Introduction
Risk analysis
Reliability and availability

Faculty of electrical engineering and computing, Zagreb

Outline

- What is risk?
- What is the reason for risk assessment?
- How to assess the risk?
- How to make decisions and manage the risk?
- Can different risks be comparable?

WHAT THE RISK IS?

Ilustration of consequences

A solider walks near the remains of a bus after a train collided with it at a railway crossing in Sri Lanka.

Risk

http://www.merriam-webster.com/dictionary/risk

1 : possibility of loss or injury : PERIL

2 : someone or something that creates or suggests a hazard

3 **a** : the chance of loss or the perils to the subject matter of an insurance contract; *also* : the degree of probability of such loss

b : a person or thing that is a specified hazard to an insurer

c : an insurance hazard from a specified cause or source <war *risk*>

4 : the chance that an investment (as a stock or commodity) will lose value

Hazard:
a source of danger

Risk

- The risk is a potential danger of loosing something valuable (health, life, material goods)
- The risk is a loss, damage or danger (hazard) that can be partially anticipated (to a certain amount) and determined

Risk

- Economic/financial risks
  - Economic risks can be manifested in lower incomes or higher costs than expected.
- Health risks
  - Risks in personal health may be reduced by primary prevention actions that decrease early causes of illness or by secondary prevention (mitigation) actions after a person has clearly measured clinical signs or symptoms recognized as risk factors.
- IT risk
  - Unauthorized (malicious or accidental) access, disclosure, usage, recording, distribution, modification, or destruction of information or the information system
- The risks in social sciences
  - influence of the human factor
- Safety risks
  - traffic – plane/car?
- Industrial risks
- etc.

Example

- You lend the money to a friend:

A) You lend him 1000 dollars, but there is a 1% probability that he will not return you the money back
B1) You lend him 200 dollars, but there is a 10% probability that he will not return you the money back
B2) You lend him 200 dollars, but there is a 5% probability that he will not return you the money back

Which option to choose?

Risk – basics

$$RISK\left[\frac{loss}{time}\right] = PROBABILITY\left[\frac{event}{time}\right] \otimes CONSEQUENCE\left[\frac{loss}{event}\right]$$

- RISK is estimated expectation (probability) of the loss (damage)
- Result which combines the damage (loss) per event and probability of the undesirable event in time
- Method for analysis - Probability risk (safety) assessment

Risk measures

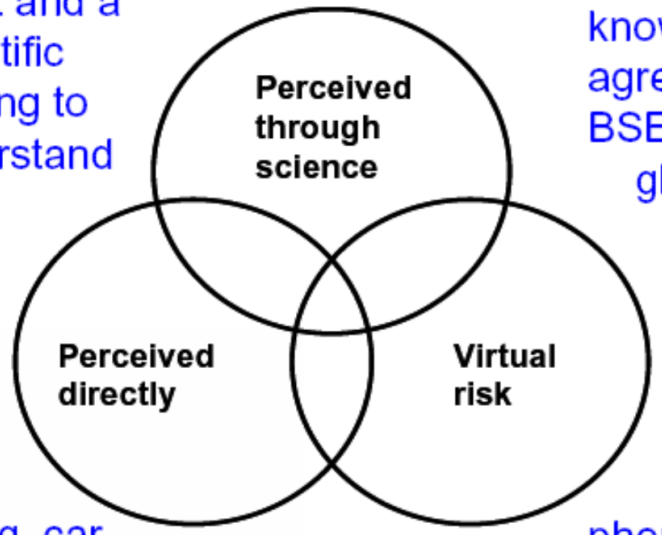
- Consequences:
  - death
  - injury
  - financial damage
- Unit:
  - Year, life, operational period
- Other measures (consequence):
  - Estimated life loss (years)
  - Loss of man-days
  - Loss of life quality
  - …

Definitions of risk and safety

- Risk – empirical or analytical (technical, scientific) measure of relationship between hazard (peril) and safeguard (protection). Risk = Hazard/Protection
- Safety = 1 – Risk
- OR
- Safety = 1 – Tolerance × Risk

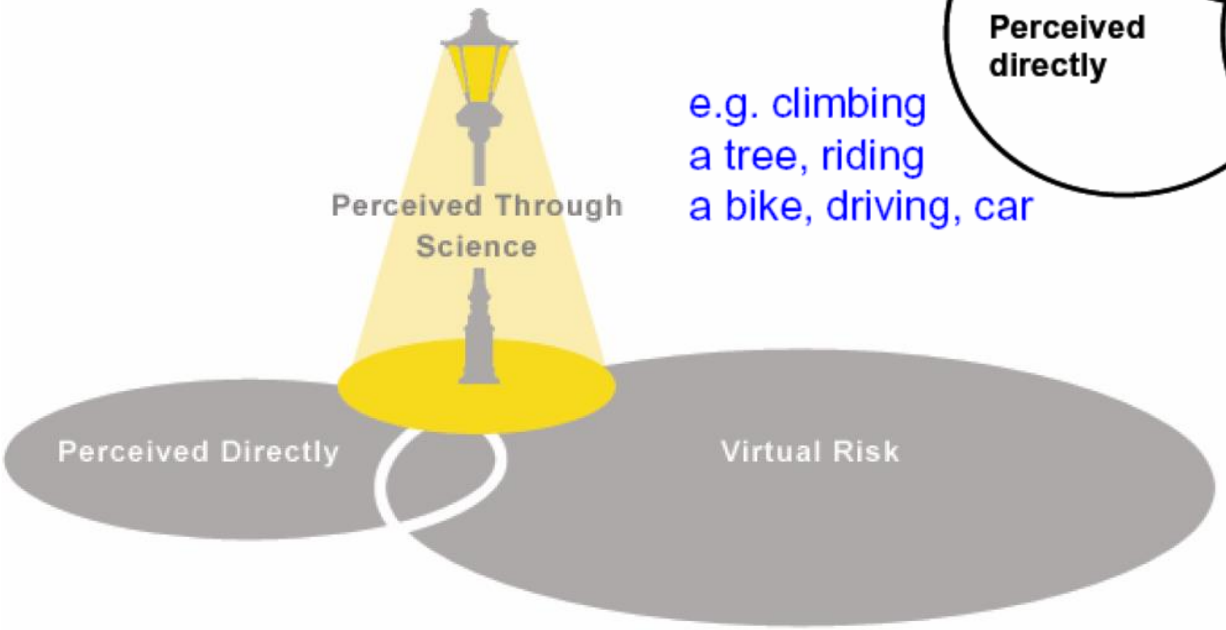
One of possible risk divisions

e.g. cholera: need a microscope to see it and a scientific training to understand



Scientists don't know or cannot agree: e.g. BSE/vCJD, global warming, low-level radiation, pesticide residues, HRT, mobile phones, passive smoking, stock market ….

e.g. climbing a tree, riding a bike, driving, car



prof. J. Adams

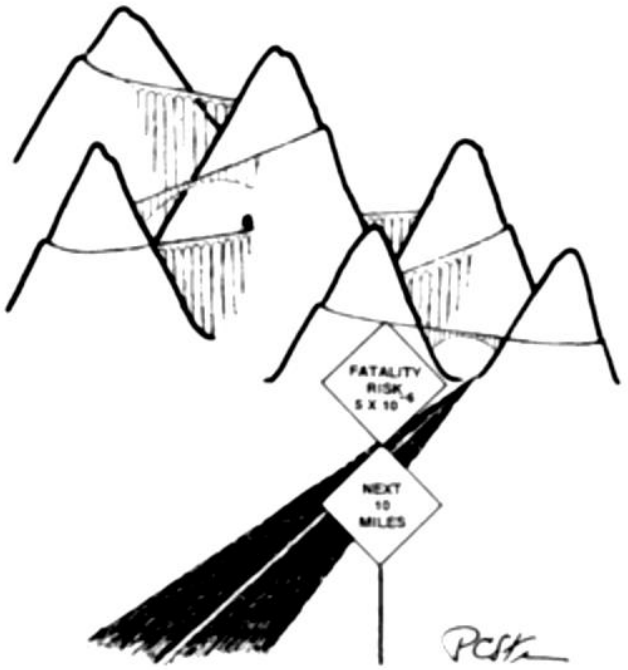


FIGURE 4.1 For personal action to reduce risks, a simple warning sign (e.g., "Hills and Curves Next 10 Miles") may be sufficient; a report of a formal risk analysis could be counterproductive. SOURCE: Courtesy of Paul Stern.

WHY TO ASESS AND ANALYZE THE RISK?

Can the accident be avoided?

Fire caused SpaceX rocket failure

A fire fed by a fuel leak caused the failure of a commercial rocket seconds into its maiden launch, the company that built it has confirmed.

Fire caused the loss of Falcon 1 during lift-off

SpaceX's Falcon 1 rocket was lost during lift-off from an island in the Kwajalein Atoll in the Pacific Ocean.

It was carrying a US Air Force Academy research satellite onboard.

