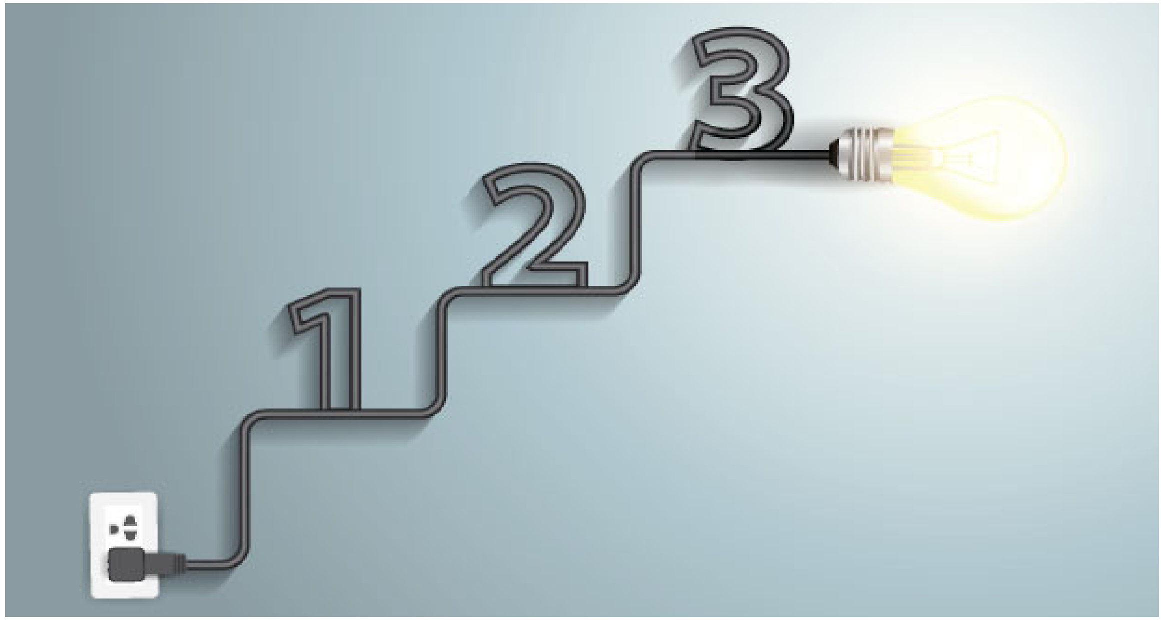
Three academic steps towards the man-made disaster prevention: Identification, Assessment, Dealing with Uncertainties



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Outline of the talk

***Step 1* Identification**

1 – What is man-made disaster from academic perspective
2 – What is a catastrophe (disaster) and what is not ?
3 – Criteria for identification

***Step 2* Assessment**

1 – Who assesses?
2 – Components of assessment
3 - Few useful methods

***Step 3* Uncertainties**

1 – Uncertainty and probability in man-made disasters prevention
2 – Sources of uncertainties
3 – Living in Uncertain World: Concepts of resilience and adaptive management

Instead of the Introduction:
the story with the Catastrophe theory

Science has at its disposal the theory devoted to disasters and rapid transformations of a system. It is the **catastrophe theory,** originated in the 1960s by French mathematician Rene Thom and later developed by Christopher Zeeman.

To discuss in brief the catastrophe theory is a good starting point for the presentation from two reasons.

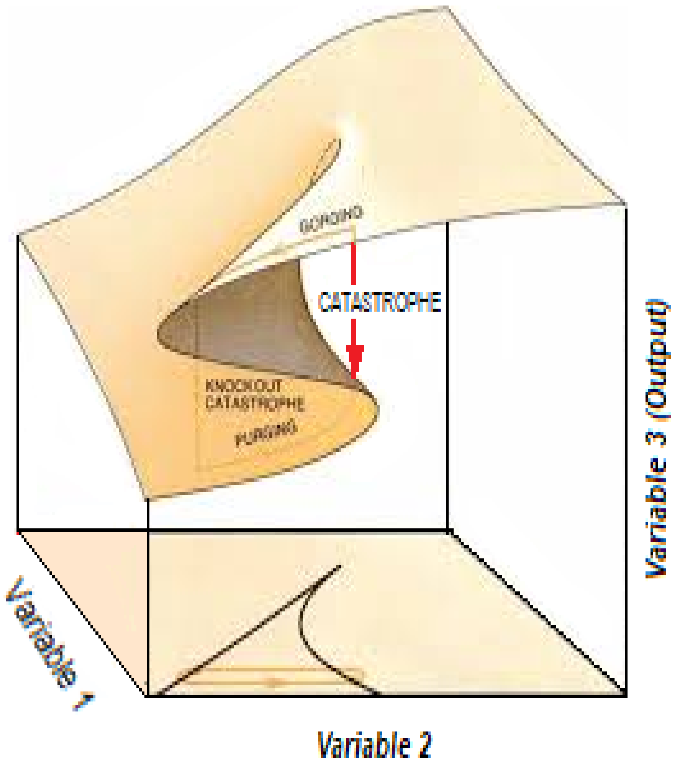
First, we simply can not omit this theory as it is the popular scientific conception of rapid changes in systems behavior. There is a believe the catastrophe theory could be applied to various fields in making predictions of processes involving sudden changes like technological accidents, natural and man-made disasters, social crises, extinction of biological species etc.

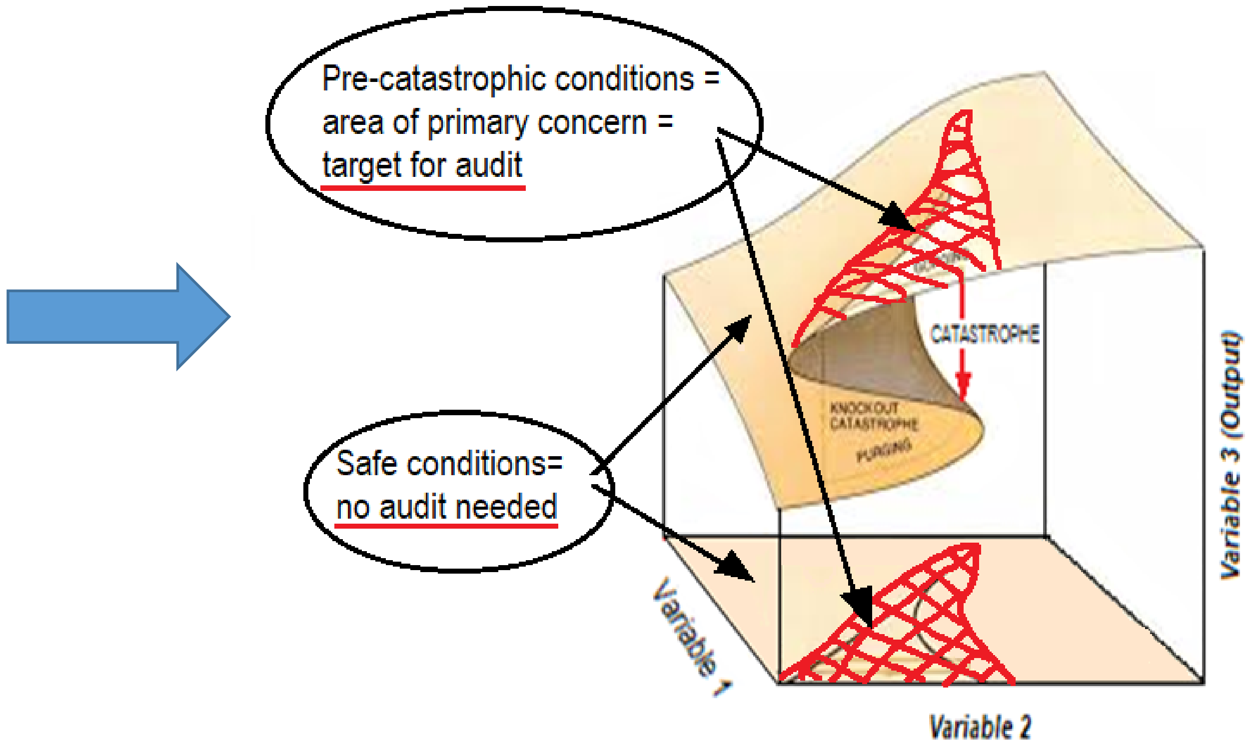
Second, the catastrophe theory serves as a good example of the possibilities and limitations of scientific concepts when applied to the real world, particularly to the analysis of complex multifactorial phenomena.

