Universidad de los Andes
Facultad de Ingeniería

ABET Engineering Accreditation Commission

# Modelos Probabilísticos IIND-2104
# Universidad de Los Andes
# 2020-I

## 1 Staff

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## 2 Objectives

1. The students will learn to apply knowledge of mathematics and probability in the design, modeling and analysis of systems. The employed modeling formalisms include Continuous and Discrete Time Markov Chains, Queueing network models and Stochastic Dynamic Programming. Through the completion of three individual written exams, we evaluate this ability (ABET Outcome A).
2. The students will apply stochastic models to analyze key performance indicators of real systems. Moreover, they will be able to provide the best answer to a decision problem among a set of alternatives aimed at improving the system and understand the ethical implications of his recommendations. (ABET Outcomes B & E).
3. The students will learn how to develop model-based computational tools that supports decision-making in real organizations. (ABET Outcome K).

## 3 Contents

| Week | Topic | Main Text | Complementary Text | Class Topics | Remarks |
|---|---|---|---|---|---|
| 1<br>20/01- 24/01 | Motivation-Introduction | Lecture notes 1 | Factory Physics 1 Kulkarni 3.1 - 3.5<br>Winston 5.1<br>Winston 8.2<br>Ross 5.1, 5.2, 5.3 | 1. Motivation, course organization and introduction to dynamic systems modelling<br>2. Exponential random variables and introduction to stochastic processes modelling | |
| 2<br>27/01-31/01 | Markov Chains | Lecture notes 2, 3 | Kulkarni 4.1, 4.2<br>Winston 5.2<br>Ross 6.1, 6.2<br>Ross 4.1 | 3. Poisson Process, memoryless property and introduction to Markov Chains | |

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|---|---|---|---|---|---|
| | | | Winston 5.3<br>Ross 4.1 | 4. Markov Chains and transition matrices | |
| 3<br>03/02-07/02 | Markov Chains | Lecture notes 3, 4 | Winston 5.3<br>Ross 6.2 | 5. Markov Chain modeling | |
| | | | Kulkarni 4.2, 4.3<br>Kulkarni 2.1, 2.2 | 6. Embedded chains modelling | |
| 4<br>10/02-14/02 | Markov Chains | Lecture notes 5 | Winston 5.4<br>Ross 4.3 | 7. Transient analysis | |
| | | | | 8. Transient analysis | |
| 5<br>17/02-21/02 | Markov Chains | Lecture notes 6 | Winston 5.4<br>Ross 4.3 | 9. Classification of states | |
| | | | | 10. Classification of Markov chains | |
| 6<br>24/02-28/02 | Steady state behavior | Lecture notes 7 | Kulkarni 4.6<br>Winston 5.5<br>Ross 4.4 | 11. Steady state and limiting behavior | |
| | | | | 12. Review class and Kahoot | |
| 7<br>02/03-06/03 | Applications of Markov Chains | Lecture notes 8 | Kulkarni 4.7, 6.1, 6.2, 6.3<br>Winston 8.3, 8.4<br>Ross 6.3 | 13. Introduction to queuing theory | Monday: 1st-Exam 6:30 pm<br>Sunday: deadline to submit Phase 1 |
| | | | | 14. Limiting behavior and mean first passage times. | |
| 8<br>09/03-13/03 | Applications of Markov Chains | Lecture notes 8,9 | Kulkarni 5.6<br>Ross 4.4, 4.5 | 15. Mean occupation time. | Wednesday: deadline to evaluate Phase 1 |
| | | | Winston 8.3<br>Ross 6.3 | 16. Absorbing chains and absorption probabilities | |
| 9<br>16/03-20/03 | **Break** | | | | Friday: last day for the 30% |
| 10<br>23/03-27/03 | Queueing Theory | Lecture notes 8,9 | Winston 8.3<br>Kulkarni 5.6<br>Ross 4.4, 4.5, 6.3 | 17. Absorbing chains and absorption probabilities | Monday: Holiday<br>Friday: last day to drop the course |
| | | Lecture notes 10, 11,12 | Winston 8.4, 8.5 8.6, 8.7, 8.8<br>Ross 8.3, 8.9<br>Kulkarni 6.3, 6.4, 6.5 | 18. Little's Law and Birth and Death Process | |
| 11<br>30/03-03/04 | Queueing Theory and Networks | Lecture notes 13 | Winston 8.9<br>Kulkarni 6.3.3 | 19. Queues | |
| | | | | 20. Open Networks | |
| 12<br>6/04-10/04 | **Holy week** | | | | |
| 13<br>13/04-17/04 | Queueing Theory and Networks | Lecture notes 14 | Winston 8.10<br>Ross 8.4<br>Kulkarni 6.7 | 21. Open Networks & Reward functions | |
| | | | Winston 5.7 | 22. Review class and Kahoot | |
| 14<br>20/04-24/04 | Dynamic Programming | Lecture notes 15,16 | Puterman 1, 2.1<br>Winston 6.2 | 23. Introduction to decision processes | Monday: 2nd Exam 6:30 pm<br>Sunday: deadline to submit Phase 2 |
| | | | Puterman 3.1, 3.2 | 24. Introduction to DDP, Backwards Iteration | |
| 15<br>27/04- 01/05 | SDP | Lecture notes 16 | Winston 7.1, 7.3, 7.4.<br>Puterman 4.5, 4.6 | 25. Formulation and solution of DDP | Wednesday: deadline to evaluate Phase 2<br>Friday: Holiday |
| | | | | 26. Labour day | |
| 16<br>04/05-08/05 | SDP in finite time and infinite time | Lecture notes 17,18 | Puterman 4.5, 4.6<br>Winston 7.1, 7.3, 7.4<br>Puterman 6.1, 6.2 | 27. Formulation and solution of SDP | |
| | | | | 28. SDP applications | |