The vision of Elon Musk, co-founder of the electronic payment system PayPal, the Falcon was designed to cut the cost of current satellite launches.

The unexplained fuel leak occurred 25 seconds into the launch near the top of the main engine on the rocket's first stage, SpaceX's founder said.

"Falcon was executing perfectly on all fronts until fire impaired the first-stage pneumatic system," Mr Musk explained.

3 Rulings Find No Link to Vaccines and Autism

By DONALD G. McNEIL Jr.
Published: March 12, 2010

The New York Times

In a further blow to the antivaccine movement, three judges ruled Friday in three separate cases that thimerosal, a preservative containing mercury, does not cause autism.

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The three rulings are the second step in the Omnibus Autism Proceeding begun in 2002 in the United States Court of Federal Claims. The proceeding combines the cases of 5,000 families with autistic children seeking compensation from the federal vaccine injury fund, which comes from a 75-cent tax on every dose of vaccine.

One dead in fire on Princess ship in Caribbean

Reuters
Thursday, March 23, 2006; 11:19 AM

MIAMI (Reuters) -- One passenger died and 11 were hurt when fire broke out on the passenger decks of a Princess Cruises ship on Thursday as the vessel sailed from the Cayman Islands to Jamaica, the cruise line said.

The blaze aboard the Star Princess, which was carrying 2,690 passengers and 1,123 crew, was extinguished but there was smoke throughout the affected area, Princess Cruises, owned by Carnival Corp., said in a statement.

"We deeply regret having to confirm that there has been one passenger fatality following a cardiac arrest, two passengers with significant smoke inhalation injuries and nine passengers with minor complications resulting from smoke inhalation," the statement said.

A file photo of the Star Princess cruise ship, as it passes by the Space Needle in Seattle, Wash., on May 17, 2003. (Ted S. Warren -- AP File Photo)

Huge flood after Hawaii dam bursts

300 million gallons of water released on Kauai; 1 body found, 7 missing


Jan Tenbruggencate / The Honolulu Advertiser

Floodwaters from the Wailapa stream ripped vegetation from the ground on the Hawaiian island of Kauai.

Air pollution tied to increased risk of strokes

Fri Oct 28, 2005 1:00 AM BST

By Anthony J. Brown, MD

NEW YORK (Reuters Health) - Increases in particles polluting the air are associated with an increase in the number of strokes caused by a blood clot in the brain -- but not the type caused by an artery rupture in the brain -- new research shows.

Previous reports have shown a link between air pollution and overall risk of heart attacks and other cardiovascular events, but the specific effect on stroke risk has not been well studied, lead author Dr. Gregory A. Wellenius, from Beth Israel Deaconess Medical Center in Boston, told Reuters Health.

"Our study is the first large study in the US to address this topic," he said

The researchers evaluated the link between air pollution and stroke among Medicare recipients in nine US cities. Specifically, they analyzed data on 155,503 artery-blockage (ischemic) strokes and 19,314 bleeding (hemorrhagic) strokes recorded as hospital admissions between 1986 and 1999.

Acceptability of risk

- Often subjective
- No practical definition
- Perceptions and attitudes vary between different industries
- Comparison is complex and controversial
- Influence of media and interested groups, …
  - For example - Sources of electrical energy

Considerable risk

Life risks regulated by different agencies (USA)

Acceptance criteria

*Risk**	*Substance (statute)*
4×10^{-1}	Arsenic (OSHA)
2×10^{-1}	Ethylene dibromide (OSHA)
1×10^{-1}	Ethylene oxide (OSHA)
6×10^{-2}	Asbestos (OSHA)
3×10^{-2}	Arsenic from primary copper smelting (CAA)
2×10^{-2}	Coke oven emissions (CAA)
1×10^{-2}	Methylenedianiline (TSCA)
1×10^{-2}	Butadiene (TSCA)
1×10^{-2}	Uranium mines (CAA)
5×10^{-3}	Benzene from coke ovens (CAA)
2×10^{-3}	Benzene from fugitive emissions (CAA)
1×10^{-3}	Radionuclides from phosphate mines (CAA)
8×10^{-4}	Arsenic from glass manufacture (CAA)
8×10^{-4}	Radionuclides from DOE installations (CAA)
2×10^{-4}	Workers in coke ovens (OSHA)
1×10^{-4}	Radionuclides from NRC licensees (CAA)

*probability of death after exposure to a maximum allowable level

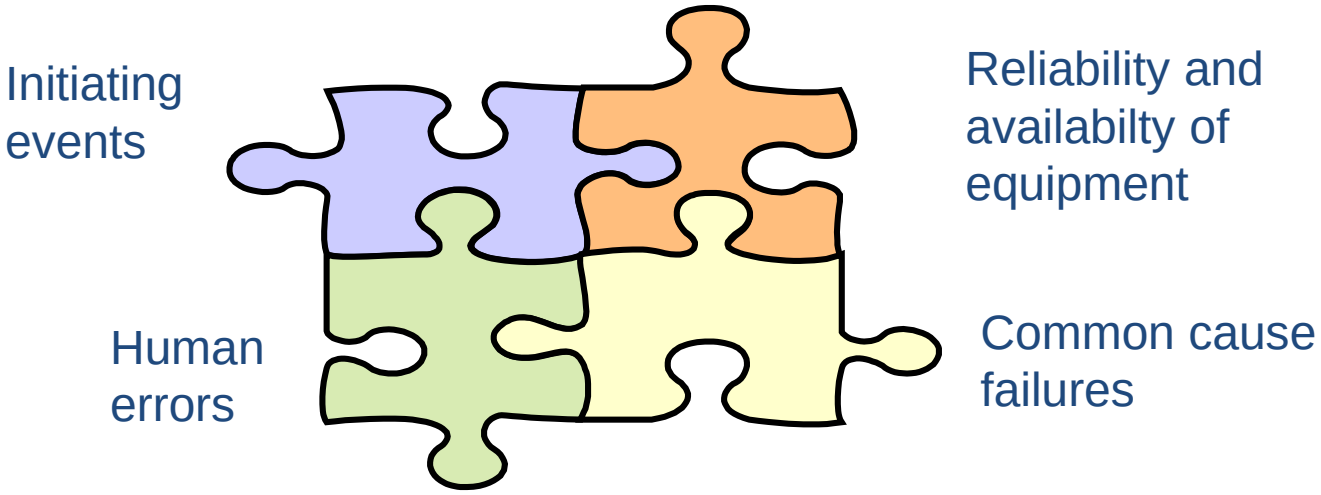
Risk - perception

- The life is being more and more riskier although we live better and better!?
- Perception influences our risk experience
- We are afraid without reason. We are spending our resources on irrelevant things
  - Average life years (USA): 1789. – 35 yrs.
    1920. – 54 yrs. 1985. – 75 yrs.
- We are taking care of diet and every day safety
  - Medicines, vitamins, nutritional supplements, ... are they needed? -> Industry and Media Impact

Kako želite – iz kristalne kugle ili procjenu rizika?

HOW TO ASESS AND ANALYZE THE RISK?

The most important elements and optimization in the PRA



Reliability – mathematical probability of satisfactory work**,** under defined ***working conditions*****,** for a specified **time.**

Availability – mathematical probability of satisfactory work**,** under defined ***working conditions*****, in a randomly selected instant of time in the future.**

Common cause failures – failures that simultaneously affect two or more components having the same cause (fire, flood).

Exposure analysis (probability of an event)

- Different methods depending on the problem and intention of the analysis
- Simple listing and risk matrix – *What-if?*
- HAZOP (*HAZard and OPerability (analysis) and risk matrix*
- FMEA (*Failure Modes and Effects Analysis*) and risk matrix
- Fault tree and event tree – FT & ET
- Markov models, etc.

What-if?

What if…	Risk	Risk reduction	Recommendation
…the pressure is too high?	Process failure	Pressure control stops the process when the pressure is too high.	Nothing
…the air flow rate is blocked between the pressure switch and the heater?	Heater burnout and smoke, potential evacuation.	Installation of a swich associated with the air flow.	Installation of a switch.
…the personnel comes in contact with the voltage equipment?	Electric shock, injury.	The tools are needed for the door to be open.	Nothing, the risk is too small.

