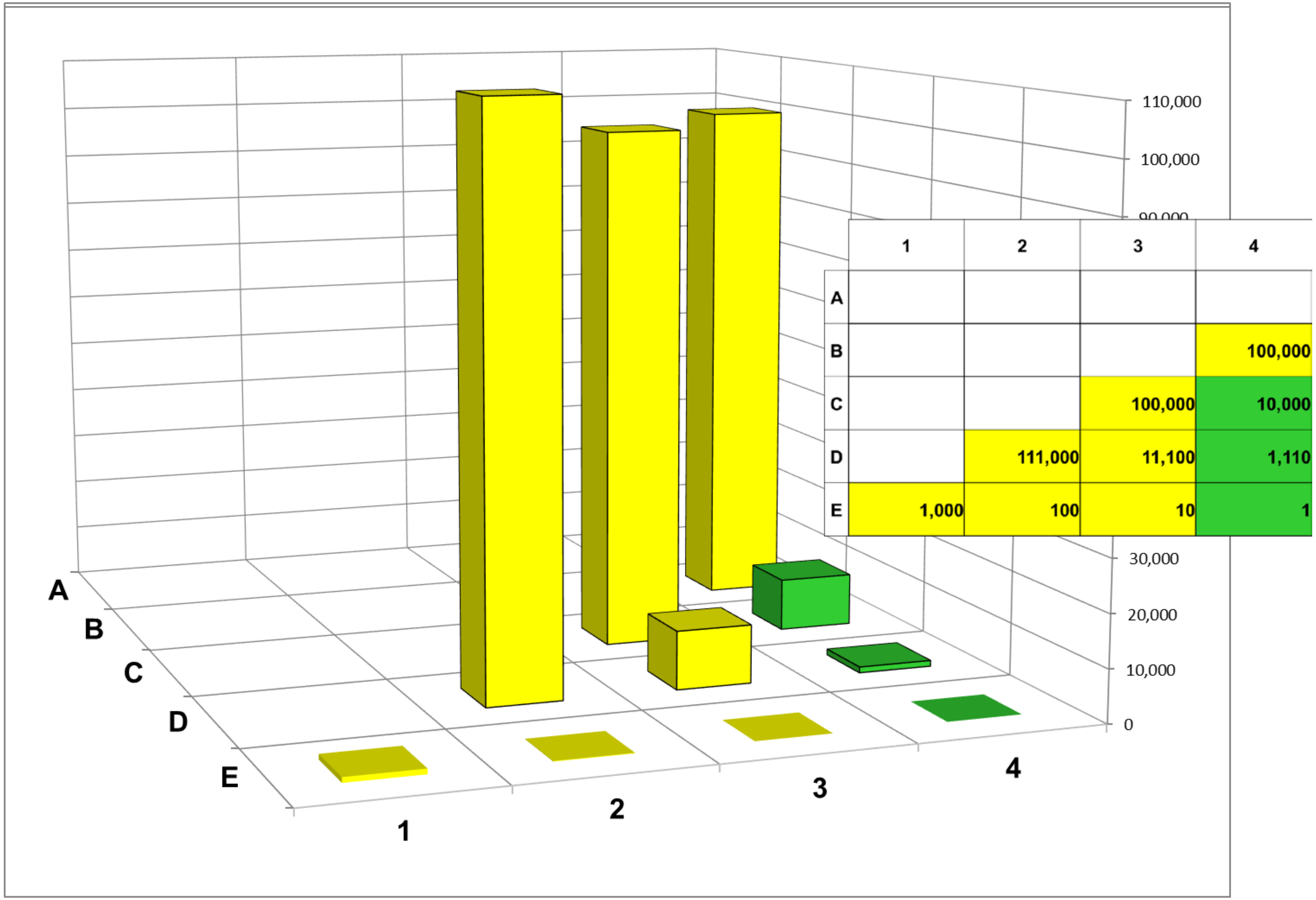
	1	2	3	4
A				1,000,000
B			1,000,000	100,000
C		1,000,000	100,000	10,000
D	1,110,000	111,000	11,100	1,110
E	1,000	100	10	1

Matrix Relative Risk Values



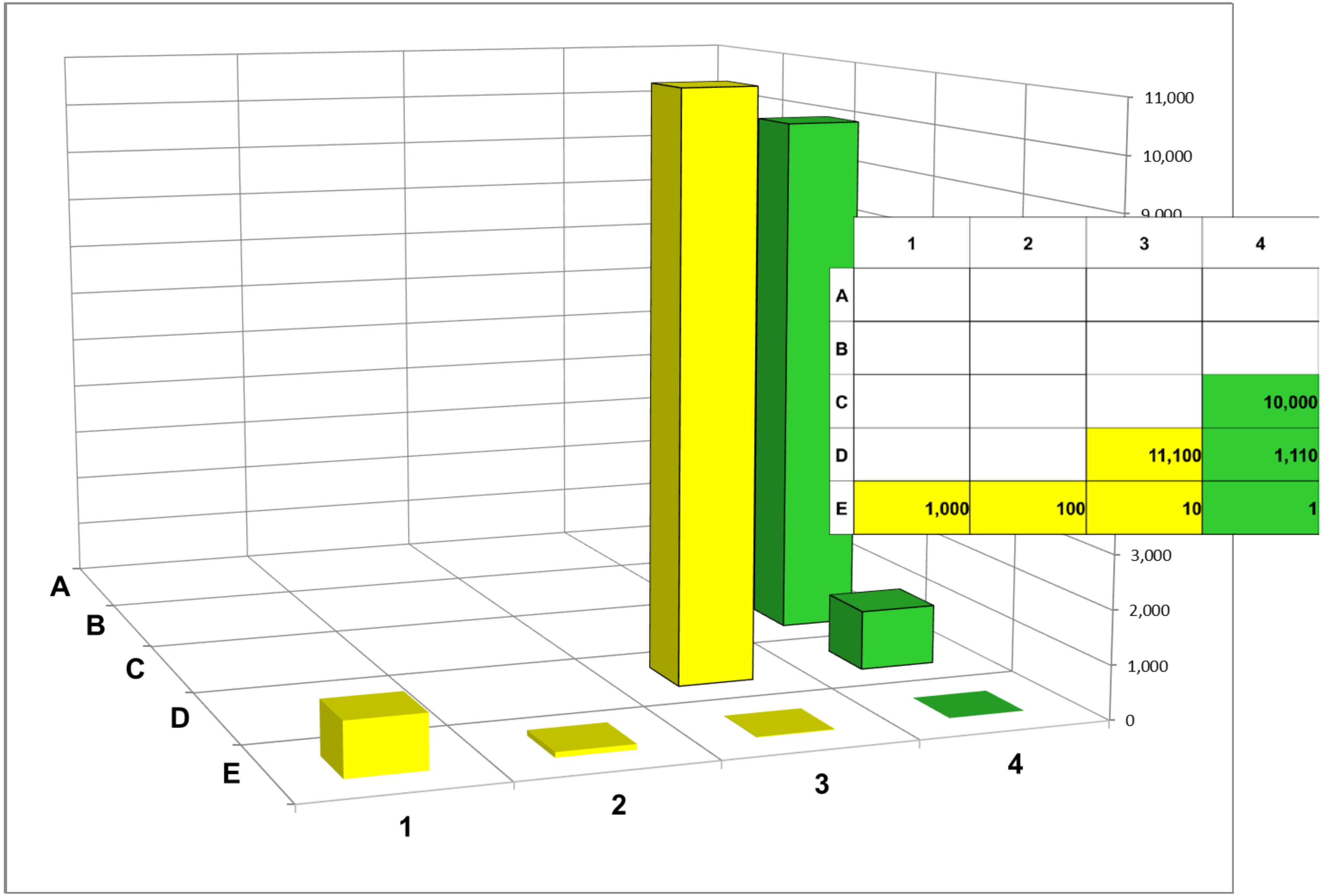
	1	2	3	4
A				1,000,000
B			1,000,000	100,000
C		1,000,000	100,000	10,000
D	1,110,000	111,000	11,100	1,110
E	1,000	100	10	1

