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► **To cite this version:**

Cristina Stoica Maniu, Véronique Letort, Cristina Vlad, G. Sandou. A Study on New Trends in Systems Modeling based on 850 Students' Interest. IFAC 2020 - 21st IFAC World Congress, Jul 2020, Berlin, Germany. hal-02632581

HAL Id: hal-02632581

<https://hal.science/hal-02632581v1>

Submitted on 27 May 2020

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A Study on New Trends in Systems Modeling based on 850 Students' Interest

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Abstract: This paper focuses on the impact of everyday questions on engineering research, starting with systems modeling in the perspective of control, optimization, prediction and diagnosis of dynamical systems. An analysis of the 850 students' interest participating to the *Model Representations and Analysis* module is proposed. The 283 subjects proposed as projects, as well as the methodologies applied during the projects development are studied.

Keywords: Teaching curricula developments for control and other engineers, systems modeling perspective

1. INTRODUCTION

Current topics and impact on future research in Systems & Control are crucial both for industry and academia. Throughout the years, inspiring studies have been conducted by numerous research groups, e.g. Lamnabhi-Lagarrigue et al. (2017), How (2017). Students' point of view is an essential element that has to be considered in research development strategies in order to keep an equilibrium between the technological challenges, the consumers' exigency and the job market evolution.

In this context, this paper proposes an analysis of students' interest in systems modeling. The study is based on the 283 projects topics elaborated by the 850 students (working in groups of 3 students) during the *Model Representation and Analysis* core module at CentraleSupélec¹ (Jankovic et al. (2019)). A second occurrence of the module has been taught in 2019-2020, both for French and international students. The theoretical content (Stoica Maniu et al. (2019), Chevet et al. (2019), Chevet et al. (2020)) of the course is divided in three parts: Part I. continuous-state system modeling and analysis (illustrated in blue in Fig. 1), Part II. discrete-event system modeling and analysis (in green in Fig. 1), Part III. model identification, evaluation and selection techniques based on uncertainty and sensitivity analysis (in orange in Fig. 1). The module has 36 on-site hours (divided into 15h lectures, 16.5h tutorials, 1.5h conference, 3h exam) for a total student workload of 60h. A project covering Part I and II allowing a deeper insight in system modeling and simulation completes this module.

¹ CentraleSupélec is one of the first top-ranking French 'Grandes Écoles', i.e. a graduate engineering school with a selective entrance exam.

Each group of 3 students proposes a subject and solves a subject proposed by another team and randomly assigned. Studying the main topics of most interest to 850 students (which is the main contribution of this demonstrator late breaking results paper) allows us to improve the attractiveness of future tutorials in Systems & Control curricula, as well as to engage stimulating industrial subjects, while increasing the level of satisfaction of the students, the researchers/professors and the industrial partners.

The remaining part of this paper is organized as follows. Section 2 focuses on the pedagogical objectives and the general description of the project activity. The main topics of the projects are presented in Section 3, while illustrative results are shown in Section 4. Concluding remarks are drawn in Section 5.

2. PROJECTS: PEDAGOGICAL OBJECTIVES AND DESCRIPTION

The main objectives of proposing projects during the *Model Representations and Analysis* module are:

- (1) Grasp the diversity of modelling methodologies as well as application domains;
- (2) Experiment the very often iterative approach aiming to mathematical model of a given system, to design a simulator (and test it), to analyze the behaviour of the proposed model with respect to the expected objectives (e.g. for control/optimization/prediction purposes), to question the validity of some assumptions;
- (3) Be able to analyse a modelling approach (continuous-state model, discrete-event model) with a fair and critical view.