HAZOP (HAZard and Operability)

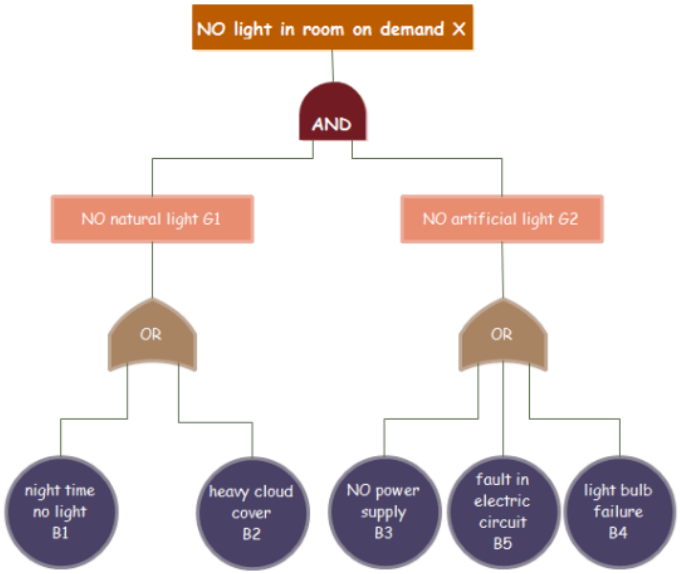
Deviation (Guide words) Parameter	Wrong	Low	Nothing	Reverse	Too high	High
Erosion					High erosion	
Information	Wrong information		No information			
Concentration	Wrong concentration					
Corosion					Large corosion	
Material	Wrong material					
Level		Low level				High level
Flow rate		Low flow	No flow	Reverse flow		High flow
Temperature		Low temperature				High temperature
Pressure		Low pressure				High presssure
Viscosity		Low viscosity				High viscosity
Time	Wrong time	Short time				Longer time
Pollution						High polution

FMEA (Failure Modes and Effects Analysis)

Eq.	Damage	Cause of the damage	Possible consequences	Probability	Criticality	Possible prevention	Recommendations
Pumpa XYZ	Cavitation	1. inlet filter plugged	Vibration and pump damage	0,0006	critical	Auxiliary pump with auto start with filter	Development of a procedure for controlling the purity of the aux. pump filter
		2. low suction pressure	Vibration and pump damage	0,0001	critical	Quality control and testing	No additional demands.
	Leakage	…	…	…	…	…	…
	Break	…	…	…	…	…	…

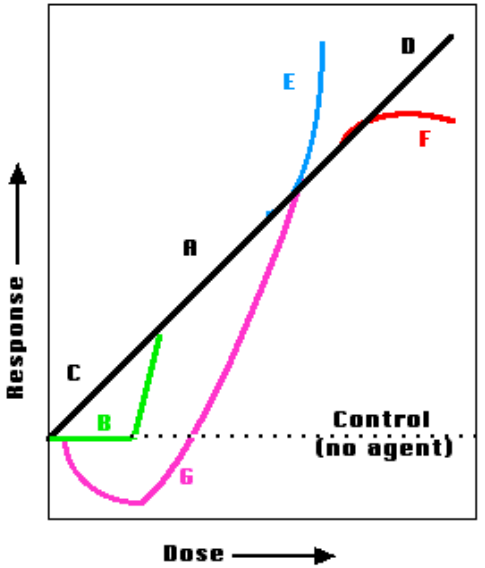
Event/Fault Tree

Initiating Event	Pivotal Events: Fire Detection Works	Pivotal Events: Fire Alarm Works	Pivotal Events: Fire Sprinkler System Works	Outcomes	Prob
Fire Starts ($P = 0.01$)	YES ($P = 0.9$)	YES ($P = 0.7$)	YES ($P = 0.8$)	Limited damage	0.00504
			NO ($P = 0.2$)	Extensive damage, people escape	0.00126
		NO ($P = 0.3$)	YES ($P = 0.8$)	Limited damage, wet people	0.00216
			NO ($P = 0.2$)	Death/Injury, extensive damage	0.00006
	NO ($P = 0.1$)			Death/Injury, extensive damage	0.001



Determination of consequences

- The best source are experience and testing
- **If no testing and experience available -> then mathematical modelling**
- Great uncertainty in determination of consequences (larger than exposure-probability)



http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/CancerRisk.html

Illustration of complexity

For example – loss of electrical energy:

- Direct consequences
  - Simple
    - economy, malfunctions, health, EPS, …
  - complex
    - transport, leisure activities, psychological, ...
- Indirect consequences
  - robberies, civic protests, evacuations, economic and political

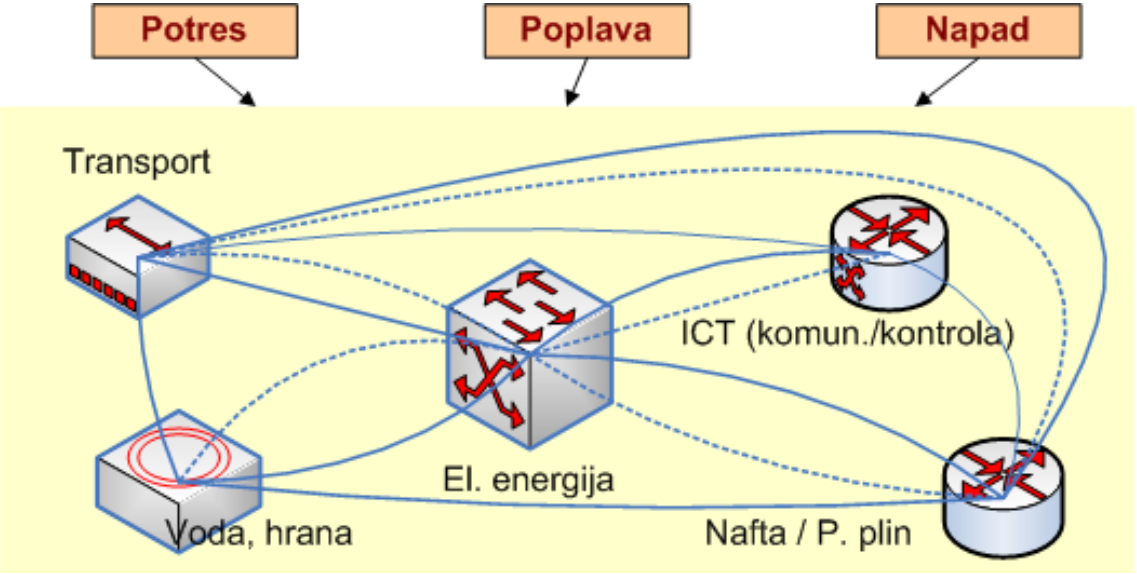


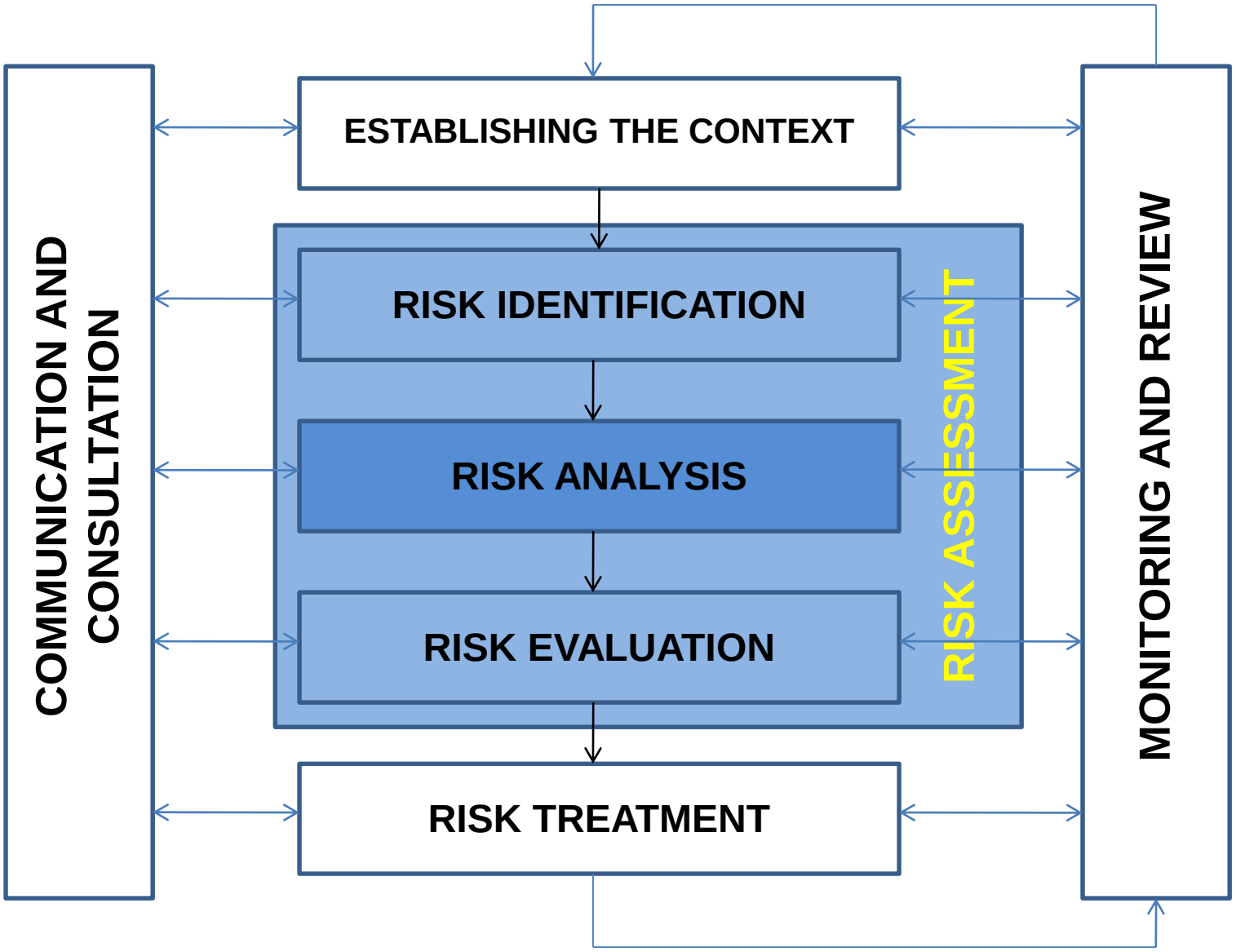
FIGURE 2.2 SOURCE: Drawing by Richter; ©1988 The New Yorker Magazine, Inc.

