**Dr. Yakov Ben-Haim**
Professor Emeritus
Former Yitzhak Moda'i Chair in
Technology and Economics (2001–2021)

**Technion**
Israel Institute of Technology
Faculty of Mechanical Engineering
Haifa 32000 Israel

http://info-gap.technion.ac.il https://yakov.technion.ac.il
Tel: +972-(0)73-378-3262, +972-50-750-1402 Fax: +972-(0)73-378-5711
yakov@technion.ac.il

Joint Undergraduate-Graduate Course on

# Info-Gap Methods for Analysis of Risk and Reliability

03 6057

**Syllabus.** Strategic decisions under uncertainty in analysis, design and certification of complex systems. Assessment and control of reliability and risk. Project management. Decision paradigms for information-gap uncertainty. Realizability with limited information. Balancing trade-offs between robustness, performance and opportuneness. Evolution of preferences through analysis of uncertainty. Value judgments. Decisions with multiple criteria. Learning and the value of information. Decisions with hybrid uncertainties.

**Audience.** Persons involved in strategic decisions in complex environments with deep uncertainty: engineers developing new and complex technologies, engineers in project management roles, systems engineers, systems analysts, project managers.

**Related areas.** Information theory, game theory, interactive decision making, conflict resolution, project management, analysis and design of systems.

**Credits:** 3.

**Prerequisites.** This course is based on concepts and methods drawn from the analysis of systems. Students with background in **systems analysis** will be able to master the course material: dynamic systems analysis, operational research, or economics. **Any one** of the following five courses serves as prerequisite:

03 4032. Linear systems, (enhanced).
09 4116. Production management 1.
09 4506. Micro-economics 3.
01 4004. Systems analysis.
01 4606. Construction management.

We also use concepts from probability, so the following course is required:

09 4480. Introduction to probability and statistics.

**Homework problems** will be posted on the course website each week. The student will work on each week's homework problem and discuss the results with the instructor in the weekly meeting. Doing the homework thoroughly and on time will assist the student to master the material of the course. Homework solutions are not turned in and no credit points are given for homework solutions.

**Midterm mini-project,** required, 40%. There is no written exam. Rather, each student will formulate and solve an exam question whose solution is based on methods and concepts developed in the course. This question will involve info-gap robustness or opportuneness functions, and will be presented in 3 different versions, based on 3 different info-gap models of uncertainty: fractional-error for multiple uncertain parameters, energy-bound for an uncertain function, and Fourier ellipsoid-bound for an uncertain function. The exam question and its solution will be submitted to the professor as a pdf file. The submission will be no more than 4 pages long. Grading: 100 for thorough and correct formulation and solution. 85 for no more than minor errors. 70 for minor errors and no more than one substantial error. 0 for anything else. Students are welcome to consult with the professor before submission (but not "Is this correct?").

**Project,** required, 60%. Guidelines are presented below.

**Office hours.** Any time, by appointment in my office or by zoom or skype.

**Course website:** http://yakovbh.net.technion.ac.il/courses/info-gap-analysis-of-risk-and-reliability/ More information at: info-gap.com

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**Outline of Topics**

Following is a typical outline of weekly topics. Specific topics may vary. See details on the course website: http://yakovbh.net.technion.ac.il/courses/info-gap-analysis-of-risk-and-reliability/

1. (1 week) **Severe uncertainty.** Paradoxes of probability. Intuitive and quantitative discussion of types of uncertainty: information gaps, linguistic and probabilistic uncertainty. Hybrid uncertainty models.[1]

2. (6 weeks) **Robustness and opportuneness functions.** This is the heart of the course. By using examples from many disciplines, we develop paradigms for formulating and evaluating strategic decisions. Evolution of preferences through analysis of uncertainty. Emphasis on generic tools, with examples from many topical areas,[2] including engineering design,[3] systems analysis, project management, technological reliability, portfolio investment,[4] public policy and biological conservation.[5]

3. (2 week) **Hybrid uncertainties.** Decision paradigms with hybrid uncertainty models: combining info-gap and probabilistic models.[6]

4. (1 week) **Value judgments.** How safe is safe enough? How much reliability is needed? How good is our decision? Qualitative calibration of quantitative trade-offs. Analogical reasoning. Calibration by severity of consequences; by prior information.[7]

5. (1 week) **Value of information.** Assessing the value of information with respect to system goals, and exploiting this evaluation to optimize further information-gathering. Demand value of information in systems with generic (not necessarily monetary) reward.[8]

6. (1 week) **Robust-satisficing behavior.** Analysis of Ellsberg and Allais "paradoxes" of behavior under uncertainty. Examination of info-gap robust-satisficing resolutions.[9]

7. (1 week) **Learning under uncertainty.** We use info-gap theory to study the design and evaluation of learning strategies.[10]

