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3-Day Intensive Course on

Reliability Assessment of Engineering Systems

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Contents

Syllabus Probabilistic, statistical and info-gap-robustness concepts of reliability. Reliability of static and dynamic mechanical components and systems. Reliable design. Probabilistic failure models. Quality control.

Course Rationale Engineers use measurements and science-based models to design systems and evaluate reliability based on measurements. However, models may be simpler than reality, causal factors may be unknown, measurements may err or be incomplete, and systems may change over time in unknown ways. Probability is useful for modeling and managing some of these uncertainties. However some uncertainties are *info-gaps:* disparities between what *is known* and what *needs to be known* in order to make good decisions. For instance, we sometimes do not know the correct probability distribution or all of the relevant physical mechanisms such as non-linearities or dependencies on space and time. We focus on probabilistic and statistical tools for evaluating reliability and designing measurements for monitoring. We augment these tools with evaluation of robustness to info-gaps.

Course Structure This course has three components. *Lectures* use simple examples to illustrate the assessment of reliability. *Exercises* help the participants to master the operational aspects of this material. The first two and one-half days are devoted to lectures and exercises. The remainder of the time is devoted to *mini-projects* that are formulated and implemented by the participants in small groups, under the supervision of the instructor, on topics of the participants' choice such as versions of projects they plan to work on after the course. This facilitates the internalization of the concepts and methods learned, their integration with other methods familiar to the participants, and

\lectures\WShops+ShrtCrs\nvidia2021\outline002nvidia2021ws.tex   24.9.2021 their application to problems of interest to the participants.

The Instructor *Dr. Yakov Ben-Haim* is a professor of mechanical engineering and holds the Yitzhak Moda'i Chair in Technology and Economics at the Technion—Israel Institute of Technology. He teaches reliability theory and decisions under uncertainty. He initiated and developed info-gap decision theory for modeling and managing deep uncertainty (see info-gap.com). Info-gap theory is applied in engineering, biological conservation, economics, project management, climate change management, national security, medicine, and other areas. He has been a visiting scholar in Australia, Austria, Canada, England, France, Germany, Italy, Japan, Korea, Netherlands, Norway, and the US. He has lectured at universities, medical and technological research institutions and central banks around the world. He has published more than 100 articles and 6 books.

The Participants Scientists and engineers involved in risk analysis and reliability assessment of technological systems.

Class size The class size for the lectures and exercises is not limited, but must be known ahead of time. The class size for the mini-project phase is limited to at most 20 people.

Outline of the Course

Day 1

MORNING

09:00–09:50 *Lecture 1.*[1] Statistical failure models: Reliability function, failure rate function, mean time to failure, Poisson process.[2]

10:00–10:50 *Lecture 2.* Continuation of lecture 1.

10:50–11:10 Coffee break.

11:10–12:00 *Lecture 3.* Statistical failure models: Exponential, Gamma, Pareto, Weibull, normal, lognormal.[3]

LUNCH 12:00–12:45

AFTERNOON

12:45–13:35 *Lecture 4.* Continuation of lecture 3.

13:45–14:35 *Exercise 1.* Failure times.[4]

14:35–14:55 Coffee break.

14:55–15:45 *Exercise 2.* Scratches and Many identical components.[5]

15:55–16:45 *Exercise 3.* Pressurized tube and Adjusted machine.[6]

Day 2

MORNING

09:00–09:50 *Lecture 5.* Probabilistic reliability analysis. Reliability with info-gap-uncertain probability distributions.[7]

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[1] Subsequent footnotes refer to Lecture Notes and Problem Sets in files on the following webpage: https://yakovbh.net.technion.ac.il/courses/introduction-to-reliability-of-mechanical-systems/

[2] ○ Høyland and Rausand, sections 2.1–2.5.
○ Lecture Notes on Probabilistic Failure Models, sections 1–5 (file: pfm.pdf).

[3] ○ Høyland and Rausand, sections 2.6–2.11.
○ Lecture Notes on Probabilistic Failure Models, sections 6–13 (file: pfm.pdf).

[4] Problem Set on Probabilistic Failure Models, #1–3.

[5] Problem Set on Probabilistic Failure Models, #4, 5.

[6] Problem Set on Probabilistic Failure Models, #6, 7.

[7] ○ *Info-Gap Decision Theory,* section 3.2.3.
○ Lecture Notes on Probabilistic Failure Models, section 14 (file: pfm.pdf).

10:00–10:50 *Lecture 6.* Continuation of lecture 5.

10:50–11:10 Coffee break.

11:10–12:00 *Lecture 7.* Statistical hypothesis testing applied to acceptance testing. Testing sample means with t tests. Sequential sampling.[8]

LUNCH 12:00–12:45

AFTERNOON

12:45–13:35 *Lecture 8.* Estimating an uncertain probability distribution.[9]

13:45–14:35 *Exercise 4.* Sampling to first failure.[10]

14:35–14:55 Coffee break.