René Thom

Instead of the Introduction:
the story with the Catastrophe theory

Catastrophe theory defines catastrophe as ***sudden shifts in behavior arising from smooth variation of the underlying parameters***. In other wording, ***small changes in certain variables of a system can cause equilibria to disappear, leading to large and sudden changes*** of the behavior of the system. Theory can predict the conditions and the directions of system dynamics which could lead to the catastrophe. An attractive feature of catastrophe theory is that both the dynamics of the system and its catastrophe can be shown graphically.





Instead of the Introduction:
the story with the Catastrophe theory

What happens when catastrophe theory meets the practice:

1- The theory is well defined for systems up to five input variables, and one or two output (response) variables. For the analysis of multifactorial changes it is poorly adapted. In the real world, these conditions (up to 5 factors only) rarely occur. Many more variables come into play when dealing with disasters.

2- The prediction of time when catastrophe would happen is problematic, the theory predicts conditions under which the catastrophe could occur.

3- Catastrophe in catastrophe theory is just rapid change of a systems output, and does not necessarily bear negative connotations.

4- Only qualified mathematicians are able to apply the theory for disaster auditing.

What I can recommend:

1 – if the system or project you plan to audit could be characterized with no more than 4 input parameters and 2 output (response) parameters you could use the catastrophe theory

2 – If you are not well trained in mathematics (topology) you should ask professional mathematician to do the job – to indentify the conditions leading to the catastrophe

3 – if the description of a system needs more than 5 parameters do not even try catastrophe theory

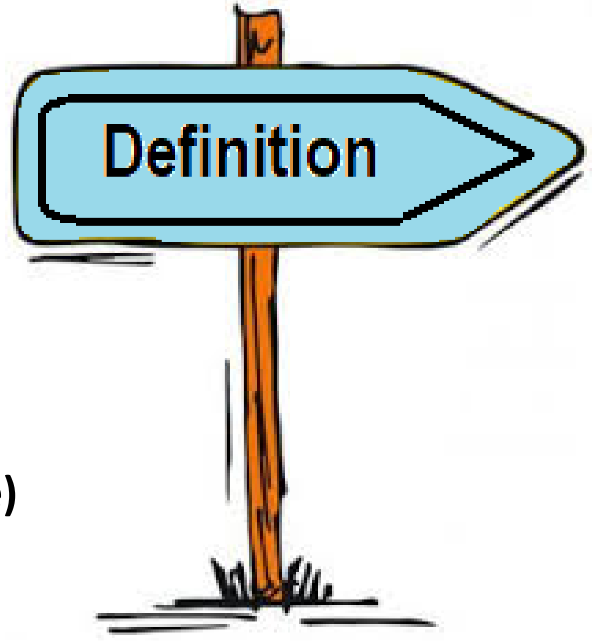
Step 1 Identification

What is the man-made disaster from academic perspective?

Scientific approach to any subject begins with its **strict definition**

In case of man-made disasters it allows:

- to separate the concept of disaster from other closely related cocepts (accident, fault, crisis, emergency situation, risk, hazard …)
- to differentiate the man-made from natural (envitronmental) disasters
- to have a common understanding of a subject, particularly to point out the general and different provisions in the legal definitions of a disaster used in different countries



A formal definition consists of three parts:

1.The term (word or phrase) to be defined **= man-made disaster (=technological catastrophe)**

2.The class of object or concept to which the term belongs **= event**

3.The differentiating characteristics that distinguish it from all others of its class = **????**

Step 1 **Identification**

What is the man-made disaster from academic perspective?

The differentiating characteristics of a man-made disaster (catastrophe)

1 – it is an event of changing the state of a system
2 – it is sudden unexpected (probabilistic) event
3 – it is caused by humans technology (by its operating or constructing)
4 – it has impact on the environments
5 – the consequences of it are unacceptable

Definition – ***first approximation (general and fuzzy)***

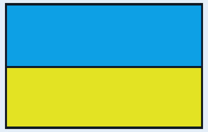
The man-made disaster means an event of changing the state of a system causing unacceptable consequences

Step 1 **Identification**

What is the man-made disaster from academic perspective?

Most of legal definitions of the technological disaster (and related to it) fall into the formal definition given above

- *Code of Civil Protection of Ukraine (on October, 2, 2012):* "catastrophe means a ***large-scale***? accident or any event, that causes ***serious***? consequences"



- *Crisis Management Act of Poland (on April 26, 2007):*"Crisis situation means a situation that has a negative ***large-scale***? impact on the level of human safety, property or the environment, with ***significant***? restrictions in the operation of competent public administration bodies… "

General definition:

The man-made disaster means an event of changing the state of a system causing unacceptable consequences

Terms of broad or with several meanings; have to be specified

Definition – *second approximation*

Step 1 **Identification**

What is the man-made disaster from academic perspective?

an event of changing the state of a system causing unacceptable consequences

probabilistic

sudden

normal (safe, predictable ...)

technological (man-made, anthropogenous ...)

No precise and unambiguous meaning exists; particular **subject** decides, perspective matters

for what

- human health
- human welfare
- natural environment
- economics
- reputation

Acceptability *versus* unacceptability relates to the **concept of scale**. A scale refers not to space only, but for any amount of smth (time, money, population size, concentration of pollutants etc.). Scale is subject depended conception. Characteristic scale means the amount (size, duration, degree) of smth normally needed for particular subject (humans, economy [local, regional, national …], biological population, air, water, soil, culture ...) to sustain.

The changes of the amount beyond the frames of its characteristic scale are usually critical, dangerous, severe or lethal for a particular subject. They definitely are not acceptable. To define what is acceptable and what is not we have to find out the parameters of characteristic scale. **GOOD NEWS:** Science has at its disposal collection of methods for solving the issue.

Step 1 Identification

What is the man-made disaster from academic perspective?

an event of changing the state of a system causing unacceptable consequences

- probabilistic
- sudden
- normal (safe, predictable ...)
- technological (man-made, anthropogenous ...)
- beyond the scope of characteristic scale
- *for what*
  - human health
  - human welfare
  - natural environment
  - economics
  - reputation

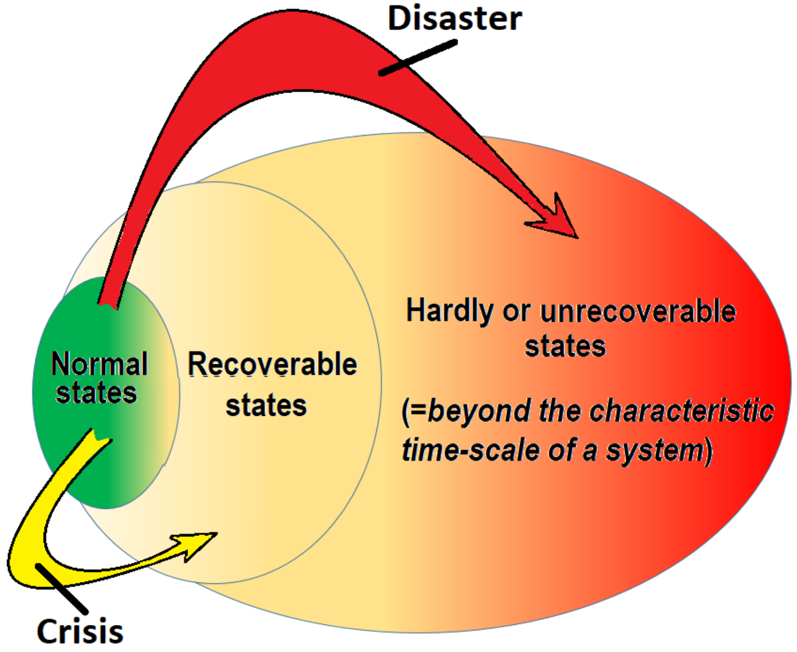
Definition – *second approximation (operational and substantive)*

The man-made disaster means a probabilistic sudden event of changing the normal state of a technological system or of its predictable behavior, leading to the shift of parameters of human health, welfare, natural environment, economy, social tensions beyond the scope of its characteristic scale.