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|---|---|---|---|---|---|
| 17<br>11/05-15/05 | MDP | Lecture notes 18 | Winston 7.5<br>Puterman 6.9 | 29. Formulation of MDP<br>30. Solution of MDP | |
| 18<br>18/05-22/05 | | | | 31. Review class and Kahoot<br>32. Guided project activity | Sunday: deadline to submit Phase 3 |

# 4 References

## *4.1 Primary Text*

- Course lecture notes

## *4.2 Complementary Texts and Resources*

- W Winston. Introduction to Probability Models, Fourth edition, Thomson, 2004.
- S. Ross. Introduction to Probability Models, Ninth Edition, Academic Press, Elsevier, 2010.
- W. Hopp and M. Spearman. Factory Physics, Third Edition, McGraw Hill, 2008.
- V. Kulkarni. Introduction to Modeling and Analysis of Stochastic Systems. Second Edition, New York: Springer, 2011.
- M. Puterman. Markov decision processes: discrete stochastic dynamic programming. New York: John Wiley & Sons 2005.
- L. Castañeda, V. Arunachalam, and S. Dharmaraja. Introduction to Probability and Stochastic Processes with Applications. New Jersey: Wiley, 2012.
- Johns Hopkins University. R Programming. Coursera [online]. https://www.coursera.org/learn/r-programming

# 5 Evaluation methods

| Activity | Value | Date | | | Comments |
|---|---|---|---|---|---|
| Exam 1 | 25% | Monday March 2nd | | | Written exam |
| Exam 2 | 25% | Monday April 20th | | | Written exam |
| Exam 3 | 20% | Assigned by Registro | | | Written exam (cumulative) |
| Project | 30% | Phase 1<br>8%<br>Submission:<br>March 8th<br>Defense until<br>March 11th | Phase 2<br>8%<br>Submission:<br>April 26th<br>Defense until<br>April 29th | Phase 3<br>14%<br>Submission:<br>May 24th<br>Defense until<br>June 1st | Phase 1 to 3 are evaluations based in meetings with the tutor's project. |
| Total | 100% | | | | |

Partial grades will be published before the 30% grades deadline.

Pop quizzes will be performed during lectures to evaluate the student's preparation on class topics. The average score of all quizzes from classes before each exam will be extra credit on the grade of the cited exam. The value of the bonus ranges from 0/5 to 0.5/5.0 and depends on the relative ranking of the student with respect to the rest of his classmates. The student with the highest average grade will receive a 0.5/5.0. Any value amongst is calculated proportionally. This extra credit will only be granted if the student's grade in the exam is equal or greater than 2.5/5.0. Occasionally, an exam may contain makeup points for previous exams; points earned in this manner do not count towards this condition.