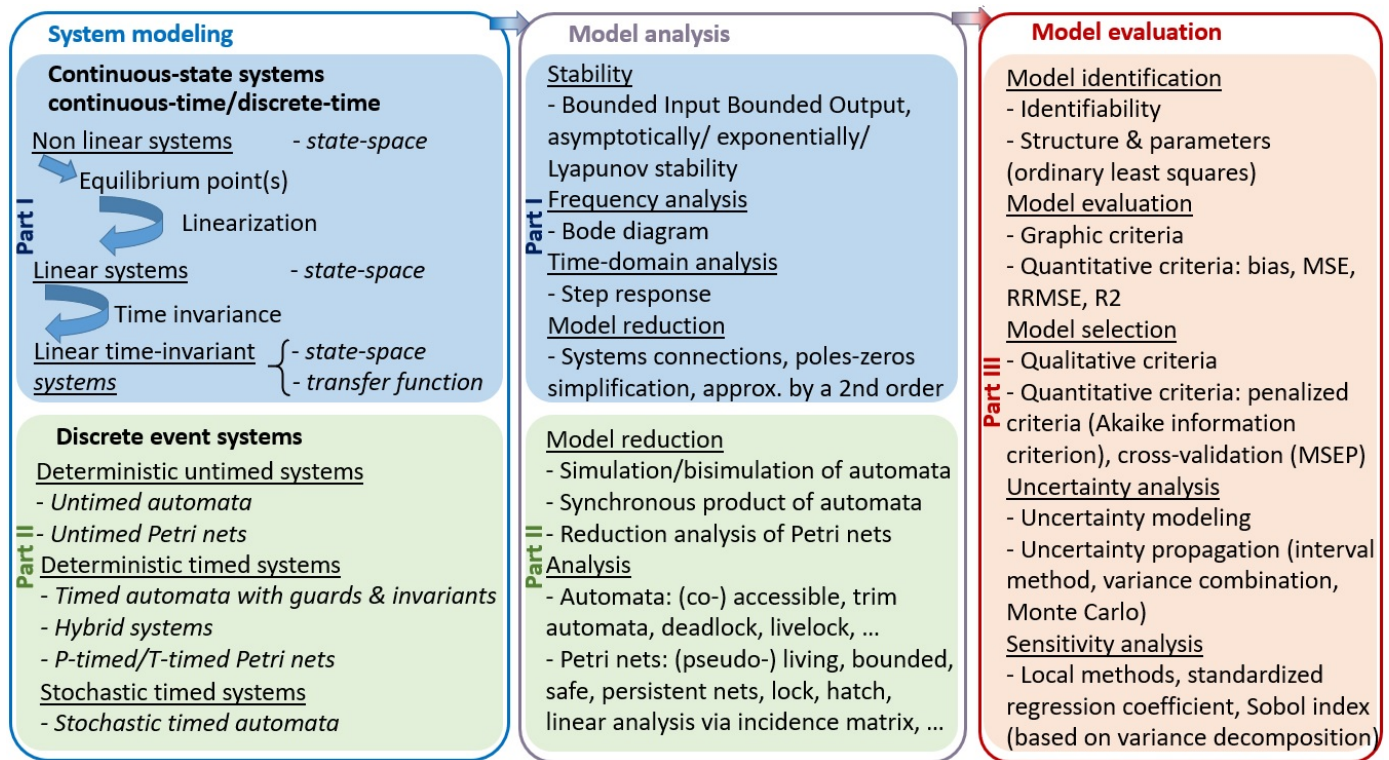


Fig. 1. Organization of the *Model Representations and Analysis* course

The estimated working load for the projects (including subject proposal, project achievement, evaluation) is between 8 and 10 hours per student.

During the **Phase 1**, each group of students proposes:

- (1) *One-page subject* explaining the context, the modeling objectives by means of a continuous-state system (Part I of the module in Fig. 1), the objectives of a discrete-event system modelling (Part II in Fig. 1) and a relevant image;
- (2) *A reference* from the literature to be given in appendix providing the necessary information to establish the mathematical equations of the model.

The **Phase 2** consists in implementing the model for the project proposed by another team (random assignment of the project to another team). The deliverables are a *simulator*² (in general in Matlab or Python) and a *short report*, including the description, the analysis and the implementation of a continuous-state model for the proposed system with a stability analysis, the description of a discrete-event system model (automata, Petri nets, hybrid systems), references used for the modelling approach.