What is the man-made disaster from academic perspective?

Disaster and related terms - *crisis, failure, accident, risk, emergency situation*

Recoverability (the probability of systems recovery to its initial pre-catastrophic state) is often a good working criteria to distinguish a disaster from related events (technical failure, fault, malfunction, accident, crisis, risk).



A system after the disaster could hardly come back to its initial normal state. In terms of scale it means the recovery time is much longer than characteristic time-scale of a system.

Disaster - the restoration of a previous (normal) state of a system is, in principle, impossible or takes long time, or requires a lot of effort

Crisis - the systems which survived crises are nevertheless recoverable.

Accident could be fatal to the technological object, but its impact on the environment, economy, etc. does not necessarily causes their transformations exceeding the characteristic scales

Technical failure (fault, malfunction) – system survives, characteristics of the environment, economy, etc. remain within the scope of characteristic scale

Risk means the possibility of undesirable event, not the event itself (disaster **is** an event)

Emergency situation is not an event (as disaster is), but the state of social and economy systems prior to anticipated disaster, or after it has happened.

Step 1 Identification

What is the man-made disaster from academic perspective?

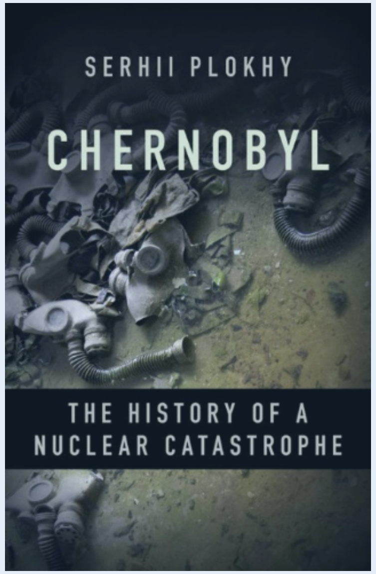
Man-made *versus* environmental disasters

The difference between these two lies not so in the source of disaster (technology or natural environment), but in **the perspective** from which its consequences are analyzed and audited.

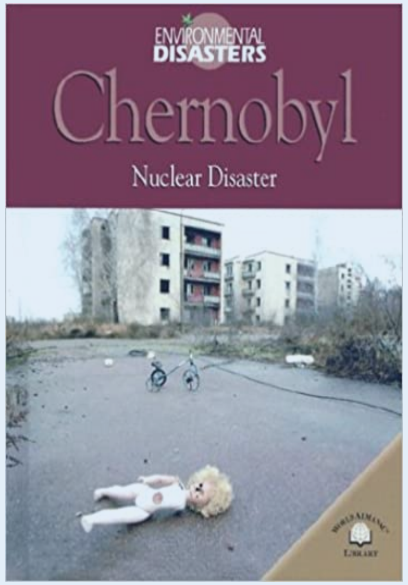
The same disaster could be treated both as man-made and environmental disaster depending on the perspective it is analyzed and evaluated. Most of environmental disasters were caused by technological malfunctions (Bhopal, 1984, Chernobyl, 1986, Fukushima, 2000 …).

Chernobyl accident (Ukraine, 1986) could be considered as:

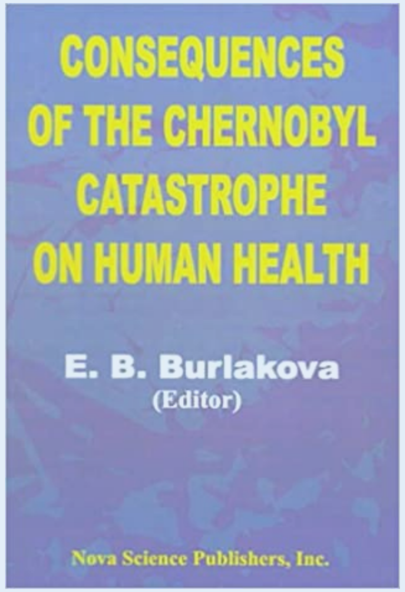
Technological (nuclear) disaster



Environmental disaster



Human catastrophe



***Step 1* Identification**

What is the man-made disaster from academic perspective?

Subjectivity

an event of changing the state of a system causing unacceptable consequences

- probabilistic
- sudden
- normal (safe, predictable ...)
- technological (man-made, anthropogenous ...)
- beyond the scope of characteristic scale
- *for what*
  - human health
  - human welfare
  - natural environment
  - economics
  - reputation

Objective component – An event | **Subjective component – Consequences**

Any technological disaster consists of two parts – an event (technical system or its part has failed) and large-scale consequences of it. **Part One** is **objective** while **Part Two** is essentially **subjective** because the consequences of disaster, their scale and acceptability <u>are determined by a particular subject</u>. It is the subject who decides whether the event is acceptable or unacceptable and to what extent (*i.e.* scale).

Step 1 Identification

What is the man-made disaster from academic perspective?

Subjectivity: *What is a subject in the context of a man-made disaster?*

The subject is any phenomenon or activity whose characteristics may change in the event of a catastrophe.

The subjects of man-made disaster are:

- People's health
- People's welfare
- Economy (for local, regional, national economies)
- Natural environment
- Reputation (of state, of company, of brand, of technology, and even of technological progress) is also a subject of a technological disaster as it could suffer if it happens.

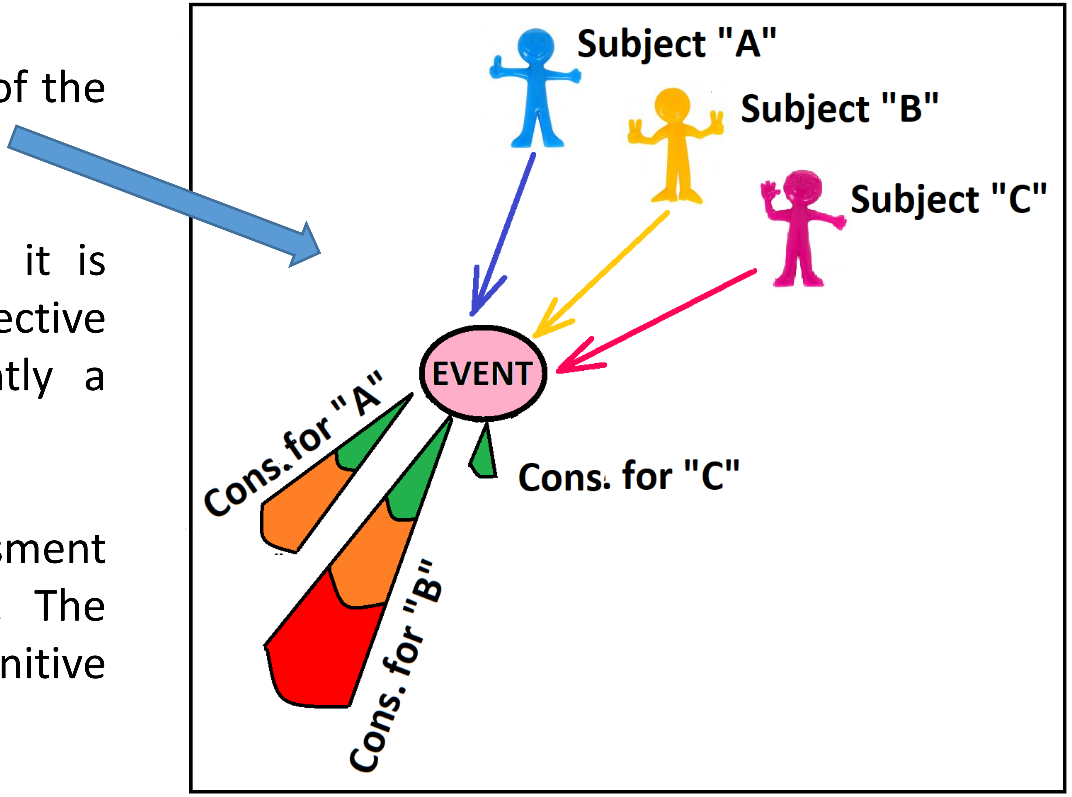
In case of the USA the subject of disaster is The President !
U.S. Code Title 42: "Major disaster means catastrophe or event, which ***in the determination of the President*** causes damage of sufficient severity and magnitude"

What is the man-made disaster from academic perspective?