Matrix Relative Risk Values



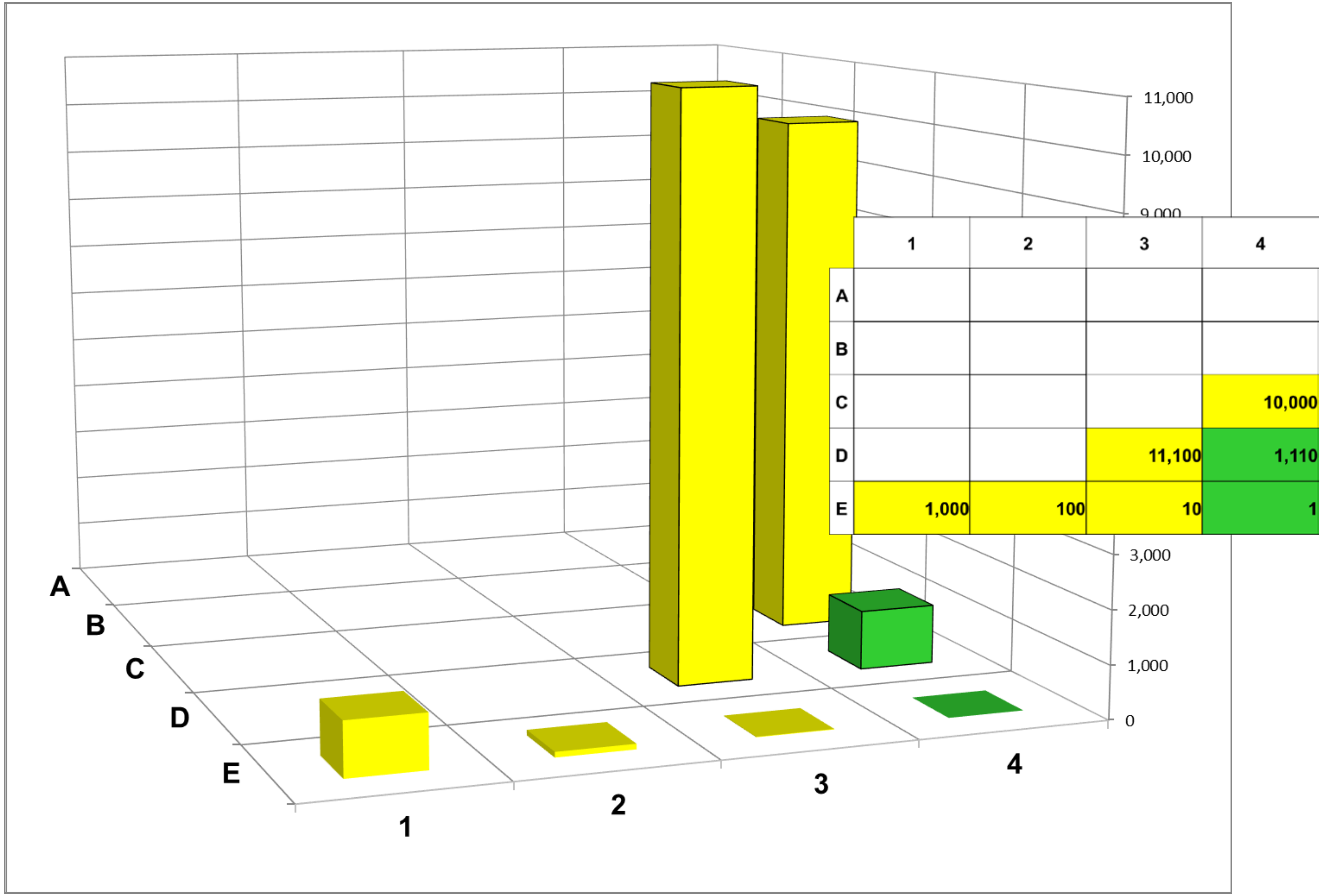
	1	2	3	4
A				
B				100,000
C			100,000	10,000
D		111,000	11,100	1,110
E	1,000	100	10	1

Matrix Relative Risk Values



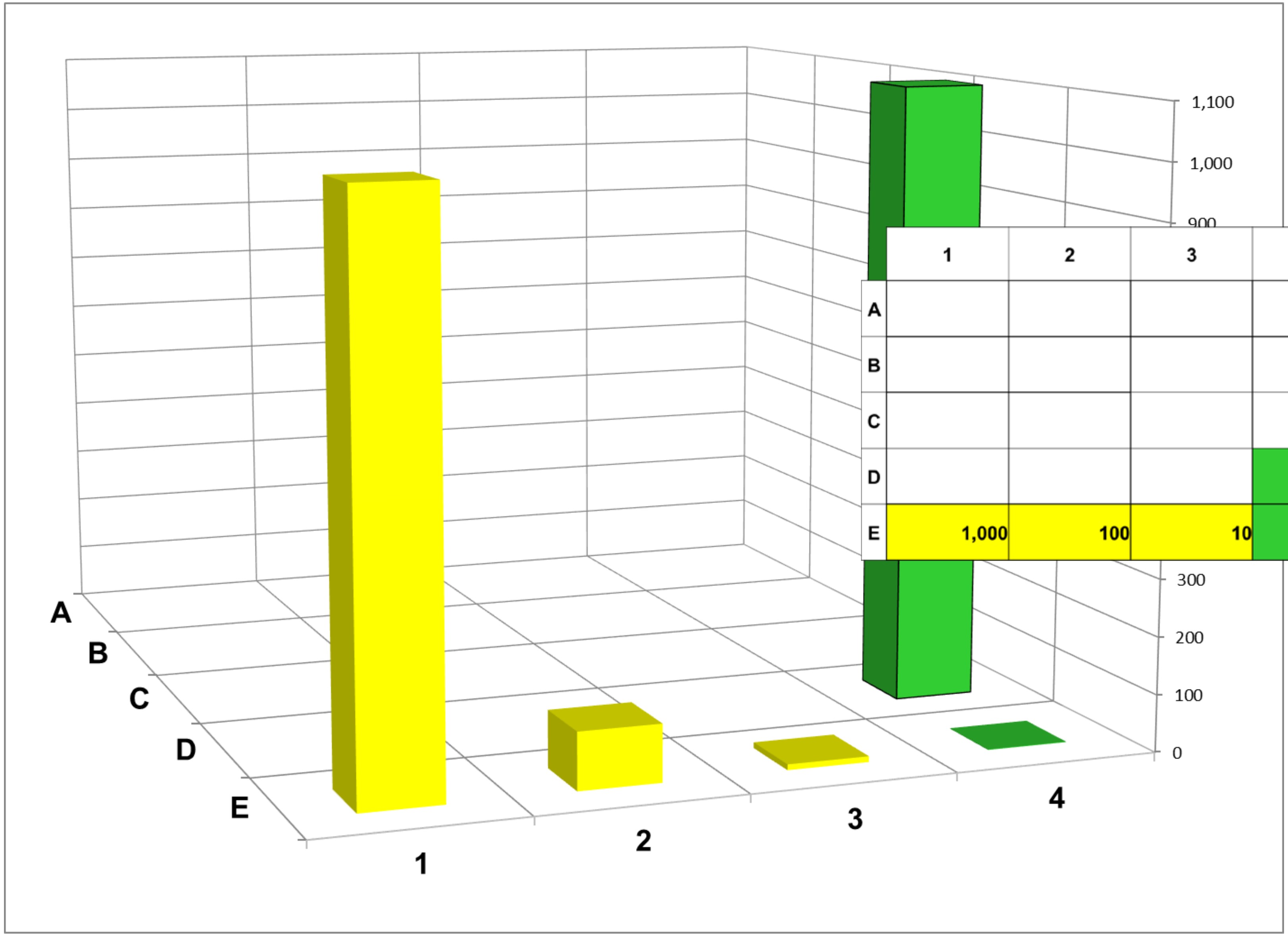
	1	2	3	4
A				
B				
C				10,000
D			11,100	1,110
E	1,000	100	10	1

Matrix Relative Risk Values



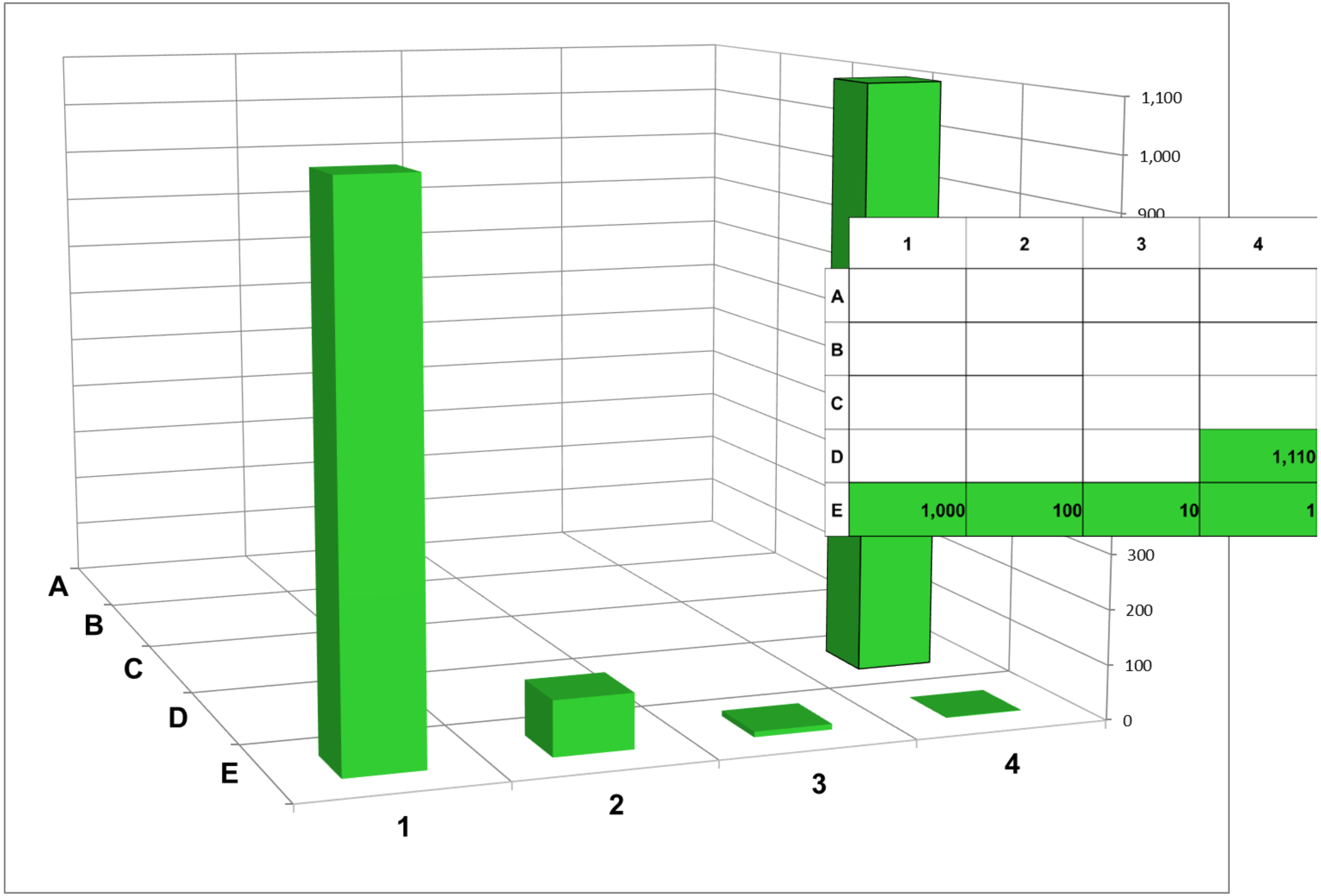
	1	2	3	4
A				
B				
C				10,000
D			11,100	1,110
E	1,000	100	10	1