[1] ○ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., sections 2.2, 2.5.
○ Y. Ben-Haim, 2004, Uncertainty, probability and information-gaps, *Reliab. Eng. & System Safety,* 85: 249–266.
○ Lecture Notes on Info-Gap Uncertainty (\info-gap-methods\lectures\igunc.pdf), pp.2–12, 15–17.
[2] ○ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 3.
○ Lecture Notes on Robustness and Opportuneness (\info-gap-methods\lectures\ro02.pdf) various sections.
[3] ○ Lecture Notes on Performance vs. Robustness of a Cantilever (\info-gap-methods\lectures\beam-op001.pdf).
[4] ○ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., section 3.2.7.
○ Lecture Notes on Robustness and Opportuneness (\info-gap-methods\lectures\ro02.pdf) section 12.
[5] ○ Lecture Notes on Conservation Management, or, Robustness, Expected Utility and the Sumatran Rhinoceros. (\info-gap-methods\lectures\rhino.pdf)
[6] ○ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 10.
○ Lecture Notes on Hybrid Uncertainties (\info-gap-methods\lectures\hybunc.pdf) various sections.
[7] ○ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 4.
○ Lecture Notes on Value Judgements (\info-gap-methods\lectures\vjud.pdf) various sections.
[8] ○ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 7.
[9] ○ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapter 11.
○ Lecture Notes on Robust-Satisficing Behavior (\info-gap-methods\lectures\rsb01.pdf) various sections.
[10] ○ Yakov Ben-Haim, *Info-Gap Decision Theory,* 2nd ed., chapters 7 and 8.
○ Lecture Notes on Info-Gap Learning (\info-gap-methods\lectures\lrn.pdf) various sections.

**Books**

The main text is:

Yakov Ben-Haim, 2006, *Info-Gap Decision Theory: Decisions Under Severe Uncertainty,* 2nd edition, Academic Press.

Supplementary material includes:

1. David E. Bell, Howard Raiffa and Amos Tversky, eds., 1988, *Decision Making: Descriptive, Normative, and Prescriptive Interactions,* Cambridge University Press. On-campus access via the library catalog at: http://ebooks.cambridge.org/ebook.jsf?bid=CBO9780511598951

   Off-campus access is open via: http://meclib.technion.ac.il/Equipment/EasyLibrary.htm
2. Yakov Ben-Haim, 2018, *The Dilemmas of Wonderland: Decisions in the Age of Innovation,* Oxford University Press, Oxford.
3. Yakov Ben-Haim, 2010, *Info-Gap Economics: An Operational Introduction,* Palgrave-Macmillan, London.
4. Yakov Ben-Haim, 1996, *Robust Reliability in the Mechanical Sciences,* Springer-Verlag, Berlin.
5. Yacov Y. Haimes, 1998, *Risk Modeling, Assessment, and Management,* John Wiley.
6. Ralph Keeney, 1992, *Value Focussed Thinking,* Harvard University Press.
7. Ralph L. Keeney and Howard Raiffa, 1993, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs,* Cambridge University Press.
8. M. Granger Morgan and Max Henrion, 1990, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis.* With a chapter by Mitchell Small. Cambridge University Press.

## Final Project Guidelines

1. The project is devoted to the **risk assessment** or **reliability analysis** of a **complex system** based on info-gap decision theory. It will contain the following elements:
   (a) **Statement of the problem:** safety analysis, mission-dependability assessment, design optimization, project management and risk assessment, etc.
   (b) Mathematical **model of the system.** The system may be technological or economic, social, environmental, medical, etc.
   (c) Mathematical formulation of **failure criteria.**
   (d) Mathematical **uncertainty model** with info-gap (and possibly probabilistic) components.
   (e) Mathematical derivation of the **risk** or **reliability** of the system as expressed by info-gap robustness and possibly opportuneness functions. The presentation may be supported by numerical analysis where needed. This step explicitly combines the previous three steps.
   (f) Application of the results derived in step 1e to **resolution of the problem** identified in step 1a.
2. The project will be submitted in two stages.
   (a) Stage 1: Project **definition and outline** of items 1a–1d above. Students are welcome to submit an outline of about 1 page length by about the 10th week of the semester.
   (b) Stage 2: **Final report.** Electronic only, as pdf file, with text (including tables and graphs) not exceeding 10 pages.
3. Each student must submit his own project. **No team submissions.**
4. **Expected depth and complexity:** much more than the typical homework problem; much less than a realistic full scale analysis.
5. **Advice and suggestions** can be obtained by consulting with the instructor.
6. **Grading.** The final project makes up 60% of the final grade. The project grade will be one of four:
   - 100 (excellent): innovative, thorough and entirely correct analysis.
   - 85 (good): Solid, thorough and correct variation on an example developed in class.
   - 70 (pass): Basically correct but simple variation on an example developed in class.
   - 0 (fail): Everything else.