TIES483 Nonlinear Optimization

Decision-making under Uncertainty (part1)

Spring 2025

Babooshka Shavazipour, PhD

Babooshka.b.shavazipour@jyu.fi

Contents

- Uncertainty
- Different types of uncertainty
- Why it should be treated
- How to handle uncertainty
- Dealing with uncertainty in (MO)O
- Traditional and novel approaches

Learning outcomes

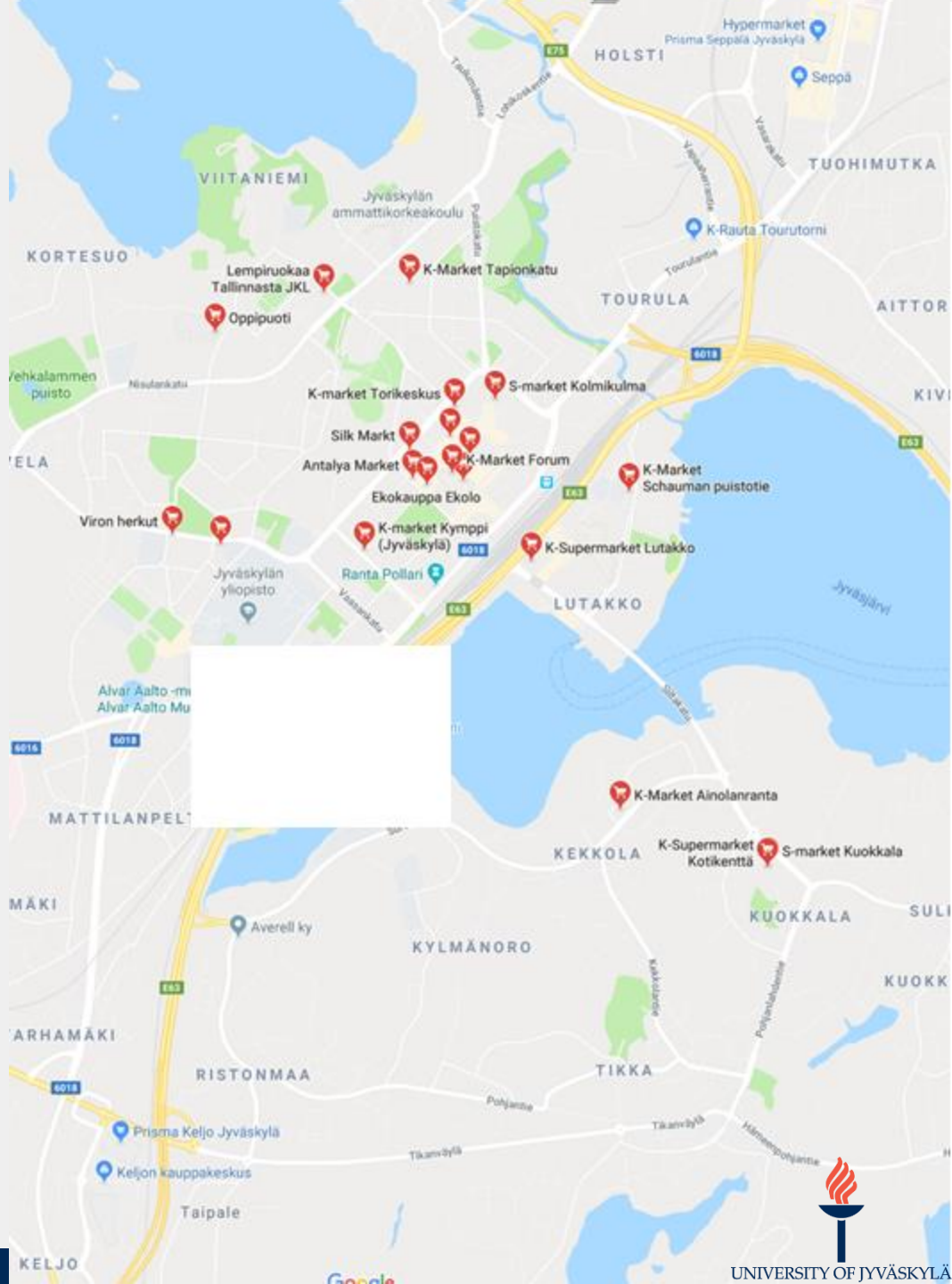
- To understand the importance of handling uncertainty in real-world problems
- To understand different types of uncertainty in (MO)OPs
- To understand how to deal with uncertainty in (MO)OPs
- Example approaches