14:55–15:45 *Exercise 5.* Fixed sample size.[11]

15:55–16:45 *Exercise 6.* Maximum likelihood estimation.[12]

Day 3

MORNING

09:00–09:50 *Lecture 9.* χ^2 test for acceptance testing and reliability analysis.[13]

10:00–10:50 *Lecture 10.* Continuation of lecture 9.

10:50–11:10 Coffee break.

11:10–12:00 *Exercise 7.* Test for equivalent performance and Vibration amplitude: χ^2 tests.[14]

LUNCH 12:00–12:45

AFTERNOON

12:45–13:35 *Brainstorm and define problems. Form small mini-project working groups.*

13:45–14:35 *Working groups formulate and implement info-gap-robust solutions.*

14:35–14:55 Coffee break.

14:55–15:45 *Working groups continue solution development.*

15:55–16:45 *Working groups present preliminary results.*

Project Guidelines

1. Preliminary advice.
   (a) Keep it simple.
   (b) Write it up.
2. English (or Hebrew): The story.
   (a) Problem statement.
   (b) Goals.
   (c) Uncertainties.
   (d) Decisions to be made:
      i. What must we decide about?
      ii. What are the options?
3. Math: Formulation.
   (a) System Model.
   (b) Performance requirements.

[8] ◦ Hines and Montgomery, chap. 11.
◦ Lecture Notes on Acceptance Testing, sections 1–2 (file: acctes.pdf).

[9] Lecture Notes on Info-Gap Estimation, section 4 (file: estim03.tex).

[10] Problem Set on Acceptance Tests, #1.

[11] Problem Set on Acceptance Tests, #2.

[12] Problem Set on Acceptance Tests, #11.

[13] ◦ Hines and Montgomery, chap. 11.
◦ Lecture Notes on Acceptance Testing, sections 4–6 (file: acctes.pdf).

[14] Problem Set on Acceptance Tests, #3, 7.

(c) Uncertainty model.
(d) Robustness definition (and perhaps opportuneness).

4. Math: Analysis.
   (a) Evaluate the probabilistic reliability and info-gap-robustness (analytical or numerical).
   (b) Sketch or plot the reliability and robustness curves for alternative decisions.
5. English (or Hebrew): Interpretation.
   (a) Interpret the reliability and robustness curves.
   (b) Make a decision, or start over.

Books and Other Sources

Books 2, 3, 15 and 16 are the main texts. The other items are useful supplementary sources.

1. J.I. Ansell, 1994, *Practical Methods for Reliability Data Analysis,* Oxford.
2. Ben-Haim, Yakov, 1996, *Robust Reliability in the Mechanical Sciences,* Springer.
3. Ben-Haim, Yakov, 2006, *Info-Gap Decision Theory: Decisions Under Severe Uncertainty,* 2nd edition, Academic Press.
4. Ben-Haim, Yakov, 2010, *Info-Gap Economics: An Operational Introduction,* Palgrave-Macmillan.
5. Ben-Haim, Yakov, 2018, *Dilemmas of Wonderland: Decisions in the Age of Innovation,* Oxford University Press.
6. Ben-Haim, Yakov, Lecture Notes on Acceptance Testing, course website, acctes.pdf.
7. Ben-Haim, Yakov, Lecture Notes on Performance vs Robustness of a Cantilever, course website, beam-op001.pdf.
8. Ben-Haim, Yakov, Lecture Notes on Probabilistic Failure Models, course website, pfm.pdf.
9. Ben-Haim, Yakov, Lecture Notes on Robustness and Opportuneness, course website, ro02.pdf.
10. O. Ditlevsen and H.O. Madsen, 1996, *Structural Reliability Methods,* John Wiley, New York.
11. G.W.A. Dummer and R.C. Winton, 1990, *An Elementary Guide to Reliability,* Pergamon Press, 4th ed.
12. C.E. Ebeling, 1997, *An Introduction to Reliability and Maintainability Engineering,* McGraw-Hill.
13. I. Elishakoff, 1983, *Probabilistic Methods in the Theory of Structures,* Wiley, New York.
14. E.A. Elsayed, 1996, *Reliability Engineering,* Addison Wesley, Reading, Massachusetts.
15. Hines, William W. and Douglas C. Montgomery, 1990, *Probability and Statistics in Engineering and Management Science,* 3rd ed, Wiley, New York.
16. A. Høyland and M. Rausand, 1994, *System Reliability Theory: Models and Statistical Methods,* Wiley, New York.
17. R.D. Leitch, *Reliability Analysis for Engineers: An Introduction,* Oxford, 1995.
18. E.E. Lewis, 1994, *Introduction to Reliability Engineering,* Wiley, New York.
19. J.D. Robson, *An Introduction to Random Vibration,* Edinburgh University Press, 1963.
20. A. Villemeur, 1992 *Reliability, Availability, Maintainability and Safety Assessment,* Vol. 1: Methods and Techniques, Vol. 2: Assessment, Hardware, Software and Human Factors. John Wiley, New York.