The **Phase 3** deals with the peer-review evaluation both of the projects subject and achievement. The *peer-review evaluation of a proposed subject* is carried out by the team assigned to the project, taking into account the global understanding of the subject, the feasibility, the relevance of the proposed document, the general interest in the subject. The *peer-review evaluation of a project achievement* is carried out by the student team that proposed the subject, taking into account the proposed continuous-state mathematical model (state-space representation or

² The programming software is at students' choice.

transfer functions), the stability analysis, the simulator, a discrete-event modeling and the associated formalism (e.g. guard and invariant conditions), the clarity of the report and the graphical illustrations (figures, tables, etc.). The evaluation criteria are synthesized in Stoica Maniu et al. (2019).

3. PROJECTS TOPICS

The main topics of the projects proposed by the students are divided in 10 categories, as represented in Fig. 2, together with their percentage. The most representative subjects on system modeling are listed below:

- (1) **Healthcare:** Epidemia/virus propagation³, Effect of modern life styles towards the immune system, Stem cell homeostasis/ cancerous tumour evolution, Vaccine efficacy, Lung volume during breathing cycles, Evolution of the Glucose-Insulin metabolism for diabetic patients, Modeling physical mechanisms of auditory perception, Signal propagation through the nervous system, Dynamics of antibiotic-resistant bacteria, Modeling an enzymatic reaction, Modeling the electrical activity of the rabbit/human heart electrical activity, Neuron functioning, Modeling the digestion in the bowel, Evolution of blood alcohol level during a party;
- (2) **Social and techno-social networks:** Modeling population dynamics⁴ (e.g. survival of the Maya

³ Thirty seven subjects were proposed on this topic, with different variations, e.g. evolution of a zombie infection, Chikungunya virus propagation. The deadline for the project subjects submission was on December 17, 2019, before the peak of the Coronavirus epidemic in China.

⁴ Thirty seven subjects were also proposed on this topic.