Matrix Relative Risk Values



	1	2	3	4
A				
B				
C				
D				1,110
E	1,000	100	10	1

Matrix Relative Risk Values

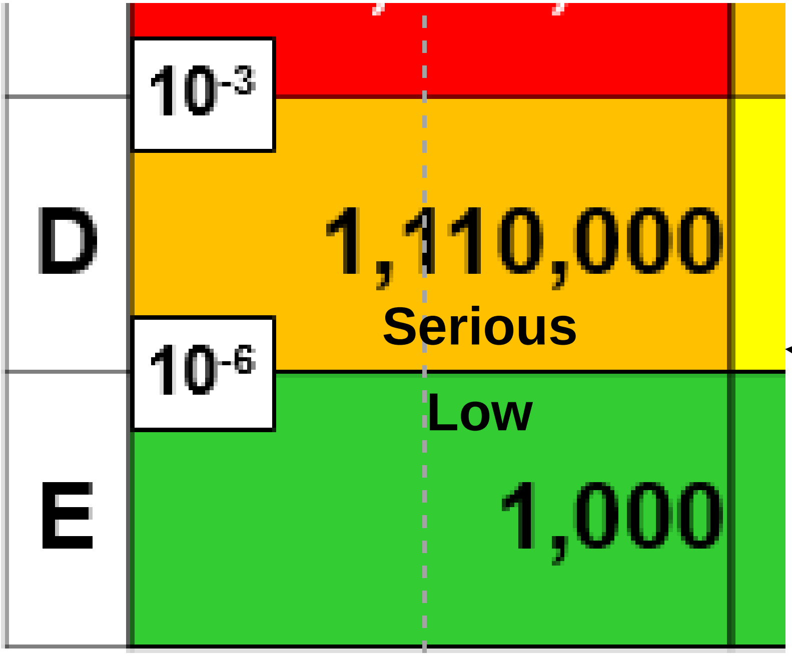


	1	2	3	4
A				
B				
C				
D				1,110
E	1,000	100	10	1

Matrix Relative Risk Values

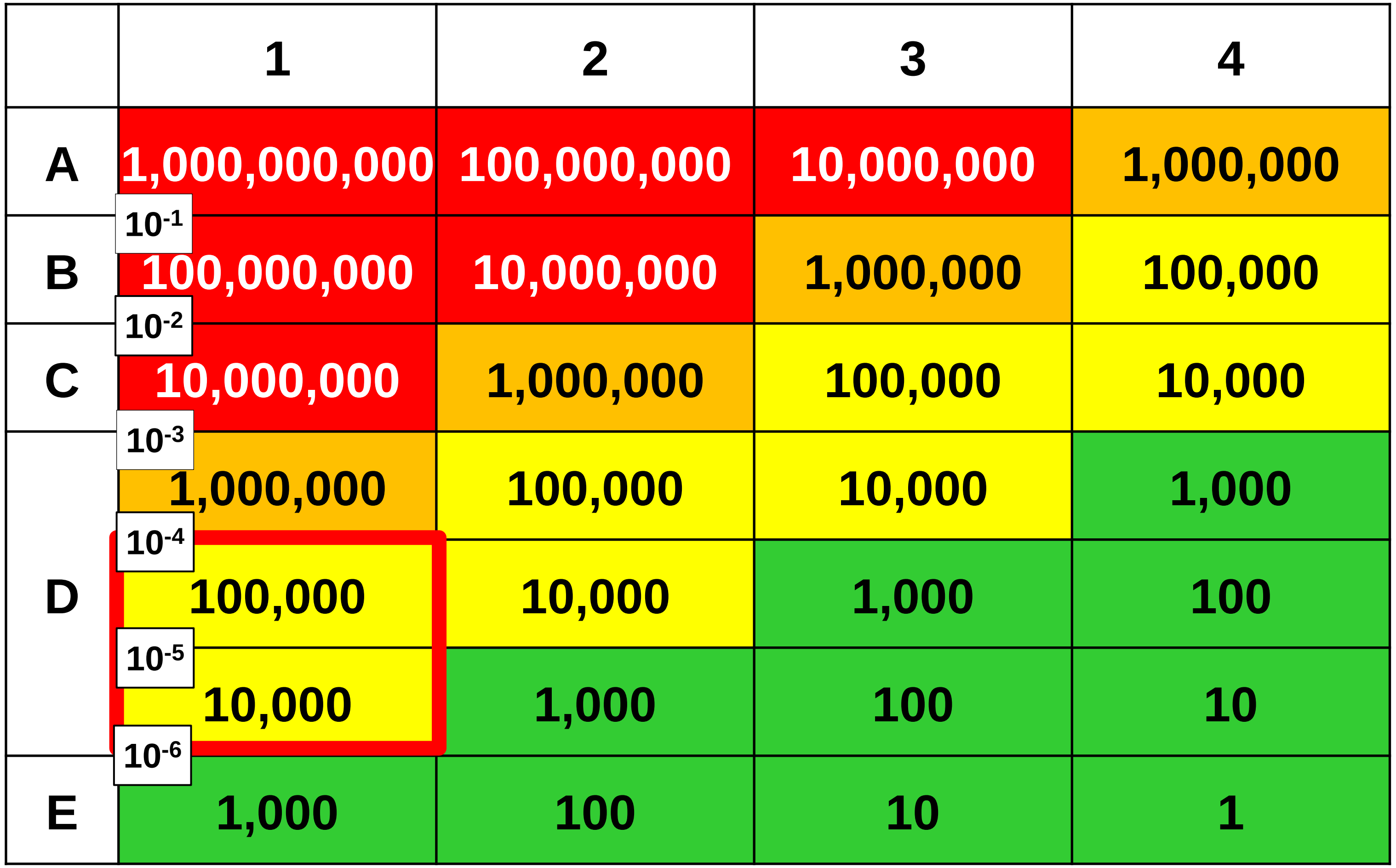
		1	2	3	4
A	10^{-1}	1,000,000,000	100,000,000	10,000,000	1,000,000
B	10^{-2}	100,000,000	10,000,000	1,000,000	100,000
C	10^{-3}	10,000,000	1,000,000	100,000	10,000
D	10^{-6}	1,110,000	111,000	11,100	1,110
E		1,000	100	10	1

Matrix Relative Risk Values



Where is the medium?

Matrix Relative Risk Values



	1	2	3	4
A	1,000,000,000	100,000,000	10,000,000	1,000,000
B	10^{-1} 100,000,000	10,000,000	1,000,000	100,000
C	10^{-2} 10,000,000	1,000,000	100,000	10,000
D	10^{-3} 1,000,000	100,000	10,000	1,000
	10^{-4} 100,000	10,000	1,000	100
	10^{-5} 10,000	1,000	100	10
E	10^{-6} 1,000	100	10	1

Matrix Relative Risk Values

	1	2	3	4
A	1,000,000,000	100,000,000	10,000,000	1,000,000
B	100,000,000	10,000,000	1,000,000	100,000
C	10,000,000	1,000,000	100,000	10,000
D	1,000,000	100,000	10,000	1,000
E	100,000	10,000	1,000	100
F	10,000	1,000	100	10
G	1,000	100	10	1