DECISION AND RISK MANAGEMENT

BASIS – SAFETY

- Safety
  - Safe and economic operation, maintenance and development
  - No simple solution –> optimizing
    - Higher price doesn't mean higher safety
- Optimizing
  - achieving desired performances while minimizing risks and cost
- Risk reduction
  - Better design, diversification, redundancy, passive safety

RISK MANAGEMENT – ISO 31000:2009



RISK MANAGEMENT – ISO 31000:2009

- Communication and consultation
  - plans for communication and consultation should be developed at an early stage. These should address issues relating to the risk itself, its causes, its consequences (if known), and the measures being taken to treat it. Effective external and internal communication and consultation should take place to ensure that those accountable for implementing the risk management process and stakeholders understand the basis on which decisions are made, and the reasons why particular actions are required.
  - Objectives: help establish the context appropriately, ensure that the interests of stakeholders are understood, help ensure that risks are adequately identified, bring different areas of expertise together for analyzing risks

RISK MANAGEMENT – ISO 31000:2009

- Monitoring and review
  - Both monitoring and review should be a planned part of the risk management process and involve regular checking or surveillance. It can be periodic or *ad hoc*.
  - Objectives: ensuring that controls are effective and efficient in both design and operation; obtaining further information to improve risk assessment; analyzing and learning lessons from events and accidents; detecting changes in the external and internal context, including changes to risk criteria and the risk itself which can require revision of risk treatments and priorities; and identifying emerging risks.

RISK MANAGEMENT – ISO 31000:2009

- Establishing the context
  - By establishing the context, the organization articulates its objectives, defines the external (the social, political, legal, regulatory, technological, economic and natural environment) and internal (within single organization or industrial facility) parameters to be taken into account when managing risk, and sets the scope and **defines risk criteria (quantitative/qualitative values)** for the remaining process.

RISK MANAGEMENT – ISO 31000:2009

- Risk identification (part of risk assessment)
  - The organization should identify sources of risk, areas of impacts, events, their causes and potential consequences. The aim of this step is to generate a comprehensive list of risks that might create, enhance, prevent, degrade, accelerate or delay the achievement of risk management objectives. Comprehensive identification is critical, because a risk (particular accident) that is not identified at this stage will not be included in further analysis.

RISK MANAGEMENT – ISO 31000:2009

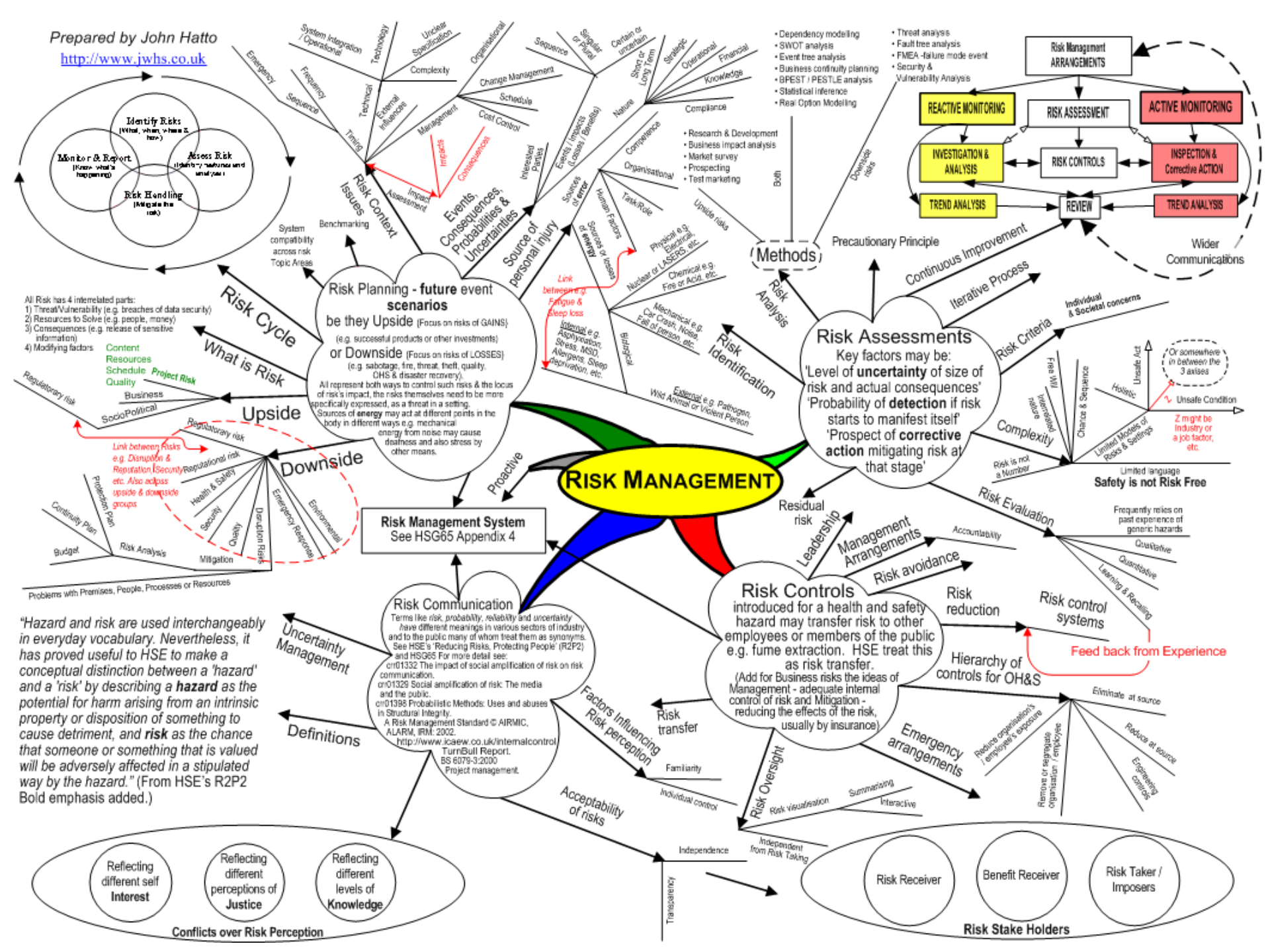
- Risk analysis (part of risk assessment)
  - Risk analysis involves consideration of the causes and sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur. Factors that affect consequences and likelihood should be identified. Risk is analyzed by determining consequences and their likelihood, and other attributes of the risk.
  - Risk analysis can be undertaken with varying degrees of detail, depending on the risk, the purpose of the analysis, and the information, data and resources available. Analysis can be qualitative or quantitative, or a combination of these, depending on the circumstances.
  - Consequences and their likelihood can be determined by modelling the outcomes of an event, or by extrapolation from experimental studies or from available data.

RISK MANAGEMENT – ISO 31000:2009

- Risk evaluation (part of risk assessment)
  - The purpose of risk evaluation is to assist in making decisions, based on the outcomes of risk analysis, about which risks need treatment and the priority for treatment implementation.
  - Risk evaluation involves comparing the level of risk found during the analysis process with risk criteria established when the context was considered. Based on this comparison, the need for treatment can be considered.