Decision-making under uncertainty

- So far, we assumed that all the required information are certainty known.
- i.e., all the parameters, objectives, constraints are certain without any variation.
- However, most of the decisions in real-life problems need to be made in the absence of complete knowledge about the consequences of the decision.
- The presence of uncertainty brings more complexity to the problem.

Uncertainty:
General definitions (Metaphorical map)

- If a complete detailed map were reached; i.e., we know everything, with absolute certainty.
- Consequences of all alternatives could be seen and compared → Choose the most preferred one.
- However, sometimes, the decisions need to be made when the complete, detailed map is unavailable.
- **Lack of any details in the map** could be viewed as ***uncertainty***.



Different definitions of uncertainty

- “Any deviation from the unachievable ideal of completely deterministic knowledge
- of the relevant system” [Walker et al., 2003].
- “At a most fundamental level, uncertainty relates to a state of the human mind, i.e. lack of complete knowledge about something” [Stewart, 2005].
- “Incomplete information about a particular subject” [Ascough II et al., 2008].
- “Lack of confidence in knowledge related to a specific question” [Sigel et al., 2010].
- “In general, uncertainty can be defined as limited knowledge about the future, the
- past, or current events” [Walker et al., 2013a].

Important note!

- Uncertainties are not merely caused by the lack of knowledge and information
- Uncertainty can exist in a situation where lots of information are available
- However, new knowledge can either increase or decrease uncertainty
- New information and knowledge on a complex process can unfold previously unknown uncertainties
- In this case, more knowledge clarifies that the processes are more complex or that our cognition is more limited than previously thought

Classification of uncertainty

- Three sources/dimensions of uncertainty related to model-based decision support exercises:
  - **Nature**:
    - Variability (Aleatory) – *Alea (Latin)* → *Die*
    - Epistemic (Limited knowledge)

Different sources of the nature of uncertainty

Classification of uncertainty

- Three sources/dimensions of uncertainty related to model-based decision support exercises:
  - **Nature:**
    - Variability (Aleatory) – *Alea (Latin)* → *Die*
    - Epistemic (Limited knowledge)
  - **Location:**

    The where the uncertainty manifests itself within the model complex (Models, Outcomes, Weights, etc.)
    - Internal (DM judgement and preferences)
    - External (lack of knowledge about outcomes)

Author(s)	Different categories	
French [1995]	Uncertainties expressed during modeling	What might happen or what can be done
		Meaning/ambiguity
		Related decisions
	Uncertainties expressed during exploration of the models	Physical randomness or lack of knowledge
		The evolution of future beliefs and performances
		Judgments
		The accuracy of calculations
	Uncertainty expressed during interpretation	Appropriateness of a descriptive model
		Appropriateness of a normative model
		the depth of analysis
Walker et al. [2003]	Context	
	Model	Structure Technology
	Input	Controllable Uncontrollable
	parameter Model outcome	
Stewart [2005]	Internal External	
Hawkins and Sutton [2009]	Internal variability of the system Model Uncertainty Scenario Uncertainty	
Marchau et al. [2010]	The value system(s) to be used to rank alternative policies The system models How the future will develop	
Kwakkel and Walker [2010]	External Forces Relations within a system Outcomes of interest Weights	
Walker et al. [2013b]	Context System model System Outcome Weights Weights on outcome	