IMPORTANT – in the eyes of different subjects the consequences of the same disaster are different.

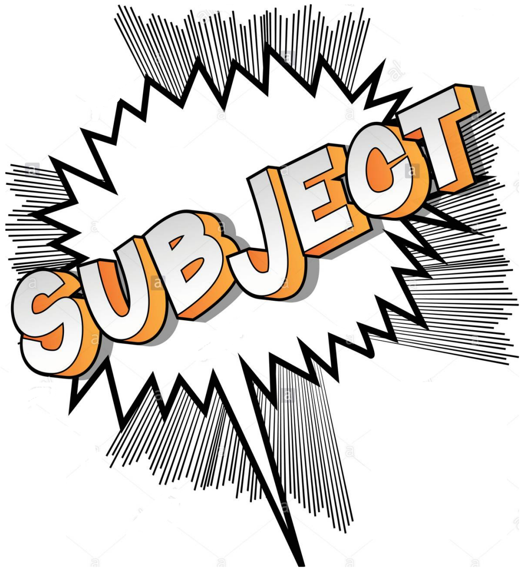
This creates a dilemma: for audit and management purposes, it is desirable to deal with a disaster objectively and evaluate it in objective terms, while a disaster (namely its consequences) is inherently a subjective category, assessed differently by different actors.

Indeed, it is not the disaster itself that is interested in the assessment and audit, but a particular subject who may suffer from it. The assessment of a disaster is an immanently subject-oriented cognitive and behavioral activity.



Theoretically, it is the subjects (in particular, different social groups of people) who should assess the disaster. However, it is well known from Behavioral Geography that people are very different in their perception of disasters and especially in their possible threats. The latest survey of the European Commission (*Special Eurobarometer 464b: Europeans' attitudes towards security, December 2017*) has proved this statement. With some exaggeration, it can be concluded that the majority of people do not even want to think about disasters and their consequences.

What is the man-made disaster from academic perspective?



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It is useless to talk about the natural environment (ecosystems, species, soil, etc.), which is the subject of man-made disasters, but cannot assess and foresee their danger to its existence. "Nature is a silent victim of man-made disaster" - is a fitting metaphor for this situation.

The decision is obvious: some body (better – few bodies) should take the responsibility for man-made disaster assessing it from various perspectives (= for various "silent" subjects).

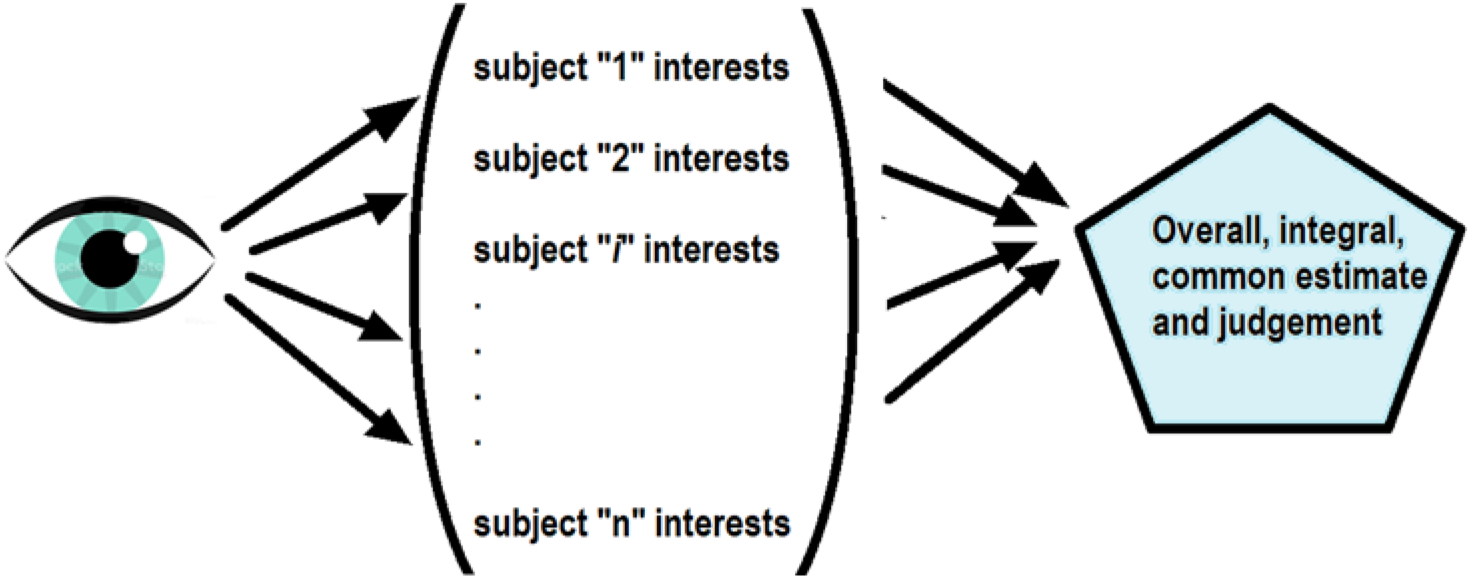
Science (a), governmental (b), and non-governmental institutions (b) are proper candidates for this position.

The Accounting Chambers are among them.

***Step 1* Identification**

What is the man-made disaster from academic perspective?

Whichever body (Science, Accounting Chamber, others) analyzes the catastrophe, it must do it polysubjectively, taking into account the interests of all subjects who may suffer as a result of it.



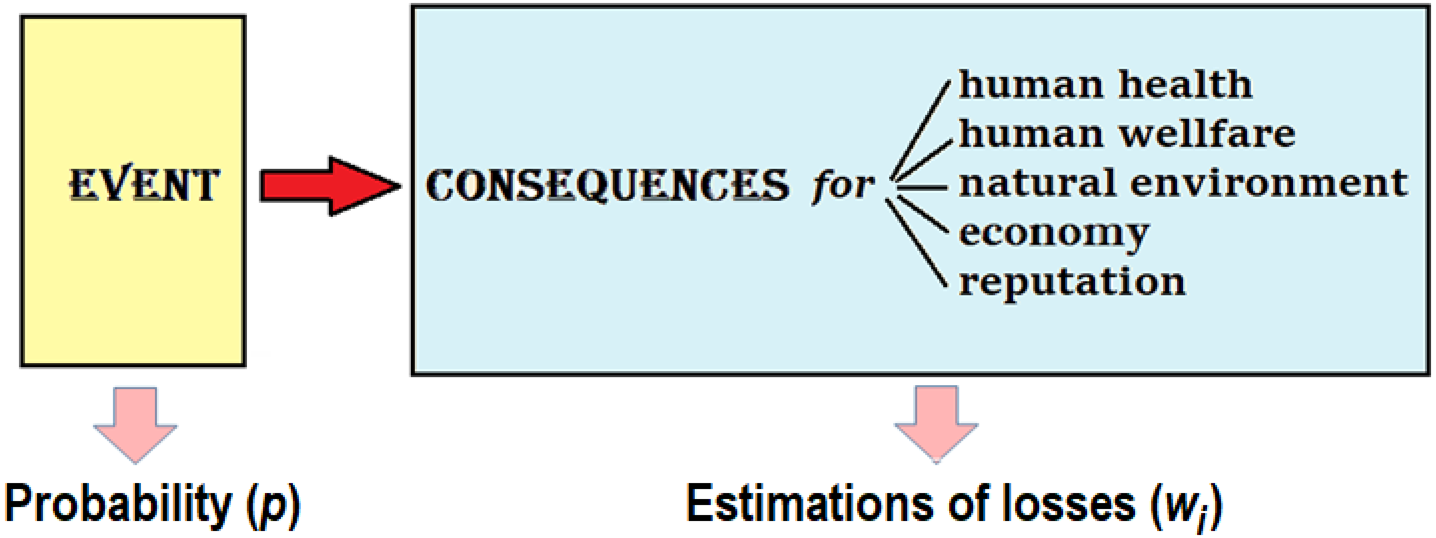
To combine multiple perceptions of disaster into one picture some common language (units of measurement) has to be applied.