RISK MANAGEMENT – ISO 31000:2009

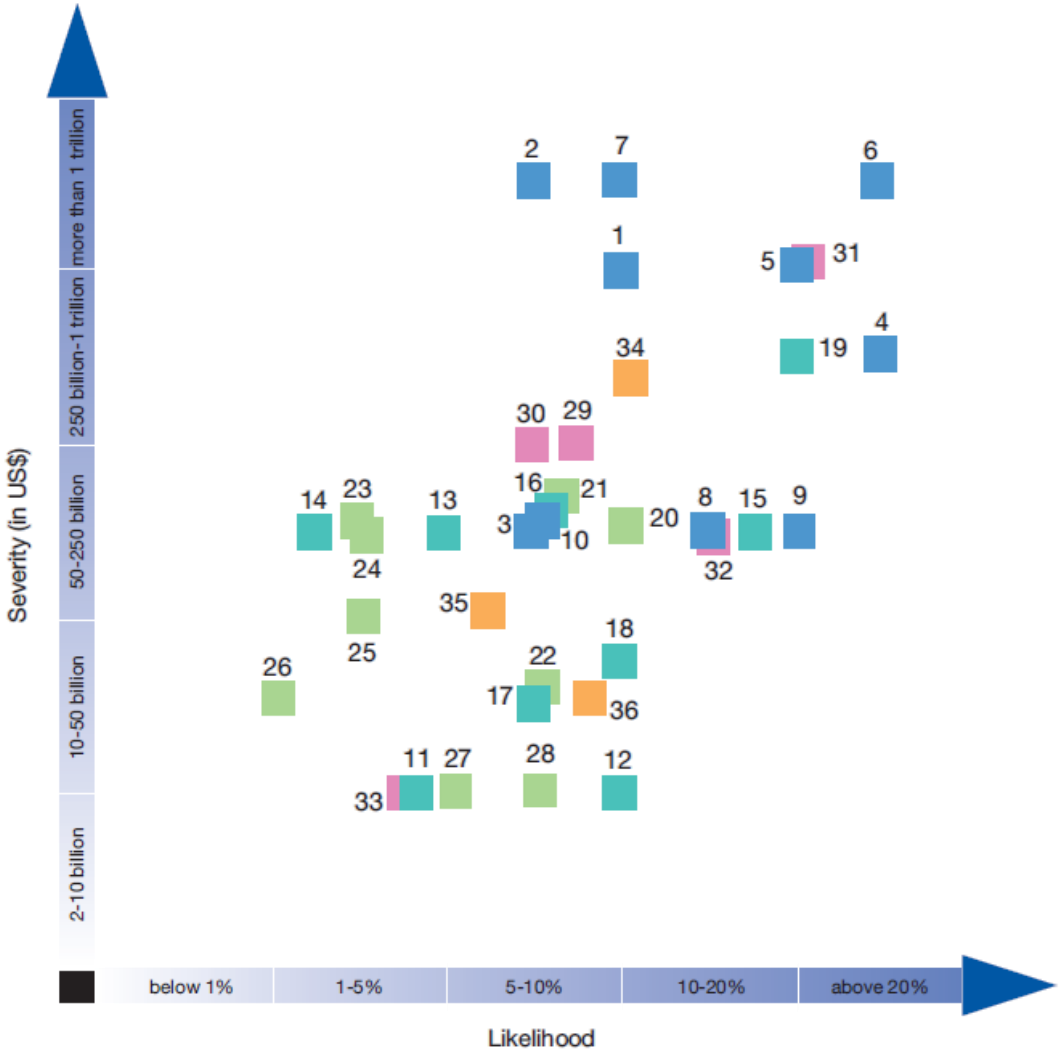
- Risk treatment
  - Risk treatment involves selecting and implementing one or more options for reducing risks.
  - Selecting the most appropriate risk treatment option involves balancing the costs and efforts of implementation against the benefits derived, with regard to legal, regulatory, and other requirements such as social responsibility and the protection of the natural environment. Decisions should also take into account risks which can warrant risk treatment that is not justifiable on economic grounds, e.g. severe (high negative consequence) but rare (low likelihood) risks.



*"Hazard and risk are used interchangeably in everyday vocabulary. Nevertheless, it has proved useful to HSE to make a conceptual distinction between a 'hazard' and a 'risk' by describing a **hazard** as the potential for harm arising from an intrinsic property or disposition of something to cause detriment, and **risk** as the chance that someone or something that is valued will be adversely affected in a stipulated way by the hazard."* (From HSE's R2P2 Bold emphasis added.)

HOW TO MAKE DECISIONS AND MANAGE THE RISKS OR CAN THE RISKS BE COMPARED TO EACH OTHER ?

Global risks 2010 – US$



ECONOMIC

1 Food price volatility
2 Oil and gas price spike
3 Major fall in US$
4 Slowing Chinese economy (<6%)
5 Fiscal crises
6 Asset price collapse
7 Retrenchment from globalization (developed)
8 Retrenchment from globalization (emerging)
9 Regulation cost
10 Underinvestment in infrastructure

GEOPOLITICAL

11 International terrorism
12 Collapse of NPT
13 US/Iran conflict
14 US/DPRK conflict
15 Afghanistan instability
16 Transnational crime and corruption
17 Israel-Palestine conflict
18 Violence in Iraq
19 Global governance gaps

ENVIRONMENTAL

20 Extreme climate change related weather
21 Droughts and desertification
22 Loss of freshwater
23 Nat. Cat: Cyclone
24 Nat. Cat: Earthquake
25 Nat. Cat: Inland flooding
26 Nat. Cat: Coastal flooding
27 Air pollution
28 Biodiversity loss