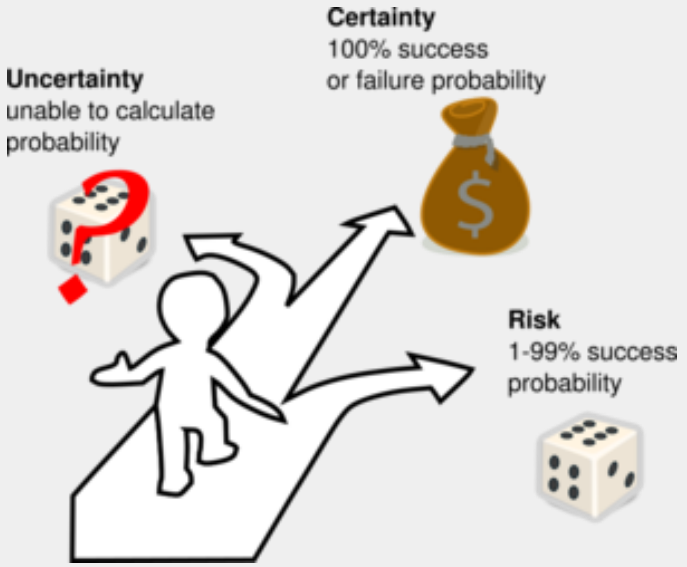
Different classifications of the location of uncertainty.

Classification of uncertainty

- Three sources/dimensions of uncertainty related to model-based decision support exercises:
  - **Nature**:
    - Variability (Aleatory)
    - Epistemic (Limited knowledge)
  - **Location:**

    The where the uncertainty manifests itself within the model complex (Models, Outcomes, Weights, etc.)
    - Internal (DM judgement and preferences)
    - External (lack of knowledge about outcomes)
  - **Depth or Level**:

    The where the uncertainty manifests itself along the spectrum between absolute certainty and total ignorance.



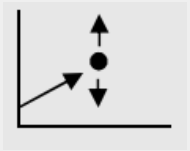
	Uncertainty of degree 0 (complete certainty)						Infinity degree of uncertainty (total ignorance)
Shavazipour [2018]		**Mild uncertainty *(First-degree)***		**Moderate uncertainty *(Second-degree)***		**Deep uncertainty *(Third-degree)***	
Walker et al. [2013a]		Level 1 (A clear enough future)	Level 2 (Alternate futures with probabilities)	Level 3 (Alternate futures with ranking)	Level 4 (Multiplicity of futures)	Level 5 (Unknown future)	
Walker et al. [2003]		statistical uncertainty		scenario uncertainty	Recognized ignorance		
					Reducible	Irreducible	
Kwakkel et al. [2010]		Shallow Uncertainty (Level 1)		Medium Uncertainty (Level 2)	Deep Uncertainty (Level 3)	Recognized Ignorance (Level 4)	
Courtney [2001]		Level 1 (so low that the traditional methods that employ point forecasts can be used with great success)	Level 2 (manager can identify a set of distinct possible outcomes, one of which will occur)	Level 3 (manager can bound the range of possible outcomes)		Level 4 (analysis cannot even bound the range of possibilities)	
Morgan et al. [1992]		Uncertainties can be treated through probabilities		Uncertainties cannot be treated probabilistically			
Quade [1989]		Stochastic uncertainty				Real uncertainty	
Knight [1921]		Risk				Uncertainty	

Different classifications of the depth of uncertainty.

Classification of uncertainty

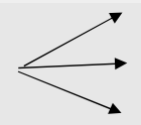
- We use the term degree of uncertainty as depth or level of uncertainty.
- Uncertainty of degree '0' as absolute certainty or deterministic knowledge.
- Uncertainty of infinity degree as total ignorance.

Degrees of Uncertainty

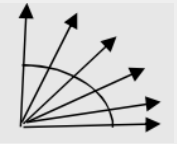


- **Absolute Certainty (clear enough future – deterministic)**

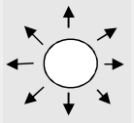
- **Mild uncertainty (1st):** Outcomes can be enumerated, and probabilities (or probability distribution) are specified (probable futures).



- **Moderate uncertainty (2nd):** Outcomes can be enumerated but probabilities are difficult to specify generally (few possible/plausible futures).
- **Deep uncertainty (3rd):** Outcomes cannot be completely enumerated, so that, probabilities are not definable (many plausible futures).