1 in <2 days

1 in 18.5 days

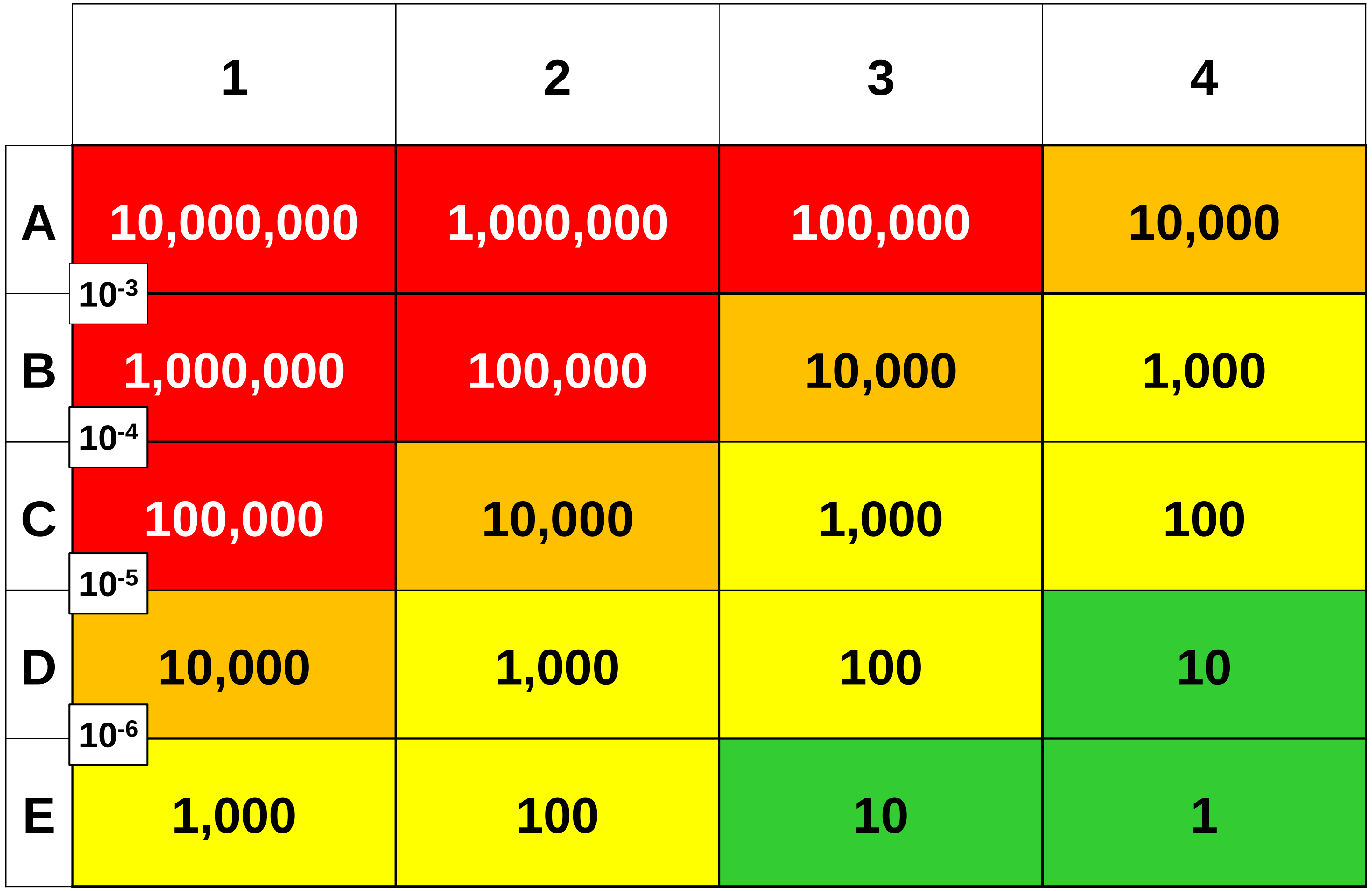
1 in 6 months

1 in 5 years

1 in 50 years

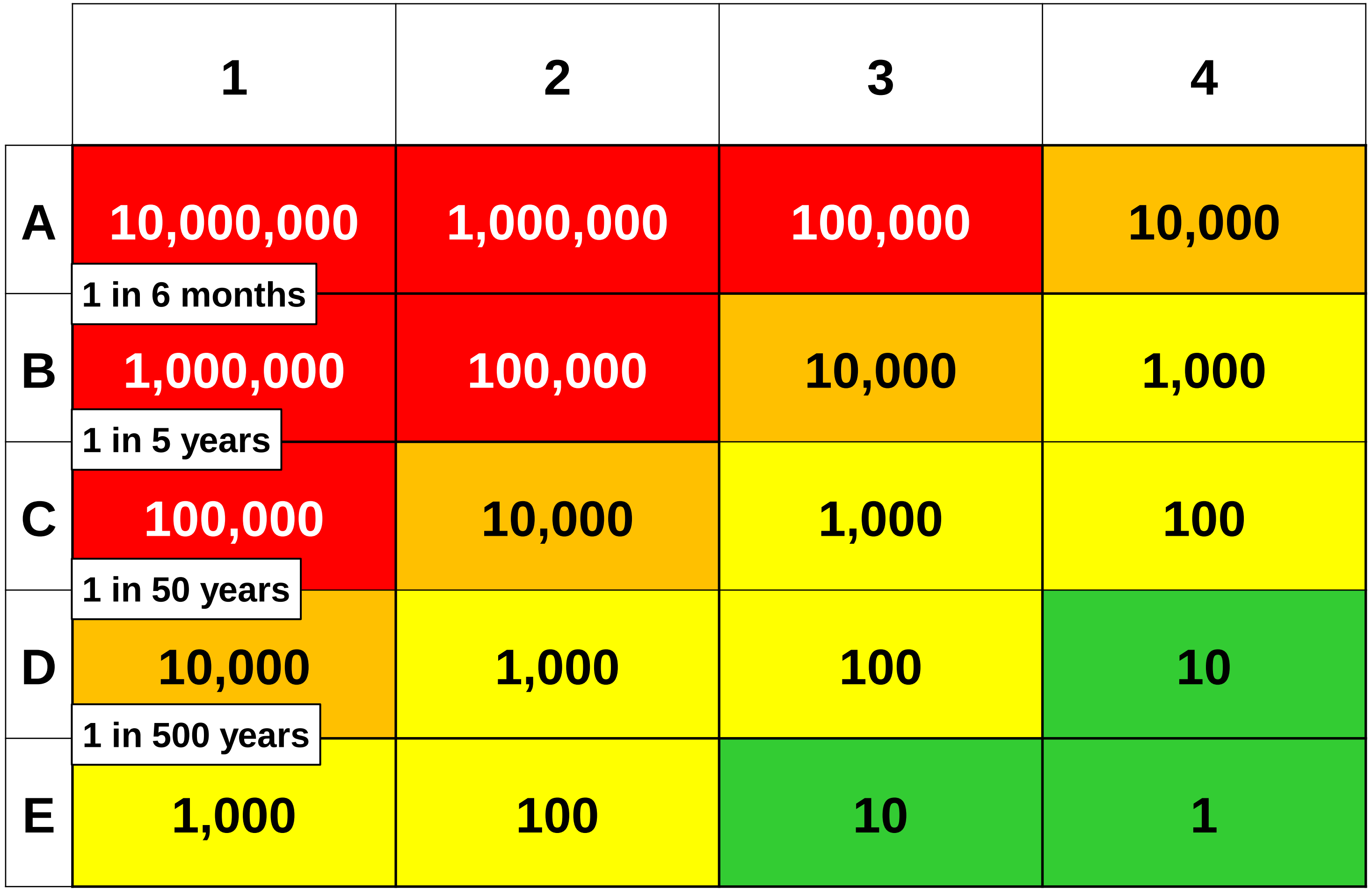
1 in 500 years

Matrix Relative Risk Values



	1	2	3	4
A	10,000,000	1,000,000	100,000	10,000
10^{-3}				
B	1,000,000	100,000	10,000	1,000
10^{-4}				
C	100,000	10,000	1,000	100
10^{-5}				
D	10,000	1,000	100	10
10^{-6}				
E	1,000	100	10	1

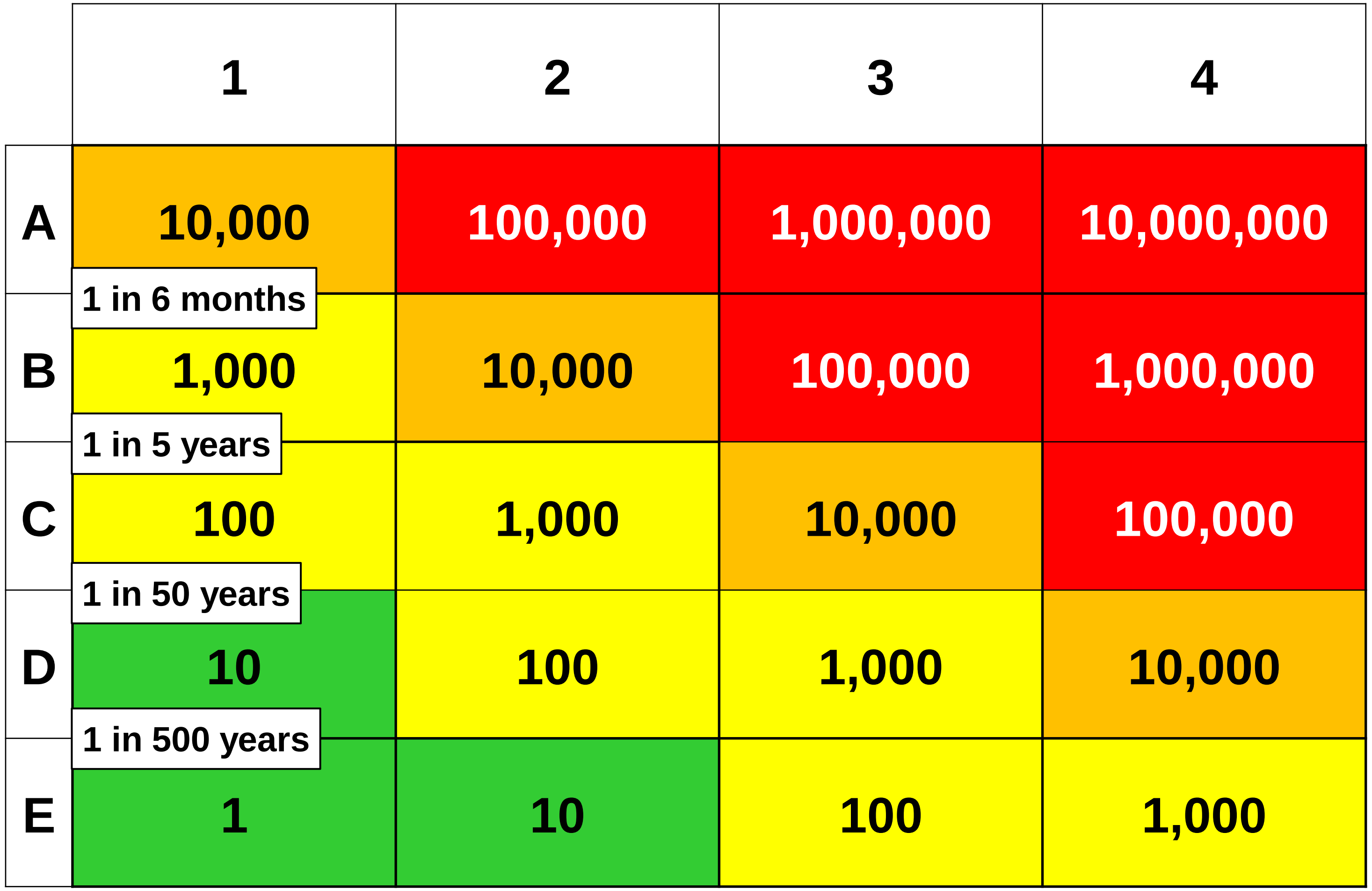
Matrix Relative Risk Values



	1	2	3	4
A	10,000,000	1,000,000	100,000	10,000
B	1,000,000	100,000	10,000	1,000
C	100,000	10,000	1,000	100
D	10,000	1,000	100	10
E	1,000	100	10	1