SOCIETAL

29 Pandemic
30 Infectious disease
31 Chronic disease
32 Liability regimes
33 Migration

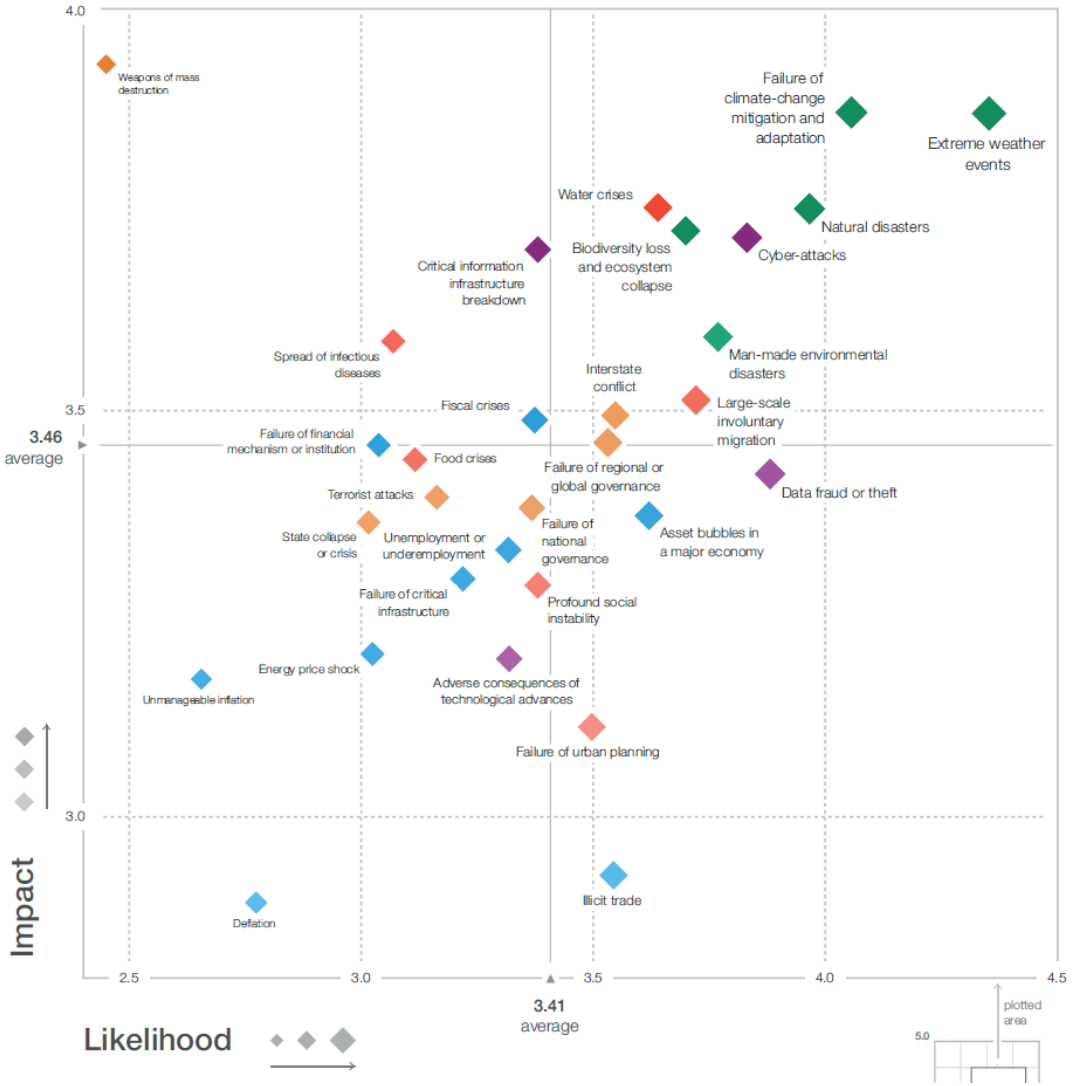
TECHNOLOGICAL

34 Crit. Inf. Infrastructure breakdown
35 Emergence of nanotechnology risks
36 Data fraud/loss

Source: World Economic Forum 2010

http://www.weforum.org/en/initiatives/globalrisk/index.htm

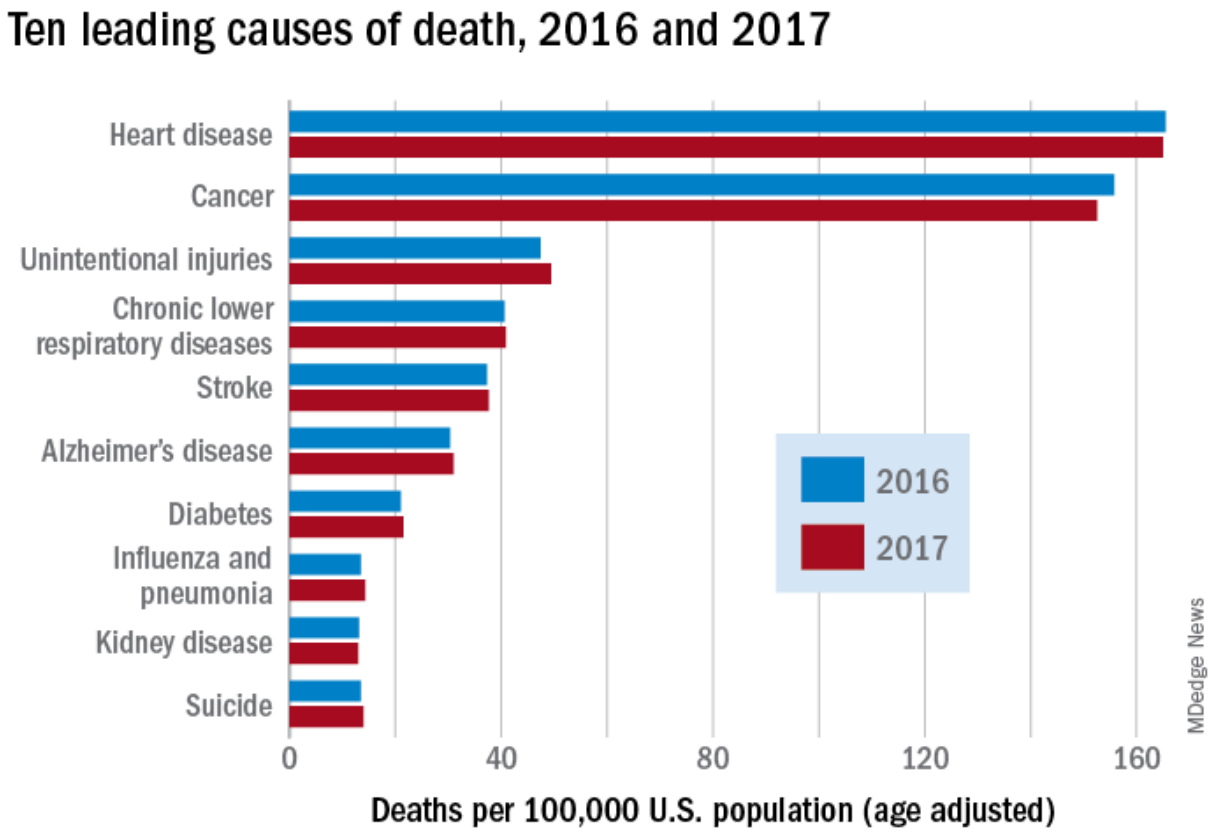
Figure I: The Global Risks Landscape 2019



Izvor: World Economic Forum 2019

http://www.weforum.org/

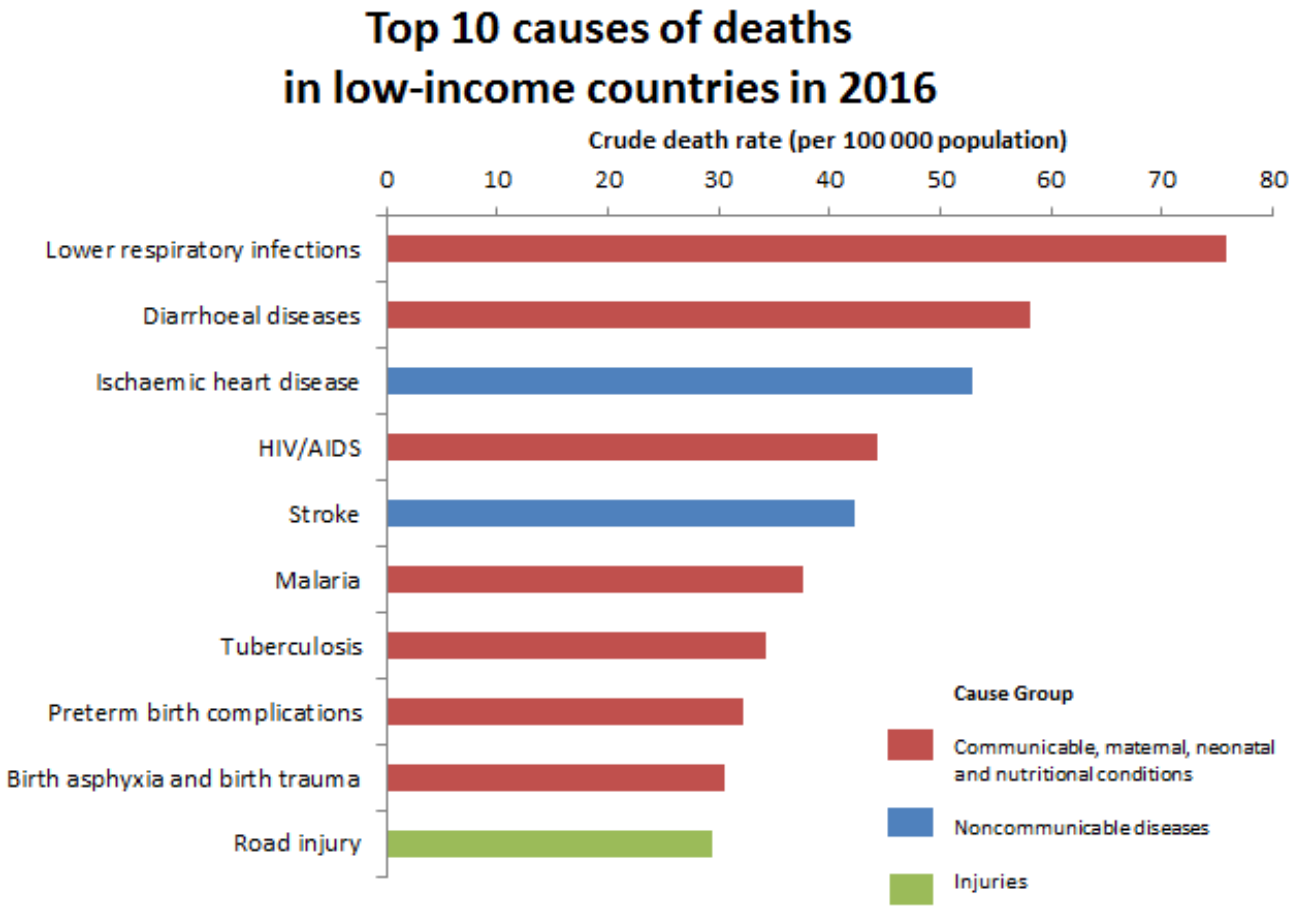
Life risks



Note: Based on data from the National Vital Statistics System.

Source: National Center for Health Statistics

Life risks



Source: Global Health Estimates 2016: Deaths by Cause, Age, Sex, by Country and by Region, 2000-2016. Geneva, World Health Organization; 2018.
World Bank list of economies (June 2017). Washington, DC: The World Bank Group; 2017 (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups).