- No nothing



Shavazipour, B., & Stewart, T. J. (2019). Multi-objective optimisation under deep uncertainty. *Operational Research*, 1-29.

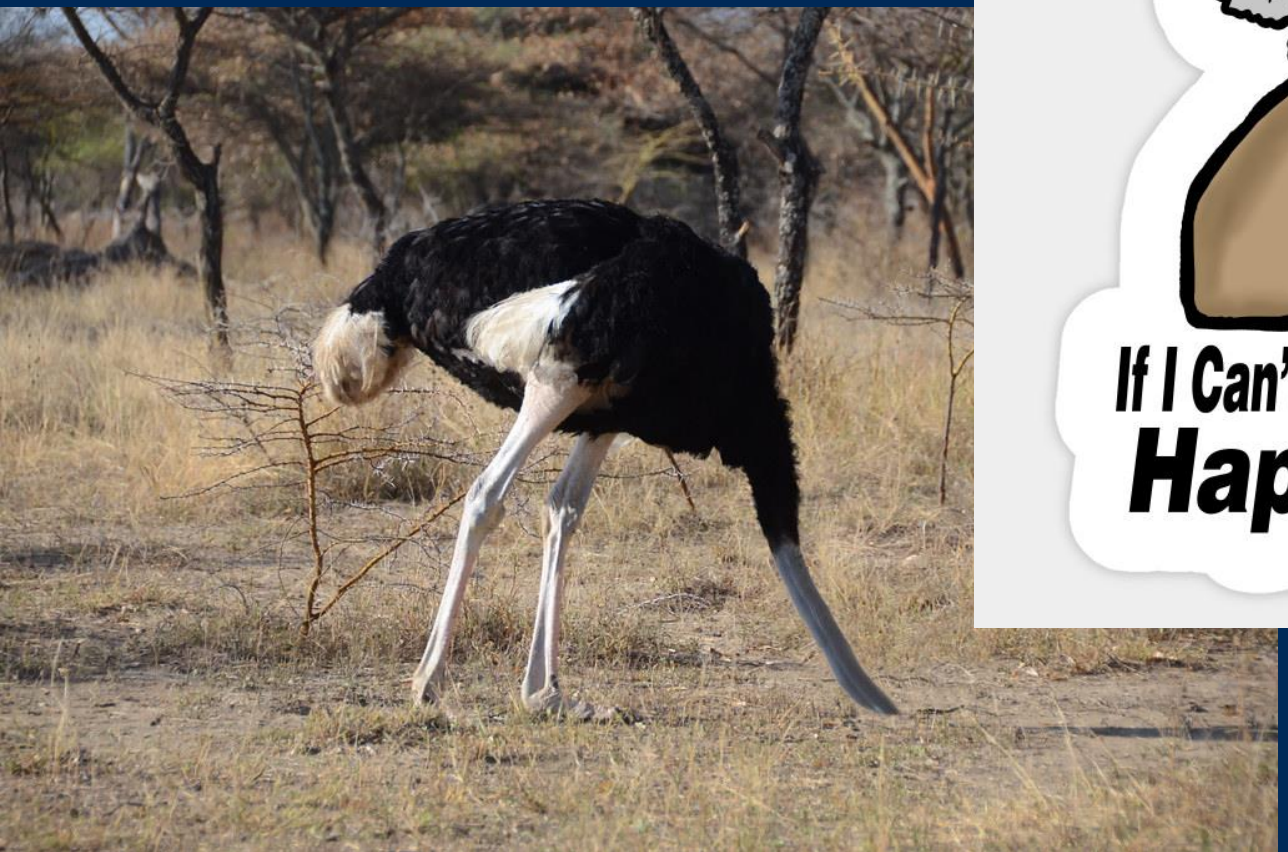
A more general definition of Deep Uncertainty

- A situation in which the relevant actors do not know or cannot agree upon:
  - how likely or plausible various future states are
  - how the system works (or would work)
  - how to value the various outcomes of interest

* Walker, Warren E., Robert J. Lempert, and Jan H. Kwakkel (2013). "Deep Uncertainty", entry (pp. 395-402) in Saul I. Gass and Michael C. Fu (eds.), Encyclopedia of Operations Research and Management Science., 3 rd Edition, New York: Springer.