1 in 6 months
1 in 5 years
1 in 50 years
1 in 500 years

Matrix Relative Risk Values



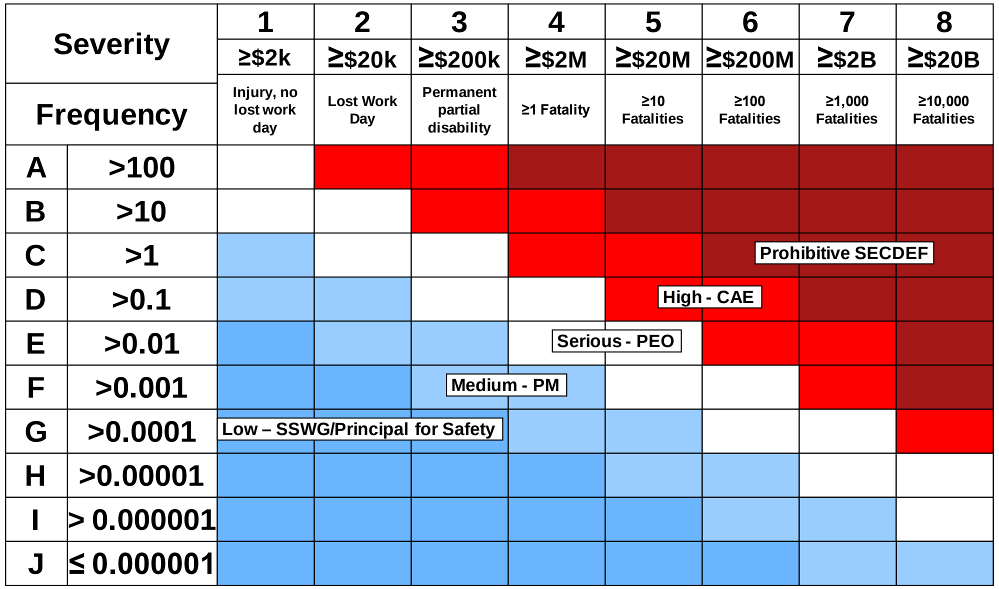
	1	2	3	4
A	10,000	100,000	1,000,000	10,000,000
B	1,000	10,000	100,000	1,000,000
C	100	1,000	10,000	100,000
D	10	100	1,000	10,000
E	1	10	100	1,000

1 in 6 months
1 in 5 years
1 in 50 years
1 in 500 years

Summary

Summary
Attributes of a well-designed risk assessment matrix

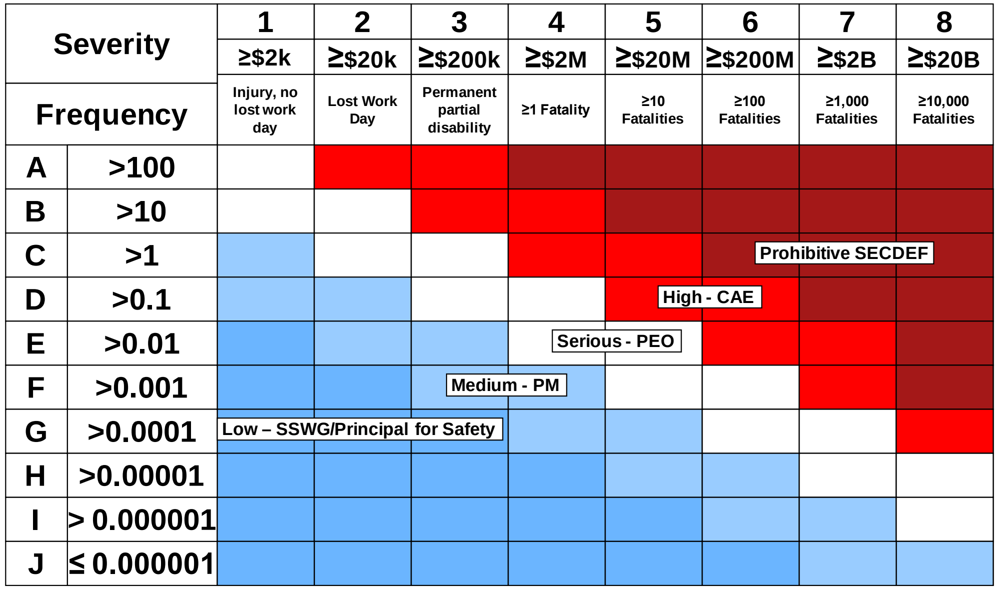
- ✓ Severity scale covers full range of possible outcomes
- ✓ Probability calibrated with reference to an exposure interval
- ✓ Equally proportioned, logarithmic scales (1, 10, 100, 1000…)
- ✓ Cartesian Orientation – Increase up and to the right
- ✓ Risk levels assigned to cells consistent with contours of equal risk



Severity		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100	⬜	🟥	🟥	🟫	🟫	🟫	🟫	🟫
B	>10	⬜	⬜	🟥	🟥	🟫	🟫	🟫	🟫
C	>1	▦	⬜	⬜	🟥	🟥	🟫	🟫 Prohibitive SECDEF	🟫
D	>0.1	▦	▦	⬜	⬜	🟥 High - CAE	🟥	🟫	🟫
E	>0.01	🟦	▦	▦	⬜	⬜ Serious - PEO	🟥	🟥	🟫
F	>0.001	🟦	🟦	▦ Medium - PM	▦	⬜	⬜	🟥	🟫
G	>0.0001	🟦 Low – SSWG/Principal for Safety	🟦	🟦	▦	▦	⬜	⬜	🟥
H	>0.00001	🟦	🟦	🟦	🟦	▦	▦	⬜	⬜
I	> 0.000001	🟦	🟦	🟦	🟦	🟦	▦	▦	⬜
J	≤ 0.000001	🟦	🟦	🟦	🟦	🟦	🟦	▦	▦

Summary
Attributes of a well-designed risk assessment matrix

- ✔ Sufficient probability categories so highest severity level reach the PM level
- ✔ Frequency category letters increase with decreasing frequency
- ✔ A RAC for hazards whose risk has been eliminated
- ✔ Easily tailored & consistent with other systems within its family of systems
- ✔ Severity Category numbers increase with increasing Severity



Severity		1	2	3	4	5	6	7	8
		≥$2k	≥$20k	≥$200k	≥$2M	≥$20M	≥$200M	≥$2B	≥$20B
Frequency		Injury, no lost work day	Lost Work Day	Permanent partial disability	≥1 Fatality	≥10 Fatalities	≥100 Fatalities	≥1,000 Fatalities	≥10,000 Fatalities
A	>100								
B	>10								
C	>1						Prohibitive SECDEF		
D	>0.1					High - CAE			
E	>0.01				Serious - PEO				
F	>0.001			Medium - PM					
G	>0.0001	Low – SSWG/Principal for Safety							
H	>0.00001								
I	> 0.000001								
J	≤ 0.000001								

How to Determine the Risk Assessment Code (RAC)

To determine the appropriate RAC for a given hazard:

(1) Identify the full range of potential outcomes for the hazard (death, injury, system loss, environmental impact, and monetary loss). The range of outcomes will often span more than one severity category.

(2) For each severity category associated with this range of severity, determine the associated probability category.

(3) Determine which severity-probability pair has the greatest risk. This pair is the RAC assigned to the hazard.

(4) If two or more severity-probability pairs are equal as the greatest risk, select the one with the greatest severity.

Summary Understanding Probability

Math Definition:

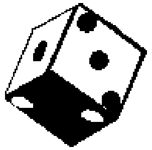
- Repeat a random experiment “n” number of times.
- If a specific outcome has occurred “f” times in these n trials, the number “f” is the frequency of the outcome.
- The ratio f/n is the relative frequency of the outcome.
- A relative frequency is usually very unstable for small values of “n,” but it tends to stabilize about some number “p” as “n” increases.
- The number “p” is the probability of the outcome.

$$p = f / n$$

for very large values of n

Simple example:

Probability of rolling a “3” with one die.



Roll #1 - “5”, f/n = 0

Roll #2 - “2”, f/n = 0

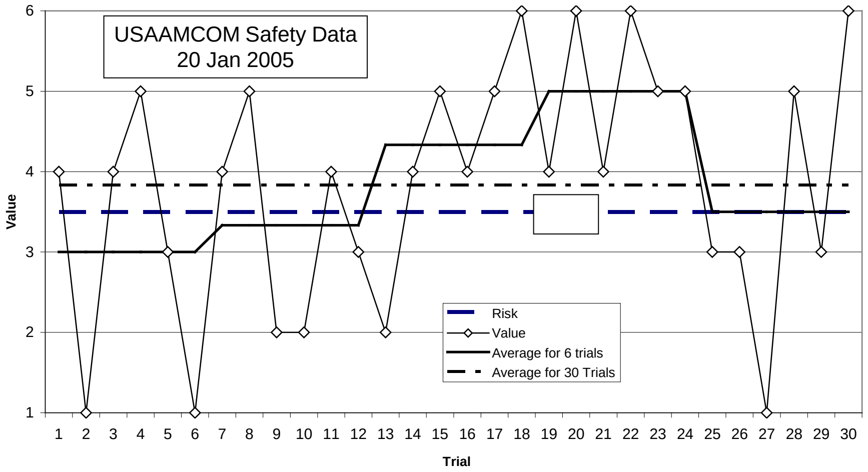
Roll #3 - “3”, f/n = 1/3 = .333…

Roll #4 - “4”, f/n = 1/4 = .25

Roll #1,000: 163 “3”s, f/n = 163/1000 = .163

Rolls approach infinity f/n = .166666….