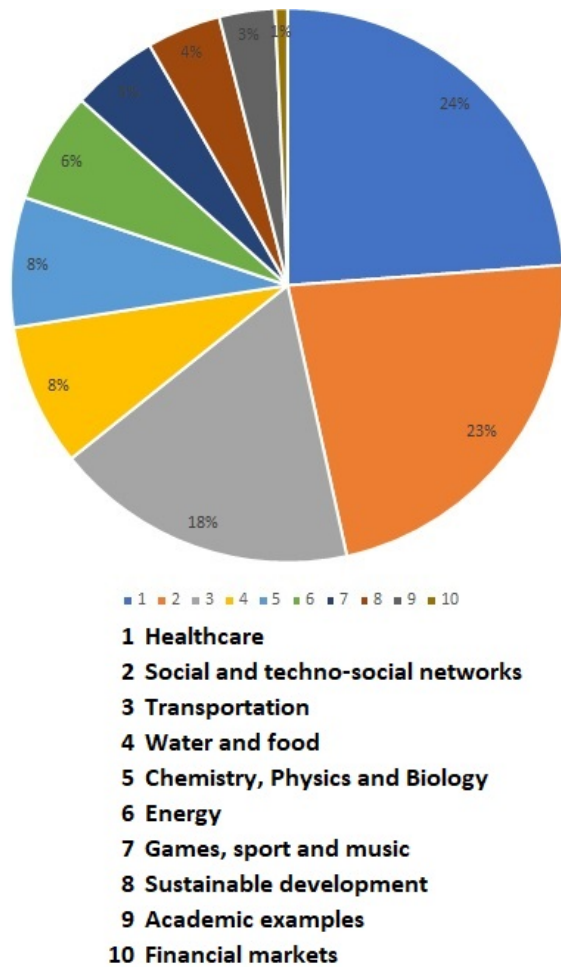


Fig. 2. Main topics of the proposed project subjects

- civilization, demographic transition), Predator-prey interaction, Modeling the evolution of armaments, Modeling of love between Romeo and Juliet/evolution of love and happiness, Modeling the propagation of a rumor, Crowd movement/pedestrian dynamics in a subway station, Modeling a consumer behavior in a supermarket, Spread of computer viruses, Battle simulation, Modeling the human behaviour in disaster situations, Memes propagation in a digital world;
- Transportation:** Segway/bike modeling, Millennium bridge modeling, Trajectory tracking modeling of an autonomous car, A fluid mechanics approach to road traffic modeling, Elevator modeling, Models in Robotics, Quadcopter modeling, An anti-ballast system modeling for overhead cranes, Characterization of a bi-thermal combustion engine according to a stirling cycle, Car damper modeling, Drive train modeling, Magnetic levitation trains behaviour modeling, Azimuth antenna modeling, Modeling the trajectory of a probe in the solar system, Orbital disturbances modeling, Polytropic model of a star, Missile modeling, Modeling the trajectory of a falling satellite around the Earth;
 - Water and food:** Modeling a water tank during earthquake, Modeling the surface variation of the water contained in the Tibetan bowl, Evaporation process modeling of a puddle of water, Modeling wave evolution, Fluid movement modeling, Snowflake

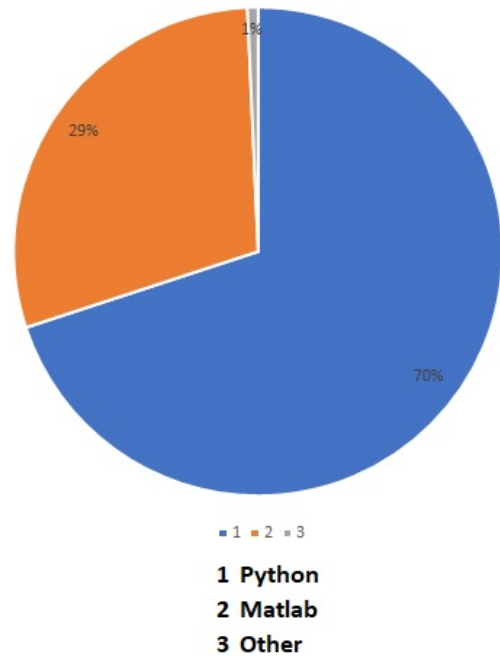


Fig. 3. Software used for model representation and analysis

- growth modeling, Fluid move modeling in a tanker truck, Evolution of the pH during alcoholic fermentation, Plant growth modeling, Dissolution kinetics of crystals in molten glass under isothermal conditions, Coffee dispenser modeling, Coca-Cola & Mentos degassing process modeling, Modelling alcohol consumption in France based on the Spanish model, Cocoa production modeling, Transesterification of soybean oil;
- Chemistry, Physics and Biology:** Chemical reaction modeling (e.g. the Belousov-Zhabotinsky reaction, the Briggs-Rauscher reaction), Modeling biochemical interactions within a cell, Bioprocess modeling, Bacterial metabolism modeling, Linear oscillator chain modeling, Modeling the Lorentz dynamical system, Modeling electron populations in a laser, Heat transfer analysis through a finned tube placed in a biomass combustion chamber, Osmosis phenomenon modeling, Mathematica model of a trebuchet, Door slamming modeling;
 - Energy:** Stabilisation of a floating offshore wind turbine, Operation of a glazed flat plate solar collector, Buck converter modeling, Heat transfer modelling in a rotating electrical machine, Modeling the temperature evolution in a supermarket frozen bin, Modeling of a swimming pool heating system, Modeling the temperature evolution in a room heated by underfloor heating, Poly-switch modeling for electrical circuits protection, Study of a heat pump for heating a building;
 - Games, sport and music:** Modeling the Magnus effect applied to a soccer ball, Boomerang path/ping-pong ball/billiard balls trajectory modeling, Swing modeling, Modeling a climber falling down on a rope, Vibratory and acoustic characterization of stringed instruments, Modeling of an electro-dynamic loudspeaker/an acoustic guitar/vocal cords sound, Modeling vibrations of a piano string;