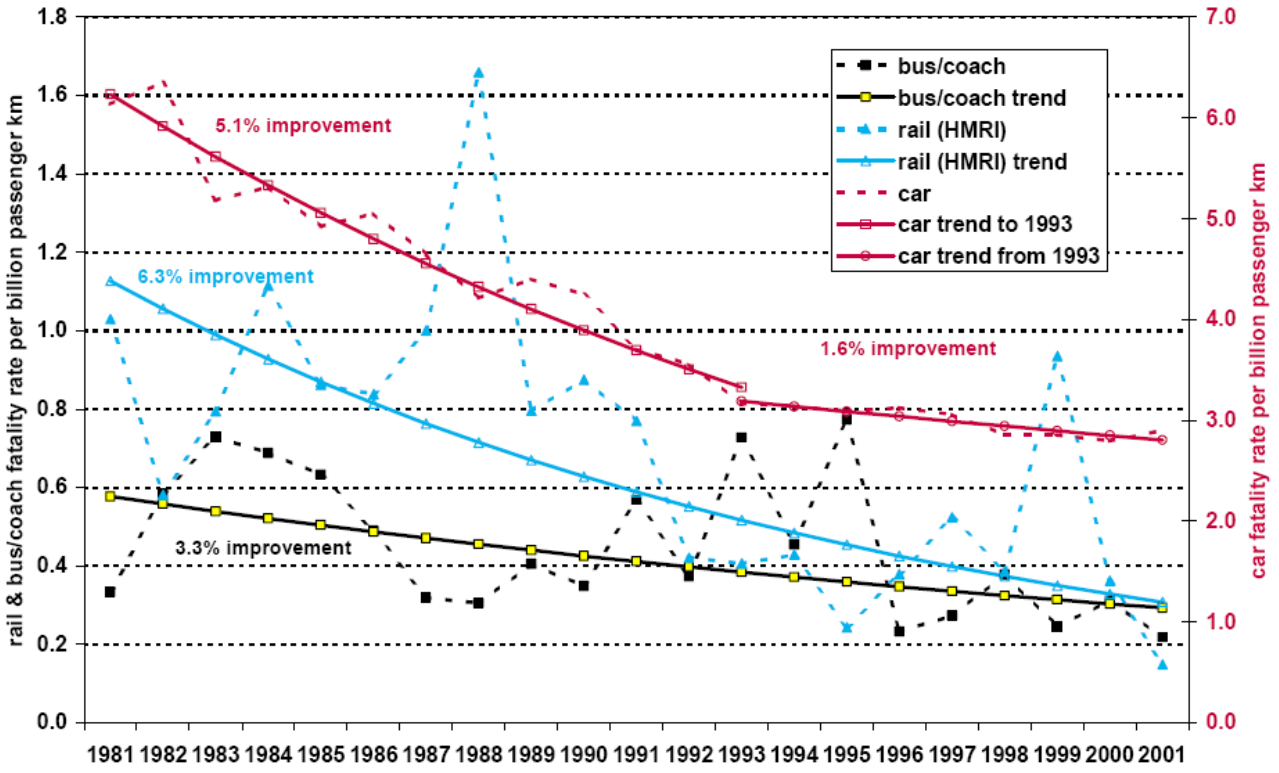
Table 3: Passenger fatalities by alternative comparison bases (EU basis)

Per billion passenger km		Per billion passenger hours	
Rail	0.4	Rail	20
Air	0.8	Bus or coach	20
Bus or coach	0.8	Ferries	105
Ferries	3.3	Car	300
Car	8	Foot	300
Pedal cycle	63	Air	365
Foot	75	Pedal cycle	900
Motor cycle / moped	160	Motor cycle / moped	5,000

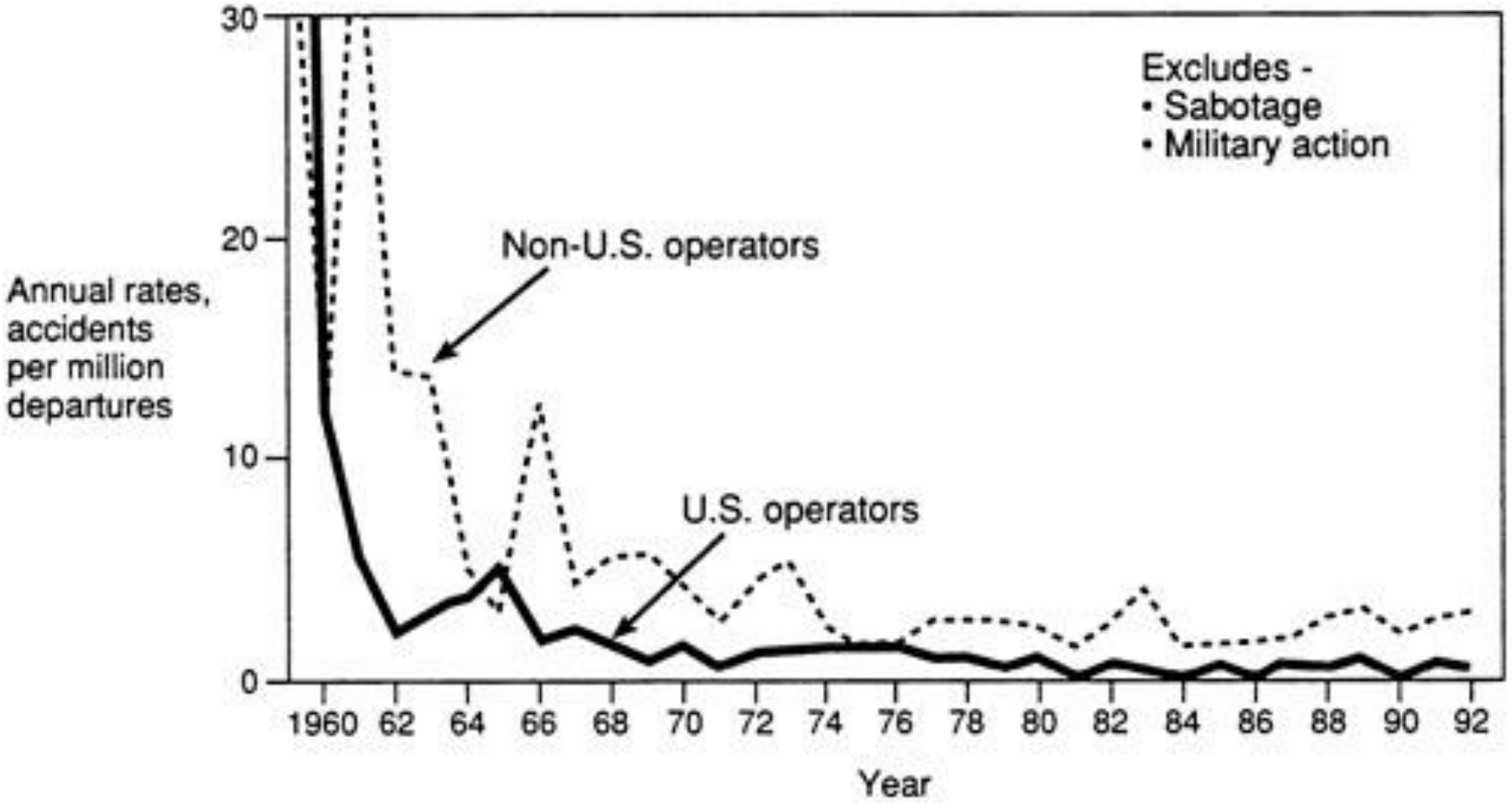
Source: EU Transport Safety Council, May 1999

Transport safety

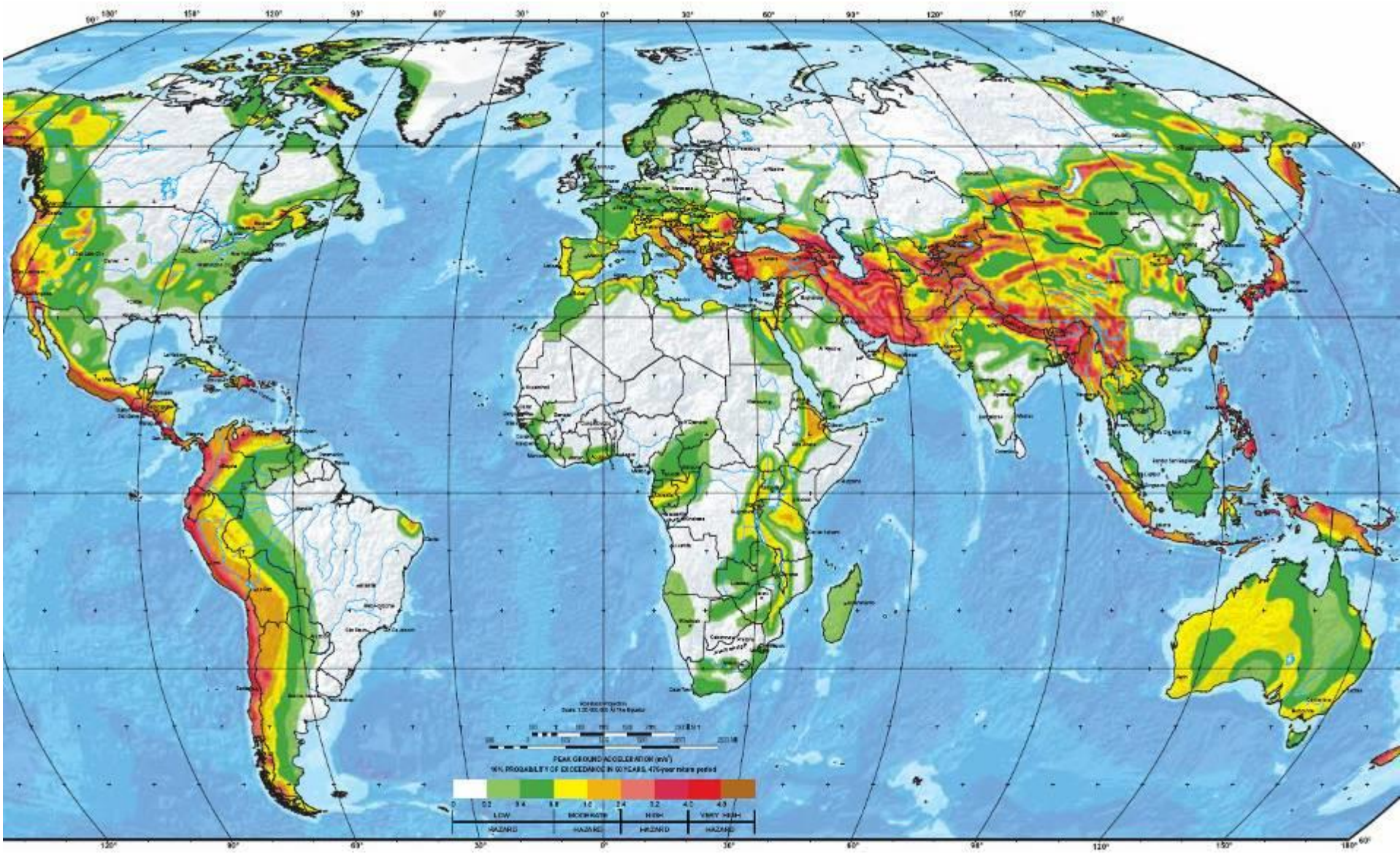
Chart 10: Trends in safety performance for different transport modes