Roll a single die 30 times. The expe
What you actually get is somewhat



Hazard: AH-64 strikes wire results in Class A mishap

Probability: 4.406E-06 occurrences per flight hour

1 Flight Hr, no mishap, rate = 0

1,000 Flight Hrs, no mishap, rate = 0

176,182 Flight Hrs, 1 mishap, rate = 5.676E-06 /flt hr

274,539 Flight Hrs, 2 mishaps, rate = 7.285E-06 /flt hr

700,462 Flt Hrs, 3 mishaps, rate = 4.283E-06 /flt hr

10,000,000 Flt Hrs, 46 mishaps, rate = 4.600E-06 /flt hr

1,000,000,000 Hrs, 4407 mishaps, rate = 4.407E-06 /flt hr

Flight hours approach infinity, rate = 4.406E-06 /flt hr

Summary Expanded Matrix

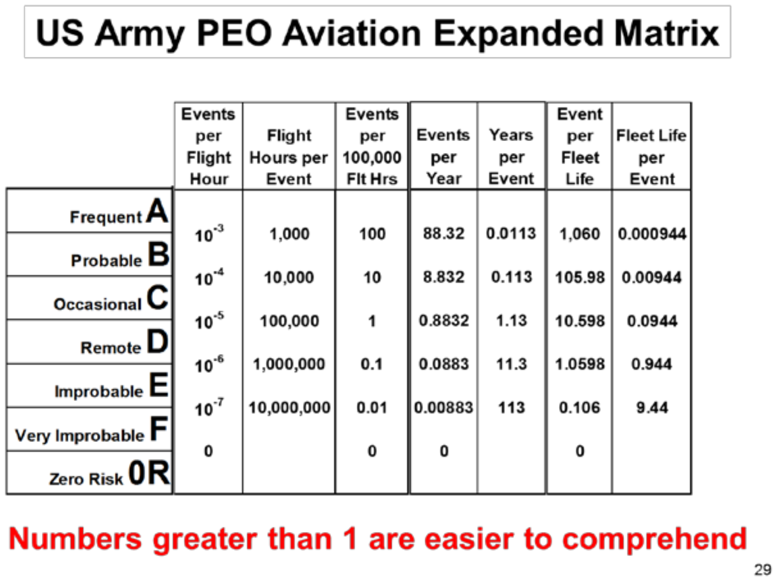
Applying Probability Classifications to a military helicopter

Fleet Size = 368 aircraft
Utilization = 240 hours/year
Life = 20 years/aircraft

Aircraft Life = 240 x 20
= 4,800 hours

Fleet Exposure Hours = 368 x 240 x 20
= 1,776,400 hours

Fleet Hours per Year = 368 x 240
= 88,320 hours



US Army PEO Aviation Expanded Matrix

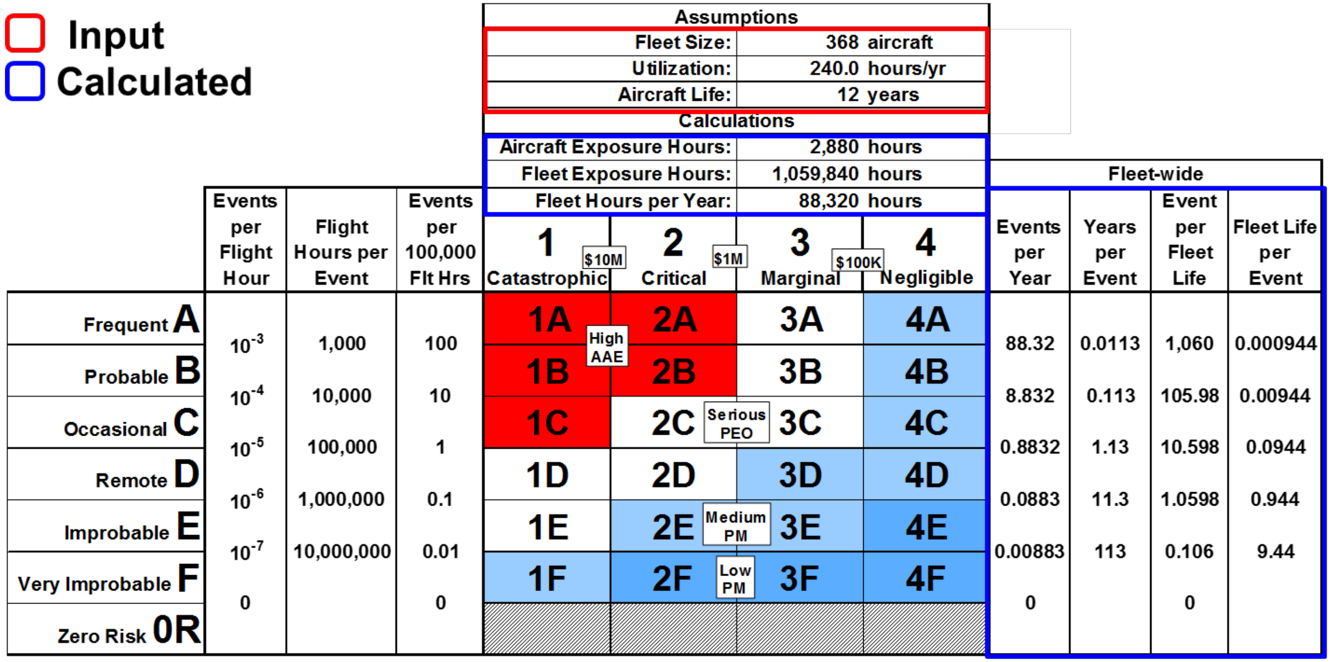
	Events per Flight Hour	Flight Hours per Event	Events per 100,000 Flt Hrs	Events per Year	Years per Event	Event per Fleet Life	Fleet Life per Event
Frequent **A**	10^{-3}	1,000	100	88.32	0.0113	1,060	0.000944
Probable **B**	10^{-4}	10,000	10	8.832	0.113	105.98	0.00944
Occasional **C**	10^{-5}	100,000	1	0.8832	1.13	10.598	0.0944
Remote **D**	10^{-6}	1,000,000	0.1	0.0883	11.3	1.0598	0.944
Improbable **E**	10^{-7}	10,000,000	0.01	0.00883	113	0.106	9.44
Very Improbable **F**	0		0	0		0	
Zero Risk **0R**							

Numbers greater than 1 are easier to comprehend

29

16

☐ **Input**
☐ **Calculated**



Assumptions	
Fleet Size:	368 aircraft
Utilization:	240.0 hours/yr
Aircraft Life:	12 years
Calculations	
Aircraft Exposure Hours:	2,880 hours
Fleet Exposure Hours:	1,059,840 hours
Fleet Hours per Year:	88,320 hours

								Fleet-wide			
	Events per Flight Hour	Flight Hours per Event	Events per 100,000 Flt Hrs	1 $10M Catastrophic	2 $1M Critical	3 $100K Marginal	4 Negligible	Events per Year	Years per Event	Event per Fleet Life	Fleet Life per Event
Frequent **A**	10^{-3}	1,000	100	1A	2A	3A	4A	88.32	0.0113	1,060	0.000944
Probable **B**	10^{-4}	10,000	10	1B	2B	3B	4B	8.832	0.113	105.98	0.00944
Occasional **C**	10^{-5}	100,000	1	1C	2C	3C	4C	0.8832	1.13	10.598	0.0944
Remote **D**	10^{-6}	1,000,000	0.1	1D	2D	3D	4D	0.0883	11.3	1.0598	0.944
Improbable **E**	10^{-7}	10,000,000	0.01	1E	2E	3E	4E	0.00883	113	0.106	9.44
Very Improbable **F**	0		0	1F	2F	3F	4F	0		0	
Zero Risk **0R**				▨	▨	▨	▨				

Summary

Accidents on a Matrix

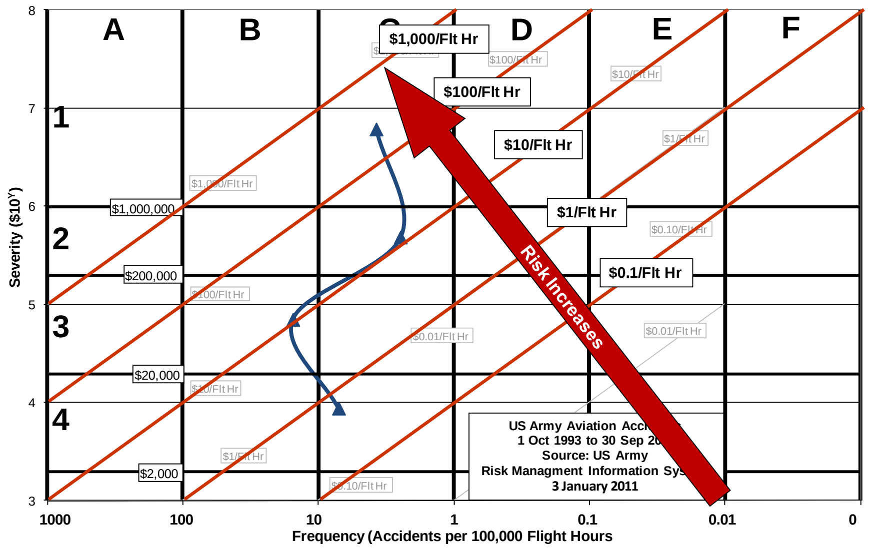
Based on this relationship between mishap risk and mishap loss, we can plot mishap histories on a risk matrix as follows:

$$\text{Severity} = \frac{\text{Total Cost from Class A mishaps}}{\text{Total Number of Class A mishaps}}$$