Dealing with uncertainty

Why must uncertainty be treated?

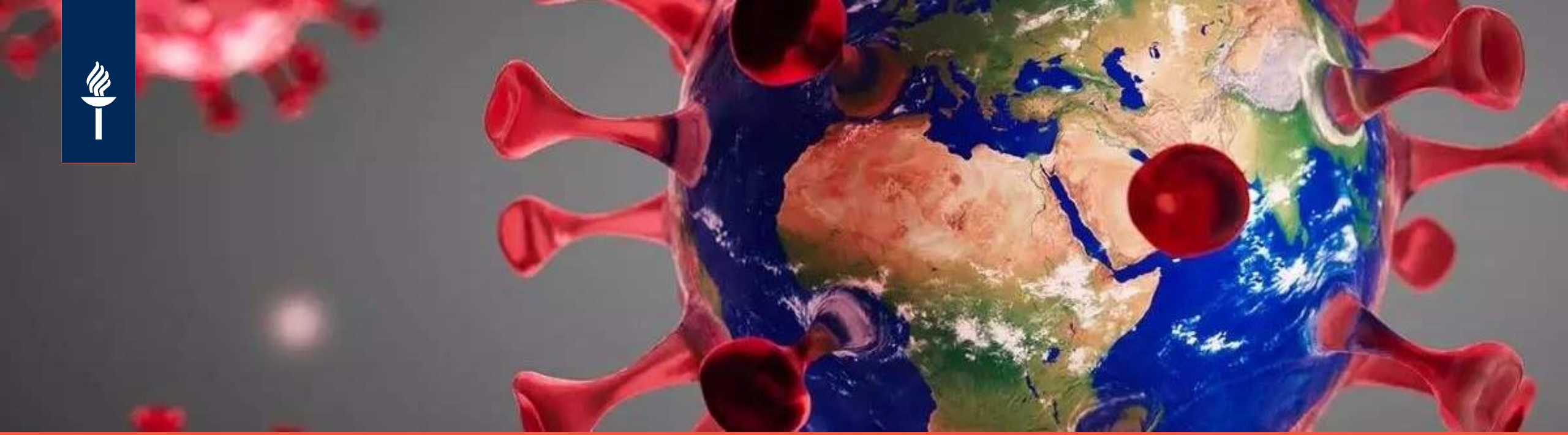


Dealing with uncertainty

Why must uncertainty be treated?

- Many people have ignored uncertainty for many years
- Still, some try to avoid the higher degrees of uncertainty
- However, they must face this challenge eventually

Why must uncertainty be treated?



COVID-19 Pandemic (2019-?)

- **In 2018**: The probability of an extreme epidemics was < **0.5 percent in a year**
- **31.12.2019**: The first COVID-19 case is reported
- **31.08.2021**: the probability of a pandemic with similar impact to COVID-19 is **about 2% in any year***
- **15.09.2021:** most countries removed the restrictions and said the pandemic was over
- **10.11.2021: 250 million** cases, **> 5 million death, …**
- **21.11.2021:** a new variant has found in South Africa (Omicron)
- **14.12.2021:** many restrictions came back
- **01.02.2022:** many goverments say we are entering the endemic Covid. (Do we??)
- **21.02.2022**: **> 424 million** cases, **> 5.89 million death, + 4996 death since yesterday**

* Marani, M., Katul, G. G., Pan, W. K., & Parolari, A. J. (2021). Intensity and frequency of extreme novel epidemics. *Proceedings of the National Academy of Sciences*, *118*(35).

Why must uncertainty be treated?

A major challenge is the requirement to accept, understand, and manage uncertainty, since:

1. Not all uncertainties can be eliminated;

2. Ignoring uncertainty limits our ability to make corrective action in the future and result in positions that could have been avoided;

3. Ignoring uncertainty can throw away the opportunity of studying real-world problems, and/or lead to get some unsustainable approaches.