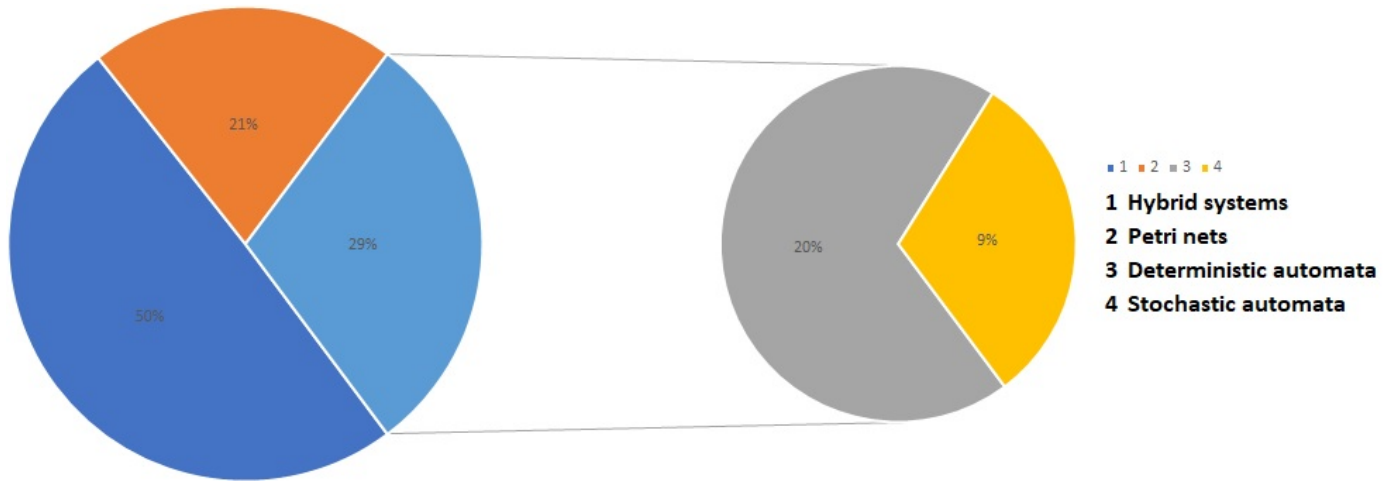


Fig. 4. Use of hybrid systems, Petri nets and automata for discrete-event systems modeling

- (8) **Sustainable development:** Iceberg drift modeling, Deforestation modeling and biomass impact, Spread of forest fires, Modeling avalanche behaviour, Thickness evolution of the ice cover of a lake, Modeling meteorological phenomena;
- (9) **Academic examples:** Inverted pendulum, Multiple pendulum;
- (10) **Financial markets:** Modelling the relation between GDP growth and the evolution of public debt, Market competition modeling.

4. PROJECTS ANALYSIS

The main topics of interest for our students in 2020 are: healthcare (24%), social and techno-social networks (23%) and transportation (18%), as illustrated in Fig. 2. Concerning the software used for simulations, 70% of our students have chosen Python, 29% used Matlab and 1% used Solidworks and Ansys Student, as shown in Fig. 3. Indeed, with the new curricula of *Preparatory classes*⁵, our students are already familiar with Python. Despite the fact that the 850 students followed a Matlab onramp Matlab (2014) introductory tutorial and all the tutorials of the *Model Representations and Analysis* module used Matlab for simulations, most of the students privileged the use of Python for a short-time project.

The main novelty of the second occurrence of the projects is the fact that the subjects focused on both the continuous-state modeling (Part I of the module) and discrete-event systems modeling (Part II of the module). Analyzing the approaches used for discrete-event models, 50% of the students used hybrid systems, 29% used deterministic/stochastic automata and 21% used Petri nets for system modeling and analysis, as illustrated in Fig. 4.

5. CONCLUSION

This paper proposed an analysis of students' interest in the main fields of system modeling, based on the project proposals of the 850 students involved in the 1st year module

⁵ Preparatory classes in France offer two years of intensive scientific higher education. These two years are followed by a selective entrance exam to the French 'Grandes Ecoles', such as CentraleSupélec.

Model Representations and Analysis at CentraleSupélec. In the continuity of this work, an interesting perspective is to study their interest in *Automatic Control*, one of the core module in the 2nd year at CentraleSupélec.

ACKNOWLEDGEMENTS

The authors would like to thank to all their colleagues, students and administrative staff of CentraleSupélec involved in the *Model Representations and Analysis* module.

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