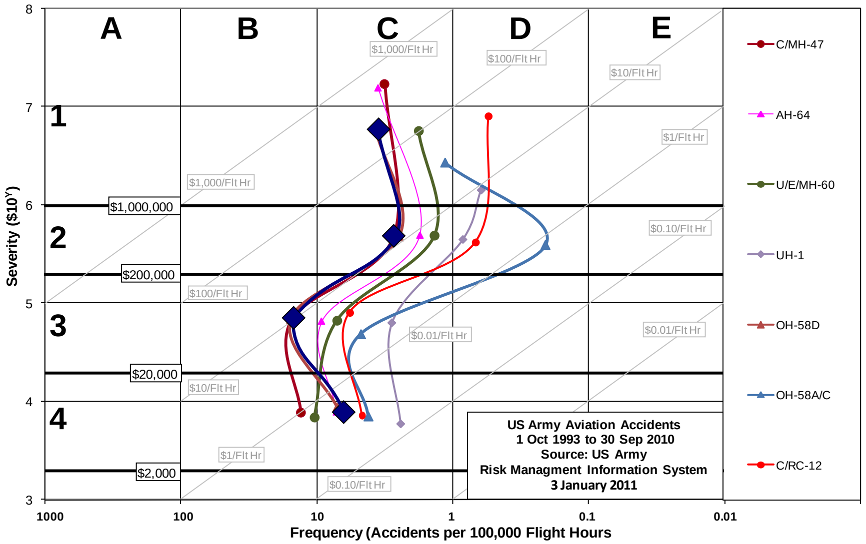
$$= \frac{\$1,305,079,886}{83} = \$\ 15,723,854$$

$$\text{Probability} = \frac{\text{Total Number of Class A mishaps}}{\text{Total Hours Flown}}$$

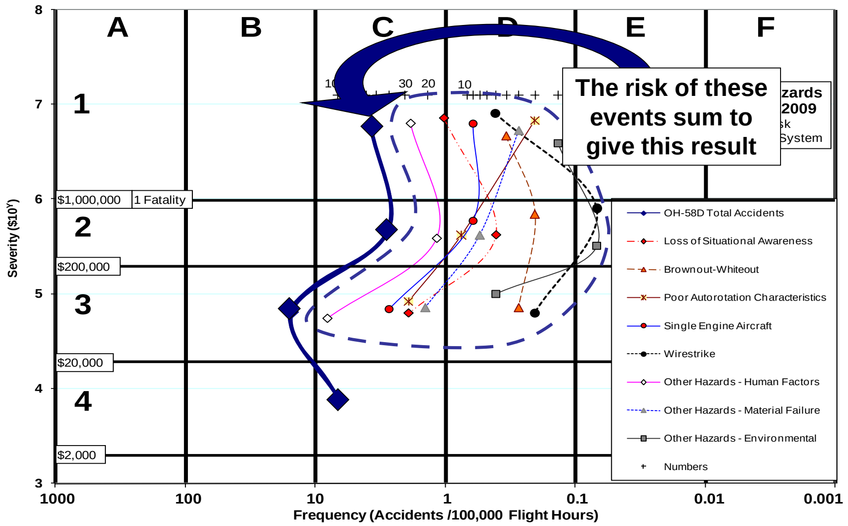
$$= \frac{83}{2,351,860} = 3.529 \text{ mishaps / 100,000 Flt Hrs}$$



US Army Aviation Acci
1 Oct 1993 to 30 Sep 20
Source: US Army
Risk Managment Information Sys
3 January 2011



US Army Aviation Accidents
1 Oct 1993 to 30 Sep 2010
Source: US Army
Risk Managment Information System
3 January 2011



The risk of these events sum to give this result

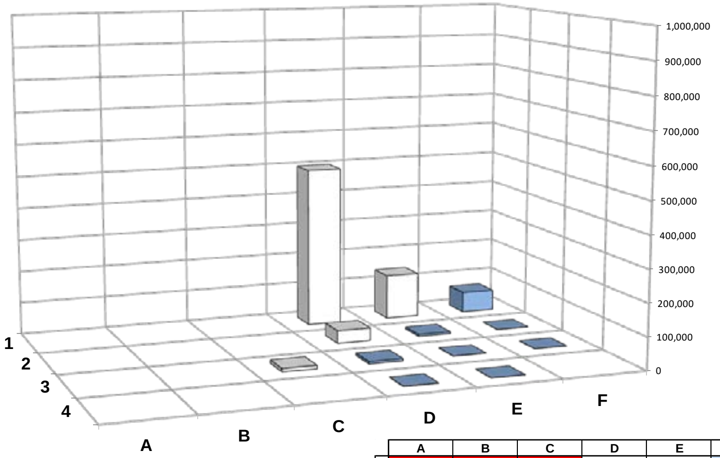
Summary

Relative Risk Values (Clemens)

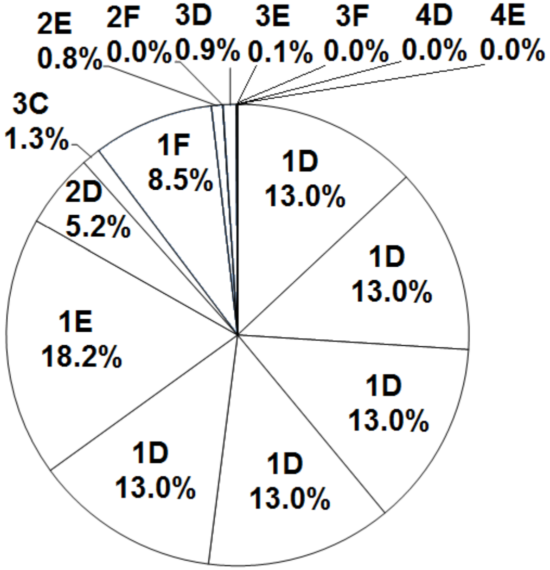
	A	B	C	D	E	F
1	100,000,000	10,000,000	1,000,000	100,000	10,000	1,000
2	10,000,000	1,000,000	100,000	10,000	1,000	100
3	1,000,000	100,000	10,000	1,000	100	10
4	100,000	10,000	1,000	100	10	1

	A	B	C	D	E	F
1				500,000	140,000	65,000
2				40,000	6,000	200
3			10,000	7,000	500	40
4				200	10	

Helicopter A



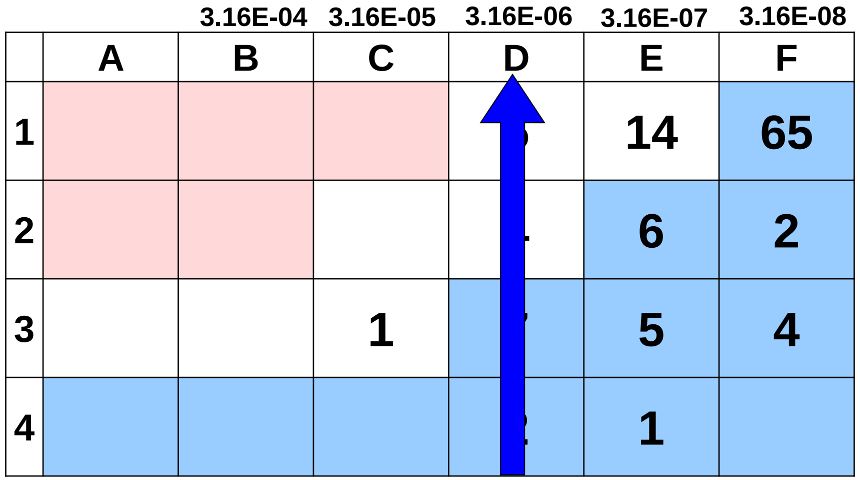
	A	B	C	D	E	F
1				5	14	65
2				4	6	2
3			1	7	5	4
4				2	1	



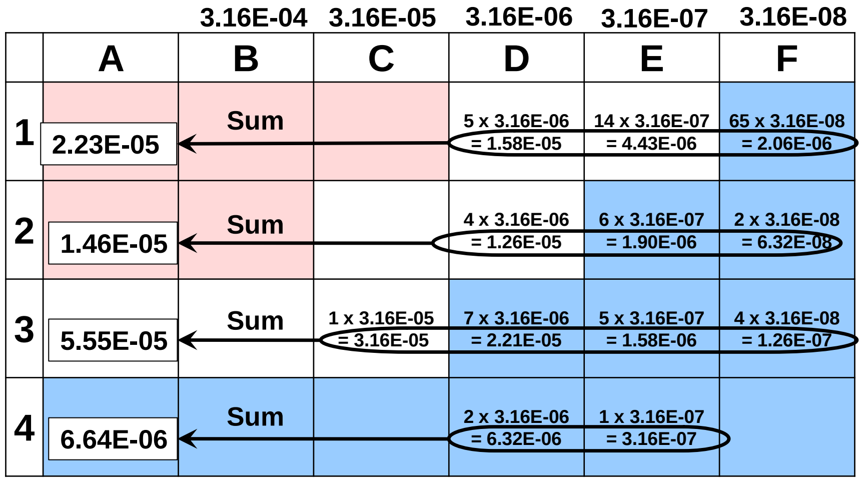
	A	B	C	D	E	F
1				5	14	65
2				4	6	2
3			1	7	5	4
4				2	1	