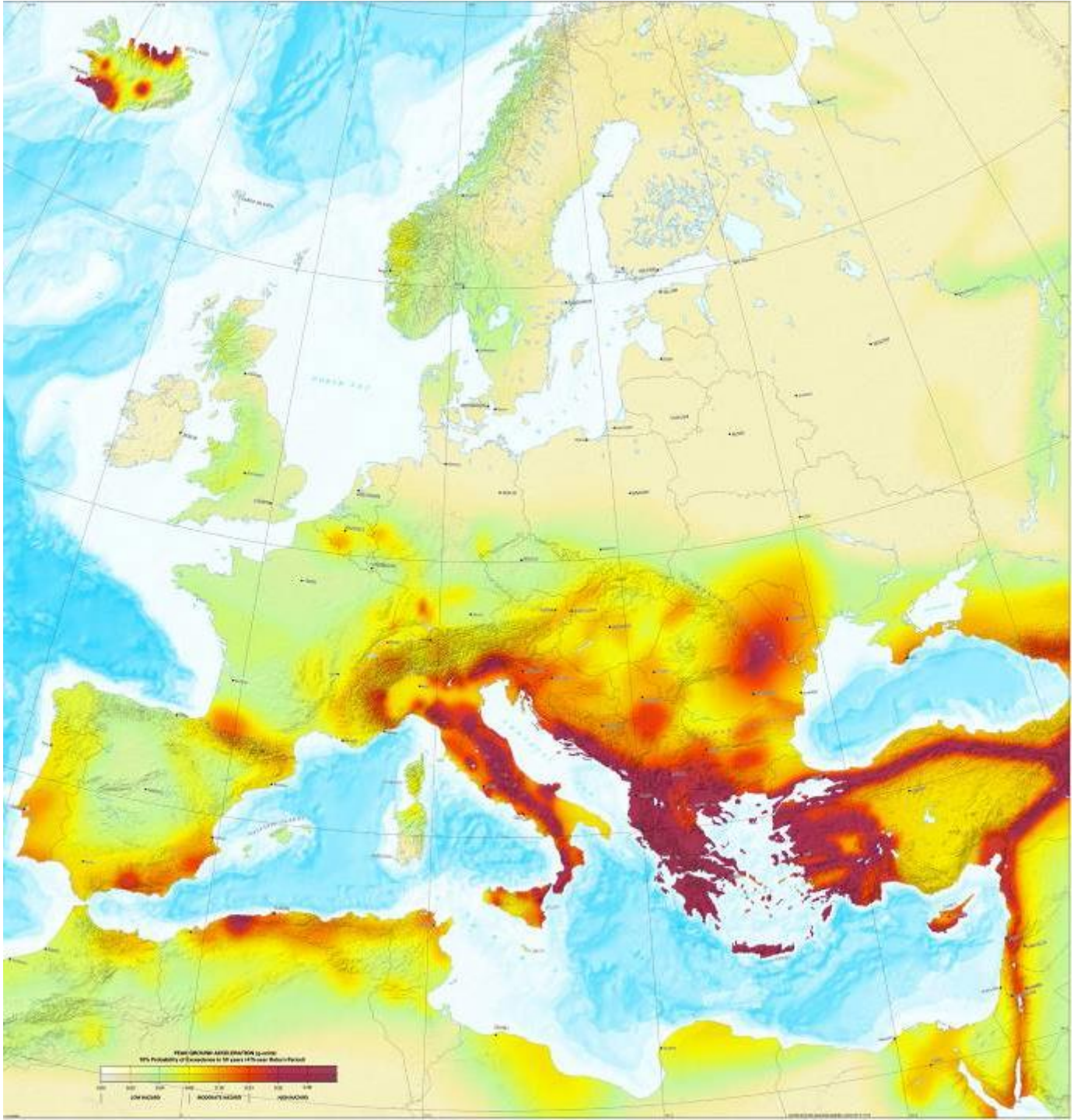
Plane accidents



Earthquake risk



Earthquake risk



Risk increase by 10^{-6}

1.	1/2 l of wine	› Liver cirrhosis
2.	Eating 100 well done steaks	› cancer
3.	Travelling 16 km by bike, 480 km by car or 1600 km by plane	› accident
4.	Travelling 10.000 km by plane	› Cancer (radiation)
5.	X-ray diagnostics	› Cancer (radiation)
6.	Smoking 1,4 cigarettes	› Cancer, heart disease
7.	Spending 3 hrs in a coal mine	› accident
8.	Living 150 yrs 30 km away from the nuclear power plant	› Cancer (radiation)

Cost of saving a human life (1/2)

- Fire detectors in homes (~$0)
- Vaccination of children (~$0)
- Mammography for women above 50 yrs ($810); between 35-49 yrs ($10.000)
- Chlorinating drinking water ($3.100)
- Smoking counselling (>20 cigarettes per day) to stop smoking ($9.800)
- Improving driving training ($20.000)
- Signalization on rail crossings ($45.000)

Harvard University Center for Risk Analysis; 1993$; Tengs et al. 1995.

Cost of saving a human life (2/2)

- Airbags in cars ($120.000)
- First aid training for drivers ($180.000)
- Disc brakes in cars (instead of drum brakes) ($240.000)
- Safety belts in school buses ($2.800.000)
- Strengthening of buildings in earthquake areas ($18.000.000)
- Restrictions for radioactivity releases from NPPs ($18.000.000)
- Restrictions for benzene releases from rubber factories ($20.000.000.000)

Harvard University Center for Risk Analysis; 1993$; Tengs et al. 1995.

Thank you for your attention!

If a man will begin with certainties,
he shall end in doubts;
but if he will be content to begin
with doubts he shall end
in certainties. – Francis Bacon

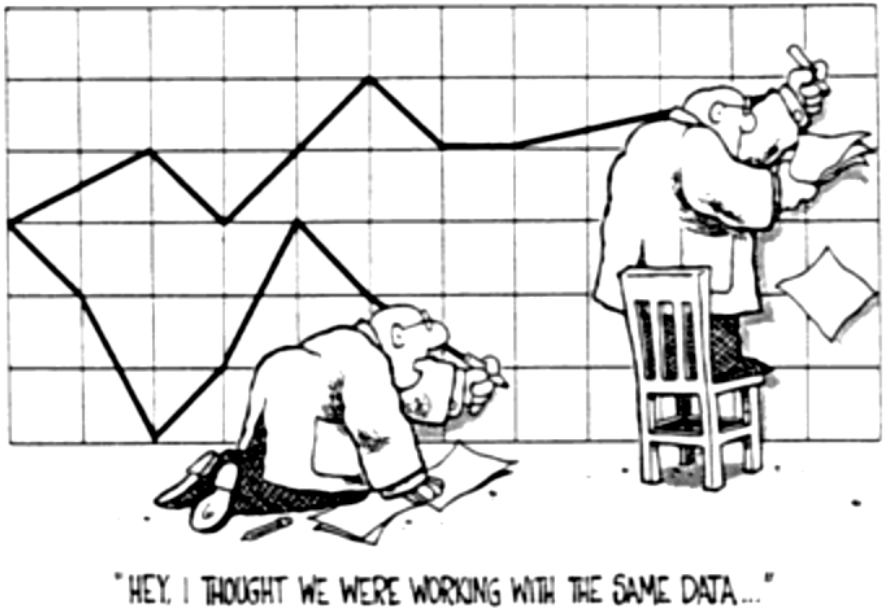


FIGURE 2.3 SOURCE: *National Wildlife Magazine*, August–September, 1984.
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The idea of calculation is knowledge and not numbers.

*Model looks perfect, it was calculated on a supercomputer, results are displayed in **colours** – How can they be wrong?*

We have never been able before to compute wrong result so fast!

Absolute certainty is a privilage of uneducated minds and fanatics. – C.J. Keyser