Money is not the best language for all actors and their interests.

Acceptability, desirability, preference are more general terms, and I will play with them later in an attempt to comprehensively assess man-made disasters.

Evaluation

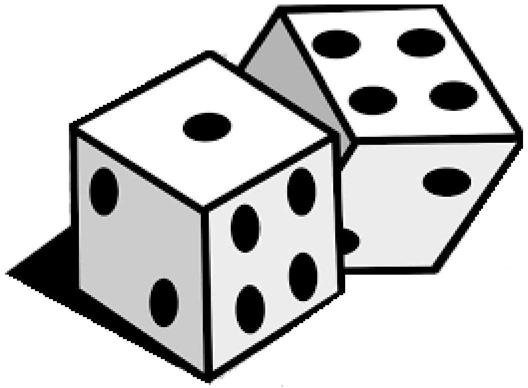
The structure for assessing a man-made disaster seems simple. It reflects the two-component nature of the phenomenon.



The probability is an estimate of an event (the occurrence of a technological accident) and the consequences are estimated as the amount of losses for various actors. The integral assessment is a function of the two (their product seems most appropriate)

$$ID = f(p, w_i) = \sum_{i}^{n} \prod_{1}^{n} p w_i \, ; \; or = \sum_{i}^{n} \sqrt[n]{\prod_{i}^{n} p w_i}$$

Evaluation – *Probability of a disaster*



Talking about the probability of a disaster, in fact, we are talking about its prediction.
In case of environmental hazards (floods, storms, even earthquakes etc.) science is able to predict them. The science called "Environmental Risk Assessment" does a good job of this.

But what about the man-made disasters?

Could we really predict accidents in Bhopal, Chernobyl, Fukushima, or technological accidents of a smaller scale? Could we calculate the probability of future technological disaster?

I dare to insist on the need to consider the probability of a man-made disaster when auditing it. If a disaster is generally unlikely, then why assess it, wasting time and money?

The main reason for the difficulties in assessing the likelihood of a man-made disaster is the lack of the necessary data

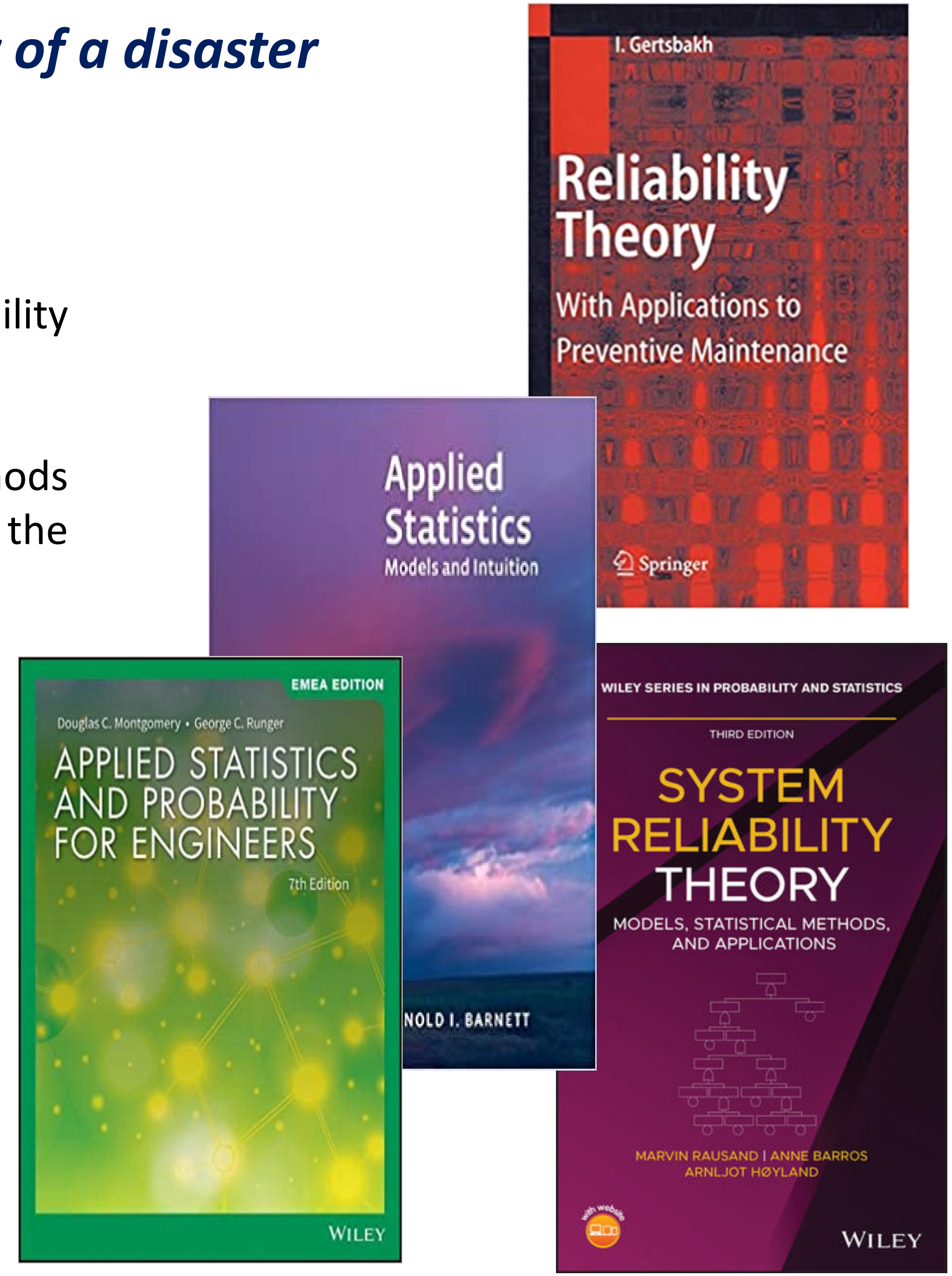
Evaluation – *Probability of a disaster*

How to calculate probability when data are scarce?

The popular belief that it is impossible to estimate the value of probability with a small sample size is in fact a misunderstanding.

Reliability theory, applied statistics, and risk assessment provide methods and models that work well with small sample sizes to calculate the probability of technical failures and other undesirable events.

MY ADVICE – do not try to apply these methods yourself, better consult the experts in the field. They are able to estimate the probability of rare events or the probability when data are insufficient.
Do not ask the experts in traditional (=large sample size) mathematical statistics to do the job. Most probably, they will not succeed,
Scientists and engineers in the field of Reliability theory and Applied statistics are proper persons to contact.