Summary

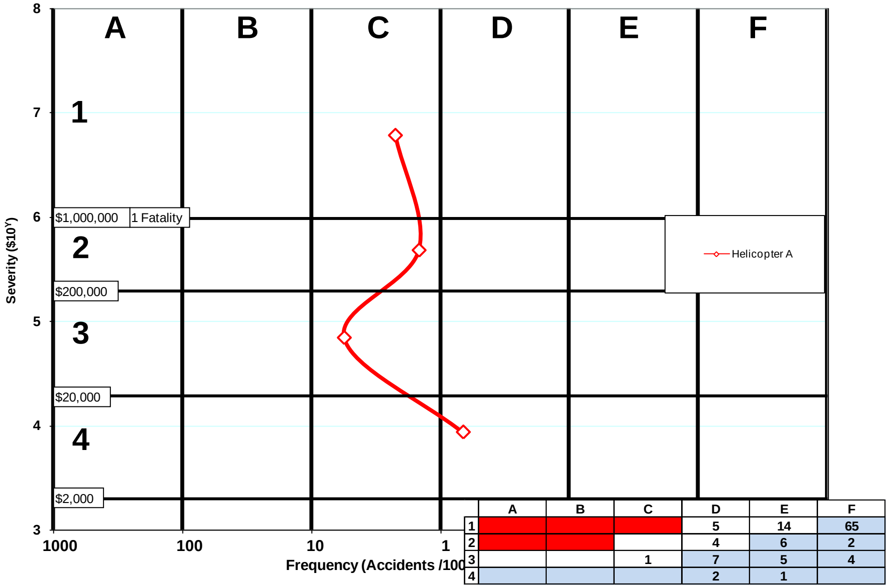
Hazard Risk Profile



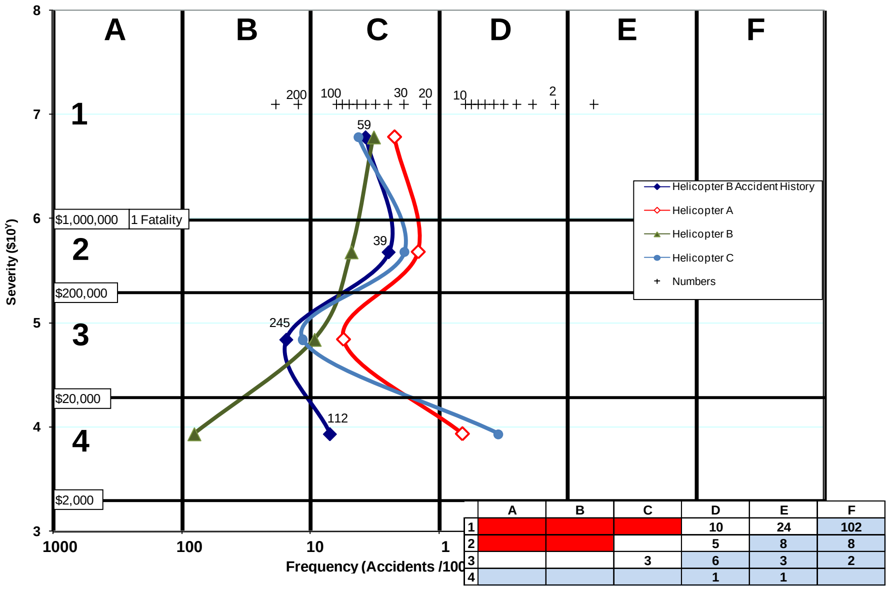
	3.16E-04	3.16E-05	3.16E-06	3.16E-07	3.16E-08	
	A	B	C	D	E	F
1				5	14	65
2				4	6	2
3			1	7	5	4
4				2	1	



		3.16E-04	3.16E-05	3.16E-06	3.16E-07	3.16E-08
	A	B	C	D	E	F
1	2.23E-05	Sum		5 x 3.16E-06 = 1.58E-05	14 x 3.16E-07 = 4.43E-06	65 x 3.16E-08 = 2.06E-06
2	1.46E-05	Sum		4 x 3.16E-06 = 1.26E-05	6 x 3.16E-07 = 1.90E-06	2 x 3.16E-08 = 6.32E-08
3	5.55E-05	Sum	1 x 3.16E-05 = 3.16E-05	7 x 3.16E-06 = 2.21E-05	5 x 3.16E-07 = 1.58E-06	4 x 3.16E-08 = 1.26E-07
4	6.64E-06	Sum		2 x 3.16E-06 = 6.32E-06	1 x 3.16E-07 = 3.16E-07	



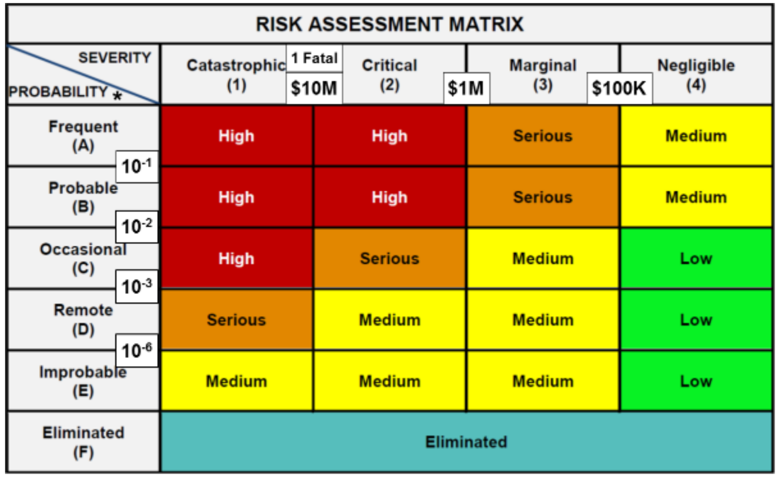
	A	B	C	D	E	F
1				5	14	65
2				4	6	2
3			1	7	5	4
4				2	1	



	A	B	C	D	E	F
1				10	24	102
2				5	8	8
3			3	6	3	2
4				1	1	

Summary

Missile Risk Matrix



RISK ASSESSMENT MATRIX				
SEVERITY PROBABILITY *	Catastrophic (1) 1 Fatal $10M	Critical (2) $1M	Marginal (3) $100K	Negligible (4)
Frequent (A) 10^{-1}	High	High	Serious	Medium
Probable (B) 10^{-2}	High	High	Serious	Medium
Occasional (C) 10^{-3}	High	Serious	Medium	Low
Remote (D) 10^{-6}	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Back of the Envelope Calculation

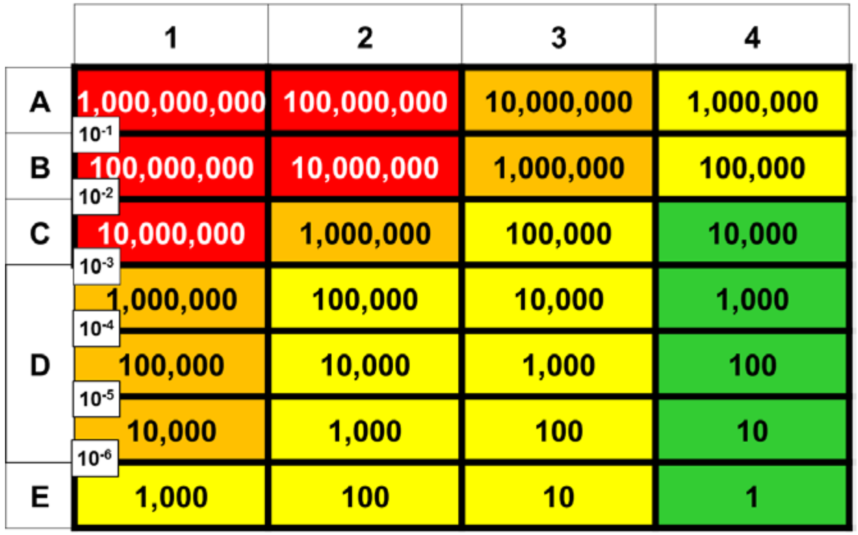
40,000 Shishkebab Missiles

Delivered over 20 years

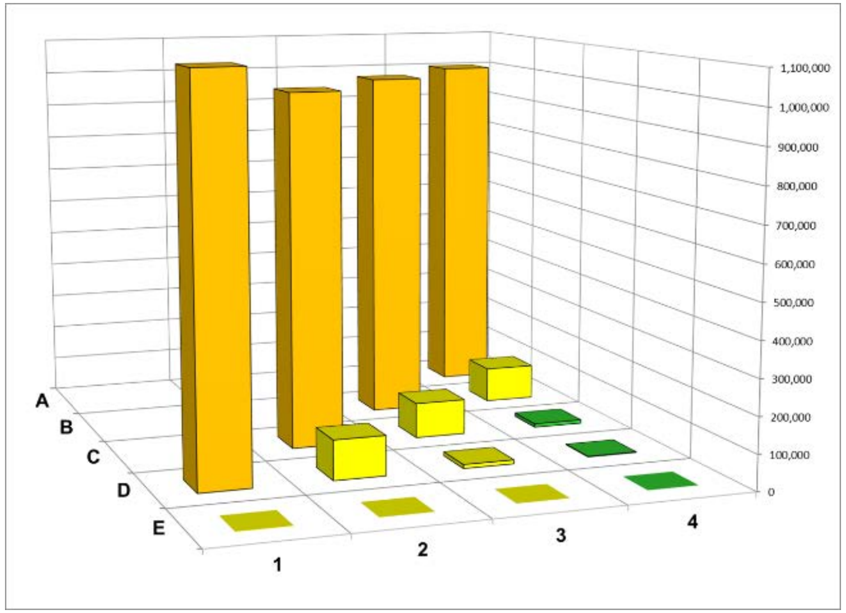
Assume all fired

1 accident in 1,000,000 firings

$$\frac{1 \text{ accident}}{1{,}000{,}000 \text{ \sout{firings}}} \times \frac{40{,}000 \text{ \sout{firings}}}{20 \text{ years}} = \frac{1 \text{ accident}}{500 \text{ years}}$$



	1	2	3	4
A	1,000,000,000 10^{-1}	100,000,000	10,000,000	1,000,000
B	100,000,000 10^{-2}	10,000,000	1,000,000	100,000
C	10,000,000 10^{-3}	1,000,000	100,000	10,000
D	1,000,000 10^{-4}	100,000	10,000	1,000
	100,000 10^{-5}	10,000	1,000	100
	10,000 10^{-6}	1,000	100	10
E	1,000	100	10	1



Take-aways

- High degree of precision? – No
- Gets hazards to the correct cell of the matrix
- Confidence that overall assessment ≈ reality
- Helps communicate risk to the risk acceptor
- Very useful for programs with:
  - Reasonably good accident data for analysis
  - A well-designed matrix
- Just one of many tools for managing system safety risk

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http://www.isss-tvc.org/Matrix_Math_Swallom_Tutorial_2018.pdf

Questions?