# 6 Rules

## *6.1 Final Grade*

The final grade of the course will be approximated to the nearest two decimal digits, e.g. 3.925 yields to 3.93.

## *6.2 Complementary Classes*

Complementary classes are not mandatory for students. However, students can reinforce particular topics of the course in the complementary class. The subjects that will be treated in these are the following:

| Complementary classes | |
|---|---|
| **Week** | **Topic** |
| 1<br>20/01- 24/01 | No classes |
| 2<br>27/01-31/01 | Motivation and introduction to R<br>Functions and control statements in R |
| 3<br>03/02-07/02 | Data handling and input data analysis in R |
| 4<br>10/02-14/02 | Linear algebra in R |
| 5<br>17/02-21/02 | Markov chains in R |
| 6<br>24/02-28/02 | Review class: Exercises |
| 7<br>02/03-06/03 | Introduction to Shiny |
| 8<br>09/03-13/03 | Shiny |
| 9<br>16/03-20/03 | Break |
| 10<br>23/03-27/03 | Time analysis in R |
| 11<br>30/03-03/04 | Queue calculator |
| 12<br>6/04-10/04 | Holy week |
| 13<br>13/04-17/04 | Review class: Exercises |
| 14<br>20/04-24/04 | Sensitivity analysis |
| 15<br>27/04- 01/05 | Dashboard |
| 16<br>04/05-08/05 | DDP in R |
| 17<br>11/05-15/05 | SDP in R |
| 18<br>18/05-22/05 | Optimization and MDP in R |

### *6.4 Exams*

There will be three written exams during the semester. It is expected that every procedure is defined and explained in detail, as well as the description of the variables, set of states, queues, servers, and other components of the system. Exams 1 and 2 are scheduled on two different dates throughout the semester. Exam 1 covers topics from week 1 through 6 and Exam 2 covers topics from week 7 to 13. Exam 3 covers topics taught throughout the entire term. Makeup exams will be given according to the rules of the university and **will be given only to students that are not present during the scheduled exam**. Additionally, the students that have a regular and prescheduled academic activity during the time of the exams should submit a written excuse during the first two weeks of classes.

### *6.5 Additional Resources*

*Office Hours*. During the semester, student can seek support from the teaching assistants regarding the course project, exams or any other issue related with the course. The schedule, rules and location of office hours will be posted on SICUA+. Students may always write an email to the professor or the teaching assistants asking for an appointment in advance.

### *6.6 Project*

The project is to be done in groups of **four** people. Each student will be assigned to a group by the course staff. The rules and dates for evaluation of the project will be given for each project phase, separately. It is required for each project to be based on original work of the team and data gathered by the members of the group, or as instructed. Failure to comply with this will be treated as fraud.

### *6.7 Claims*

Once the graded evaluations are published, deadlines to present claims will be announced. Students will submit a claim by filling and signing a claim template, declaring that the evaluation was not modified in any form.

### *6.8 Fraud*

Any suspicion of fraud within the activities of the course will be treated according to the University's rules. Make sure to review them at Chapter X of the student's regulation, at the following link:

http://secretariageneral.uniandes.edu.co/images/documents/ReglamentoGralEstudiantesPregrado.pdf

# ABET Outcomes

| | ABET Outcome | Contribution | Description | Course Measures |
|---|---|---|---|---|
| A | Math, Science, Engineering | **Major** | An ability to apply knowledge of mathematics, science, and engineering | Three individual exams |
| B | Design and Conduct Experiments | **Major** | An ability to design and conduct experiments, as well as to analyze and interpret data | Project Phase I, II and III. |
| C | Design Systems, Components, Process | Minor | An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability | |
| D | Multi-disciplinary Teams | Minor | An ability to function on multi-disciplinary teams | |
| E | Engineering Problems | **Major** | An ability to identify, formulate, and solve engineering problems | Project Phase III |
| F | Professional and Ethical Responsibilities | Minor | An understanding of professional and ethical responsibility | |
| G | Communication | Minor | An ability to communicate effectively | |
| H | Impact of Engineering Solutions | Minor | The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context | |
| I | Life-long Learning | Minor | A recognition of the need for, and an ability to engage in life-long learning | |
| J | Contemporary Issues | Minor | A knowledge of contemporary issues | |
| K | Modern Engineering Tools | **Major** | An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. | Project Phase III |