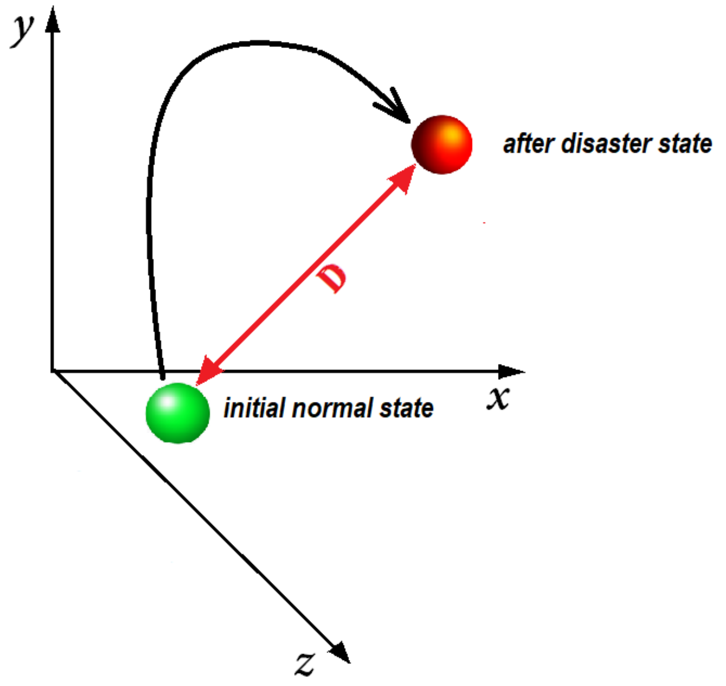
Evaluation - *Losses*

We may estimate the losses of a certain type in the units in which it is usually measured (macroeconomic losses in GDP reduction, loss of biodiversity in number of locally extinct species, etc.).

Economic costs	
Macroeconomic effects	GDP growth; loss of value added over given period
Sectoral impacts	GDP growth in specific sector (e.g. agriculture)
Emergency Services Costs	Necessary provision of equipment and people; Incident specific costs (staffing, fuels, materials)
Cost of Clean-up	Estimated cost of labour and material for clean-up
Damage to Property and Infrastructure	Value of damaged private property / infrastructure; Value of damaged public property / infrastructure; Replacement costs, Value of time spent for reconstruction
Reduction in economic activity	Estimated loss in earnings by comparison of forecast; economic activity (without disaster), and actual economic activity in the event of the disaster
Loss of Life	Value of a Statistical Life (VOSL)
Ecological Effects / Impact on Natural Capital	
Damage to the environment	Contingent Valuation Method, e.g. to estimate the recreational value of a coastal area
Social Consequences	
Injury and Illness	Medical expenses; Loss in wages through time spent away from work
Displacement	Cost of lost income; Medical costs for psychological damage; Costs of emergency shelter; Costs of returning people to their location
Loss of Household	Possessions Value of lost goods
Losses in Livelihood, for income	Estimate losses in income by comparison with baseline data
[Based on DFID (2005) "Natural Disaster and Disaster Risk Reduction Measures: A Desk Review of Costs and Benefits"]	

Evaluation - *Losses*

From purely formal (academic) point of view, the loss after disaster is the difference between the initial pre-disaster state of a system and its disturbed state after a disaster. It could be measured in multidimensional space using any distance metric *D* (Euclidean distance, Manhattan distance, Minkowski distance or other).



If the characteristics of the initial state before the disaster are known and we can predict the parameters of the state after the disaster, we can easily estimate the losses.

Two disadvantages of the "distance" approach: a) the characteristics of post-disaster state are usually unknown; b) the calculated value of distance coefficient does not indicate whether the measured loss is acceptable to the subject or not.

Euclidean distance De

$$D_e = \left(\sum_{i=1}^{n} (p_i - q_i)^2 \right)^{1/2}$$

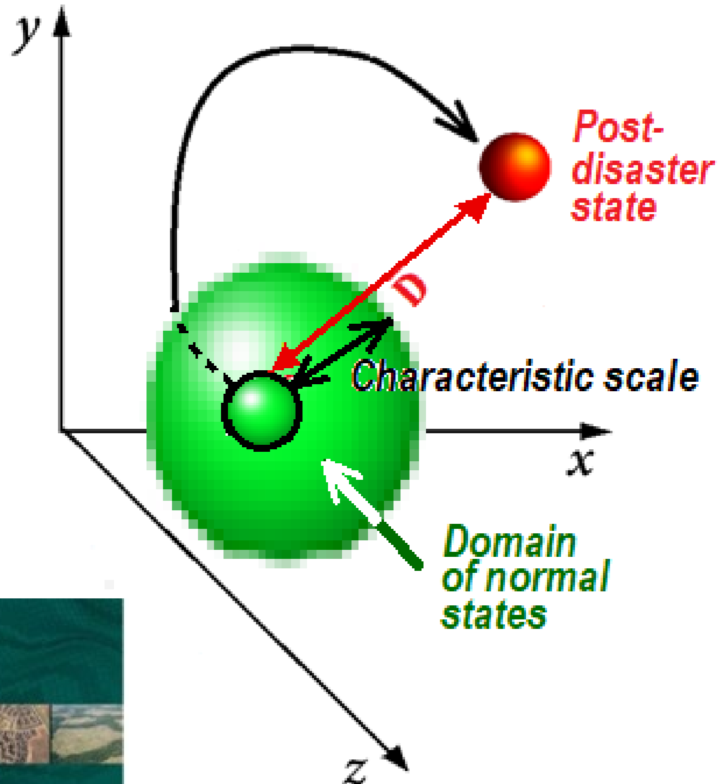
Manhattan distance Dm

$$D_m = \sum_{i=1}^{n} |p_i - q_i|$$

Minkowski distance

$$D = \left(\sum_{i=1}^{n} |p_i - q_i|^p \right)^{1/p}$$

Evaluation - *Losses*



A possible way to overcome the lack of criteria in distance coefficients is to use the concept of a characteristic scale.

A characteristic scale in geometric (visual) interpretation means an area in a multidimensional space in which a system normally evolve. The ratio of the distance D to the characteristic scale S is a measure of the loss. Its advantage is that losses of any kind and for any subject are measured in the same unit – the distance between what is normal and what has happened after a disaster.

Many methods for finding the characteristic scale exist. The science of Landscape Ecology is especially well in their testing and application.

- Semivariance method
- Scaleogram method
- Quadrat variance method
- Wavelet analysis
- Spectral analysis
- Fractal dimension method
- Lacunarity analysis
- Ripley's K-distribution method

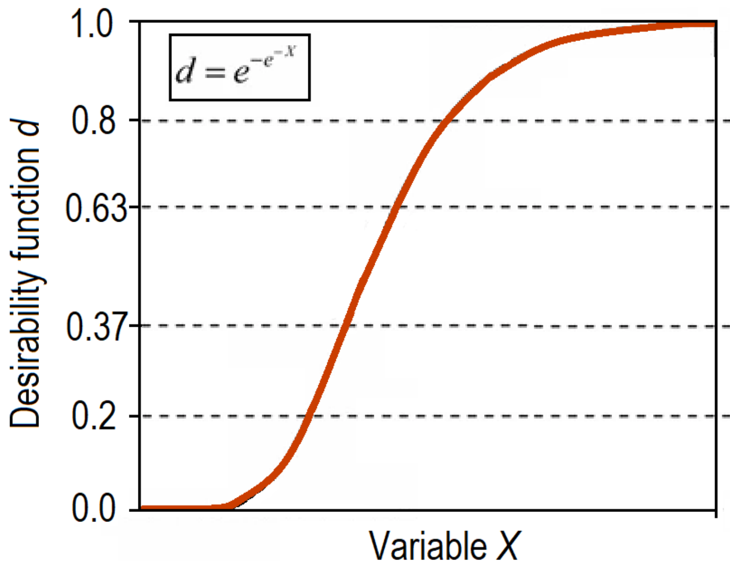
However when the state of a system after the disaster remains unknown (it is often the case) the distance metric methods do not work.

Evaluation - *Losses*

The approach using the **desirability function** is especially promising for assessing the consequences of man-made disasters. The desirability function was originally developed by E.C. Harrington for industrial quality control purposes, but soon was applied in many fields, including safety issues.

$$d = e^{-e^{(-x_i)}}$$

The desirability function transforms each variable describing the systems respond to disaster into a dimensionless individual desirability scale ([0, 1]). A remarkable feature of the desirability function lies in the fact that it has 4 standard values (namely d=0.2, 0.37, 0.63, and 0.8) which indicate the grades of desirability for ane value of variable x. To calculate the desirability function we need just to fix two values of any varible – the most desirable and the least desirable. In most cases we are able to do this based on empirical knowledge or other considearations.



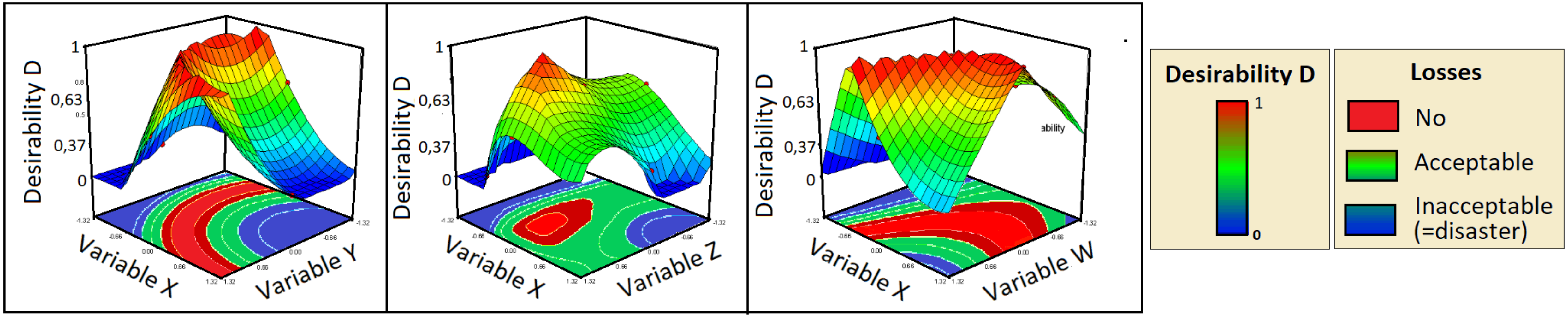
Desirability scale	Negative consequences scale	
Very good	None	Acceptable
Good	Minimal	
Satisfactory	Acceptable	
Badly	Inacceptable	Inacceptable
Very badly	Lethal	

Evaluation - *Losses*

We can construct desirabilty functioins for just one characteristic of a disasters loss, or for any their number. The overall (integral) desirability ofa system's state is calculated through the geometric average of individual desirabilities *di* of all variables.

$$D = \sum \alpha_i \sqrt{\prod_{i=1}^{n} d_i^{\alpha_i}}$$

The desirability function coulod also be used to define the conditions that are undisartable (= inacceptable). Therephore it could serve as a criteria for disaster in terms of inaceptable losses after it. Thus, it can serve as a criterion for a disaster in terms of unacceptable losses after it.

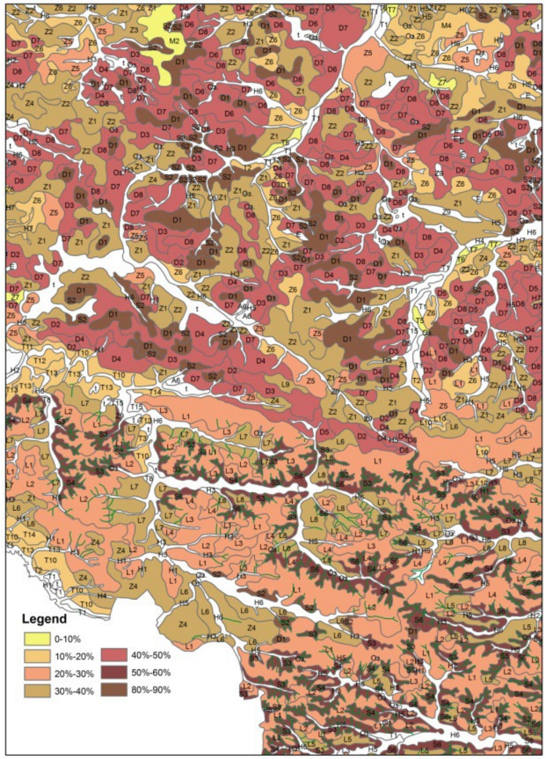


Evaluation - *Losses*

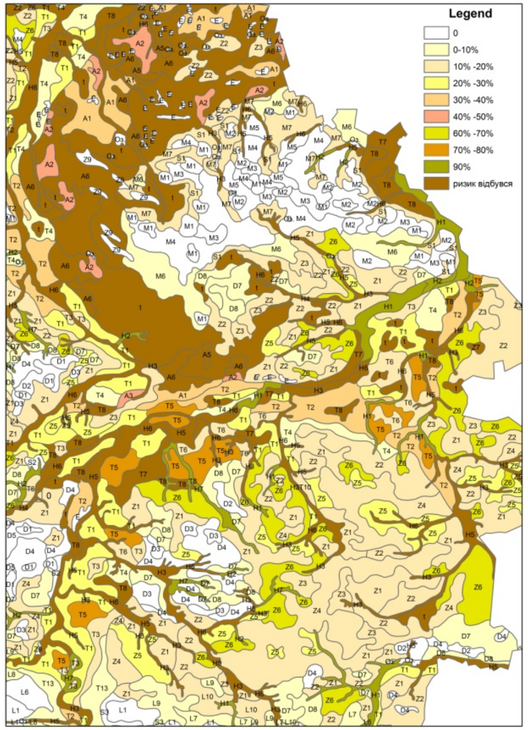
The consequencess of a man-made disaster are spatially distributed. It means in different places and areas they varies. Estimations for disaster probability *P* and the losses *W* after it have to be performed not „in ngeneral”, but for particular spacial units – ecosystems, river basibs, administrative units, etc.
under the assumption

We can map the disaster’s consequences !

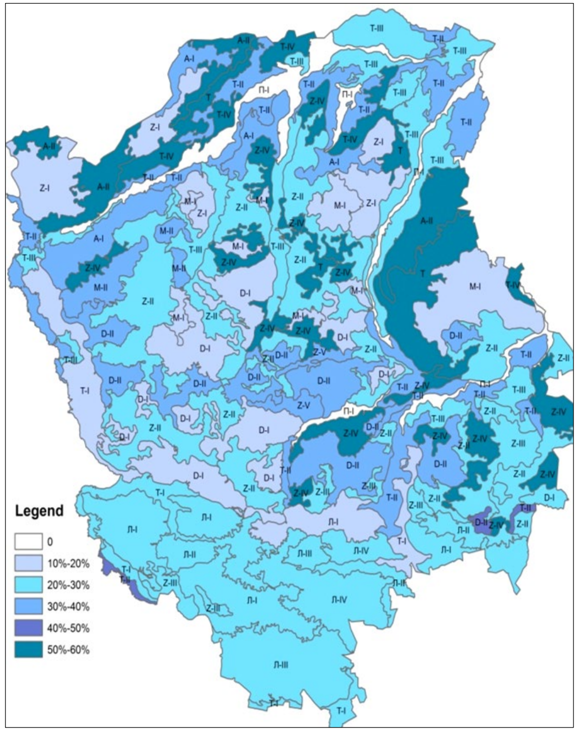
Examples of maps of environmental consequences under the assumption of drainage system failure in the area of Volyn region, Ukraine



Risk of *LS-3 type* – surface stability



Risk of *W-6 type* – water logging

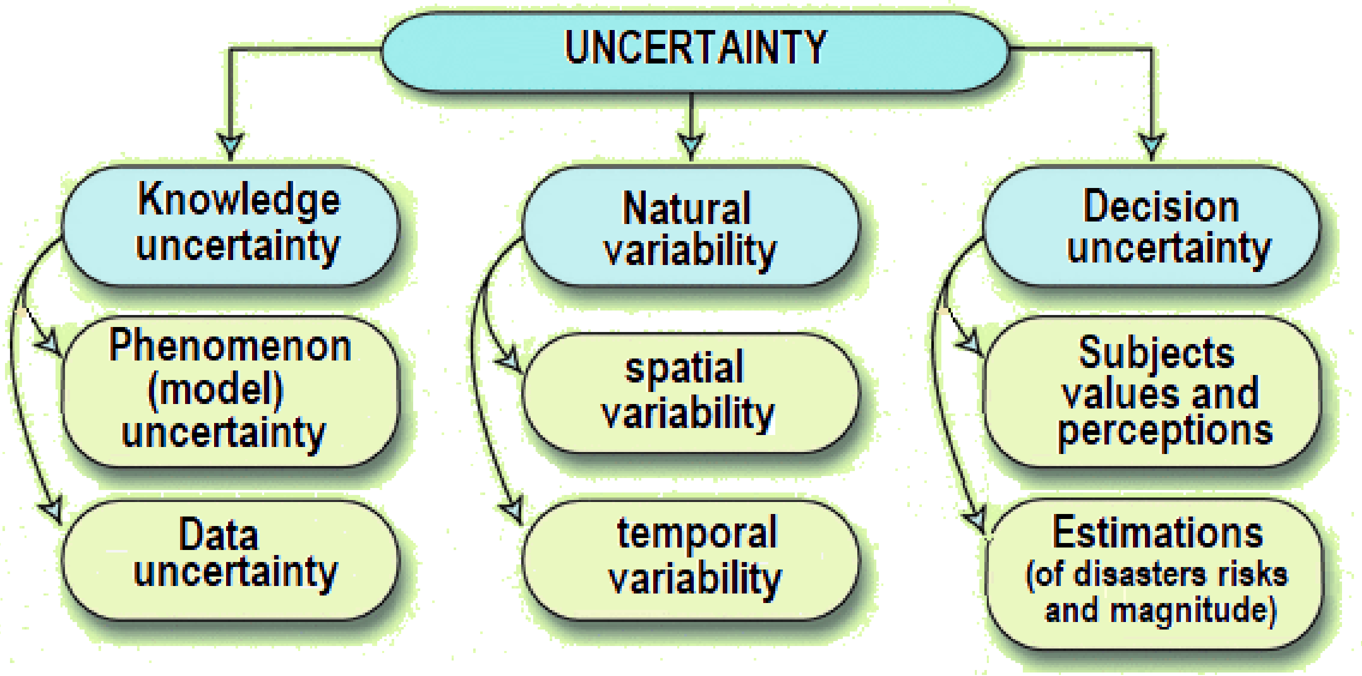


Risk of *DS-2 type* – wind erosion

Dealing with uncertainties

What is uncertainty? –
From academic perspective, uncertainty means a judgment (in particular, an estimate and information), the probability of the truth of which cannot be determined.

There are few types of uncertainty



We cannot completely eliminate uncertainty - this is an innate feature of the "information" environment in which we live.

It would be a mistake to try to characterize and evaluate the phenomenon (a disaster) in precise terms, while it is inherently uncertain. ***Special approach is neded !!!***

Dealing with uncertainties

The sources of uncertainty of man-made disasters

- absence, inaccuracy, incompleteness of information on the frequency and severity of man=-made disasters
- lack of direct analogues of facilities and technologies affected by the disaster
- approximate descriptions of disasters consequences
- probabilities of future man-made disaster, even when estimated, remains uncertain
- when and when a disaster could happen - ???
- the subjects that will be affected by the disaster are uncertainnot identified (both their type and number)
- subjective and individual perception of disasters by people
- unpredictable behavior of some actors before, during and after the disaster

Dealing with uncertainties

How to deal with uncertainties

Fuzzy set theory (L.Zadeh) is a research approach that can deal with problems relating to uncertain, subjective, imprecise judgments. It also can quantify even linguistic facet of available data (words!) and preferences for individual or group decision-making.

Subjective logic is applicable when the situation (=disaster) is characterized by considerable uncertainty due to incomplete knowledge. In this way, subjective logic becomes a probabilistic logic for uncertain probabilities. The advantage is that uncertainty is preserved throughout the analysis and is made explicit in the results so that it is possible to distinguish between certain and uncertain conclusions

Resiliecne and adaptive management (C.S. Holling) is a structured, iterative process of robust decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring.
In particular it says the system has few stable states (some of which could be unknown or uncertainly defined). Usually we hardly could predict the systems dynamics as its trajectory from one steady state to one of possible many. What we have to do is develop a strategy (or description of the system) which is resilient enough and can be modified when the trajectory of the dynamics of the system becomes less uncertain.
Adaptive management is a tool which should be used not only to change a system, but also to learn about the system

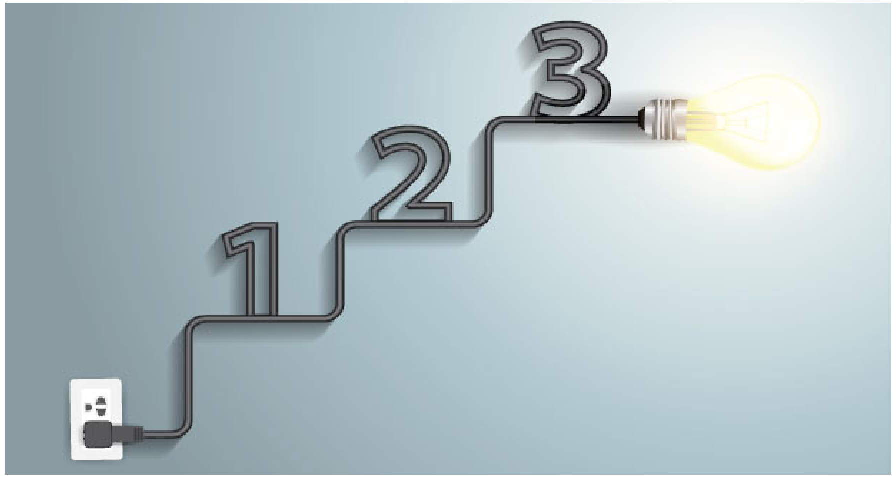
Instead of the Conclusion:

A few points for discussion or reflection

Thesis 1 – Academic perspectrive is just one of many, and is not necessarily the best one
Thesis 2 – It should neceserely be considered
Thesis 3 – The catastrophe theory seems promising, but do not expect much of it (if you should analyze more than 5 characteristic, which usually is the case, - forget about it!)
Thesis 4 – Without strict definition of a man-made disaster one can hardly recognize it
Thesis 5 – Disaster, crisis and related events are object-subject, perceivable categories
Thesis 6 – It is the subject who defines the particular event as disaster or not
Thesis 7 – In the eyes of different subjects (stakeholders) the same event could be considered as a disaster or just minor change of a system
Thesis 8 – To evaluate the disaster we need to calculate its probability and evaluate its possible consequences (losses) from the perspectives of various actors to Peoples perception has crucial role
Thesis 9 – Predicting a man-made disaster is almost impossible,…. but it is necessary
Thesis 10 – Applied Statistics, Reliability theory, Risk Assessment provide methods for probability of rare events estimation
Thesis 11 – Harrington's desirability function is a good tool to assess quantitatively the consequences of a disaster
Thesis 12 – Disaster is spatially distributed phenomenon, we can map it
Thesis 13 – Uncertainty is not fatal, it is a reality in which everything (including disasters) happens
Thesis 14 – We cannot completely eliminate uncertainty, we can only take it into account.

Three academic steps towards man-made disaster prevention: Identification, Assessment, Dealing with Uncertainties

THANK YOU FOR YOUR ATTENTION!



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