SF2866 Applied Systems Engineering, SF2868 Systems Engineering, Business and Management, Part 1

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Optimization and Systems Theory
Department of Mathematics
KTH Royal Institute of Technology

Starting Period 1, 2016

1. Course Information
2. Projects
3. Systems Engineering - Modelling and Simulation

Outline

1. Course Information

2. Projects

3. Systems Engineering - Modelling and Simulation

Teachers

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Target group

Mainly for students in the master programs:

- Aerospace
- Applied and Computational Mathematics
- Optimization and Systems theory track TIEMM

Prerequisites
SF1811/41/61 Optimization
SF2863 Systems Engineering

Course goals

The objectives of the course is for the students to

- reach deeper understanding of the fundamentals of the subject (defined by the SF2863 course), practice the ability to apply the general theory and generalize or specialize it to particular problems.
- collaborate in groups; discuss and apply mathematical principles and techniques to practical scientific problems.
- synthesize mathematical models for processes and be able to analyze the models, explain and motivate the assumptions and approximations made and discuss their consequences, and finally use the model for optimization.
- communicate professionally and present scientific results, by writing technical reports, and preparing and giving oral presentations

Main content

The course is based on different topics in systems engineering and operations research that are related to local industry and research projects.

A theoretical framework will be presented in lectures, but the main content will be introduced in terms of two larger projects.

The projects will be done in groups (designed by the examiner) to practice teamwork, generate peer learning and cooperative skills.

The topics may change from year to year and have different focus depending on which projects are selected.

Numerical and statistical aspects of the projects will also be regarded when relevant. The theorethical framework is based on, but not limited to, the following subjects: (next page)

Main content

- Optimization
- Marginal allocation.
- Multiobjective optimization.
- Pareto optimality. Game theory.
- Sherbrooke's models for optimization of spareparts, including multi-echelon techniques.
- Inventory theory.
- Queueing theory.
- Dynamic programming.
- Markov decision processes.
- Reliability theory
- Project management
- Scheduling

Literature

The course is not centered around a book, but for first reference we recommend the books:

- “Introduction to operations research”,
  by Hillier and Lieberman.
- “Operations research and Management Science handbook”,
  by A. Ravi Ravindran.
  (available for free on the internet for KTH students)

Further material will be posted on the homepage.

Course homepage

On the course homepage

http://www.math.kth.se/optsyst/grundutbildning/kurser/SF2866/

you can/will find

1. a preliminary schedule
2. reading instructions, *et.c.*
3. these slides

Preliminary schedule for the course

Date	Time	Room	Subject
Mon 29/8	10-12	D42	Course introduction. Modelling and simulations
Wed 31/8	15-17	D32	Airline Optimization
Fri 2/9	8-10	H33	Sabre presentation of project 1
Mon 5/9	10-12	M24	Airline Optimization
Wed 7/9	15-17	E53	QaA1
Fri 9/9	8-10	B21	Production systems
Mon 12/9	10-12	V12	QaA2
Wed 14/9	15-17	V11	Production systems cont
Fri 16/9	8-10	Q22	Peer review feedback seminar
Mon 19/9	10-12	E53	
Wed 21/9	15-17	D42	Tio100 presentation of Project 2
Fri 23/9	8-10	E33	Final presentation Project 1
Mon 26/9	10-12	E36	
Wed 28/9	15-17	D42	QaA1
Fri 30/9	8-10	E33	Inventory theory
Mon 3/10	10-12	H33	QaA2
Wed 5/10	15-17	Q15	Inventory theory
Fri 7/10	8-10	V12	Peer review feedback seminar
Mon 10/10	10-12	E36	Guest lecture SAAB avionics
Wed 12/10	15-17	D32	
Fri 14/10	8-10	E33	Final presentations project 2

Project assignments

There will be 2 group projects

Examined by evaluations of oral and written reports, scientific content and the process. PRO1, 4HP.

This year

- GP 1: Gate assignment - Sabre
- GP 2: Route planning - Tio100

Examination

Second part: written exam, TEN1, 3.5 HP

Preliminary grade convertion:

	A	**B**	**C**	**D**	**E**	**F**	Grade on PRO1
A	A	A	B	B	C	F	
B	A	B	B	C	D	F	
C	B	B	C	D	D	F	
D	B	C	C	D	E	F	
E	C	C	D	D	E	F	
F	F	F	F	F	F	F	
Grade on TEN1							

The written exam considers theory used in the projects and from the theory classes.

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Projects

The project groups will be designed by the examiner and changed for each of the projects.

The objective of the group design is to create as diversified groups as possible when it comes to previous study background, special skills *et.c.*

For each project there will be one or more lectures presenting the underlying theory and concepts developed in the field. Then there will be time scheduled for the groups to work on the projects, and seminars where the groups can ask each others or the teacher about relevant issues.

Finally the groups should write a report and give an oral presentation of their results.

GP1: Gate Assignment

The first project is on Gate assignment optimizaton and is developed by **Sabre**.

It considers the problem to determine which aircraft should be assigned which gate and at what time.

The assignment should satisfy certain constraints, to avoid collisions, gate compatibility, et.c., and the best solutions according to some criteria, e.g. total passenger walking distance, should be determined.

Data for the airport layout, flight info, aircraft types, passenger data, *et.c*, will be provided.

GP2: Route Planing

The second project deals with route planning and is developed by **Tio100**.

Tio100 is located in Norrtälje and works in home care service. The planning of the routes taken by the service teams amounts to complex combinatorial problems. In addition to the planned service there are also unplanned visits that may occur. These visits are complicated by the fact that the keys to these clients have to be fetched at some depot.

Data representing clients, depots and service personell will be provided.

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Systems Engineering - Systems

According to the INCOSE SE handbook

System - A combination of *interacting elements* organized to achieve one, or more, stated purposes.

An integrated set of elements, subsystems, or assemblies that accomplish a defined objective. These elements include products, processes, people, information, techniques, facilities, services and other support elements.

Systems Engineering - SE

According to the INCOSE SE handbook

Systems Engineering A discipline that concentrates on the design and application of the *whole system as distinct from the parts*. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspects.

Systems Engineering is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system.

Systems Engineering - SE

According to the INCOSE SE handbook

SE is an interdisciplinary approach and means to enable the realization of successful systems.

It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal.

SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Modelling

Define the purpose of the modelling.

Often the purpose is to understand, predict or control the system. (this could be restricted to some particular operation range of the system)

- Determine a model for the system from physical laws and relations known to hold for the system under the assumed conditions.
- Gather data from the system relevant for that purpose and fit a model.
  (this usually involves a lot of preprocessing of the data)

Considering every detail of the system quickly leads to very complex and often very sensitive models.

The aim should be to determine a model that is as simple as possible while still representing the behaviour and characteristics of the system that are relevant for the purpose of the model.

Modelling

The procedure to find a good level of complexity is based on validation of the model and refinements/approximations. For the validation it is important to have access to measurements from the system that can be compared to the output of the model, or experts that can evaluate the quality.

Model development cycle: Plan - Build - Test - Refine the model

Note: A model developed for one purpose, should be revalidated before it is used for another one.

Sensitivity analysis can be used to evaluate the robustness of the model.

Model qualities

What do we want from the model ?

Simple - Occam’s razor “A simpler model should be preferred”

“Everything should be made as simple as possible, but not simpler.”
- Albert Einstein

Complete

Computationally manageable

Adaptive

Provide qualitative insights

Five Simple Principles of Modelling - Pidd 1996

1. Model simple, think complicated
2. Be parsimonious, start small and add
3. Divide and conquer, avoid mega-models
4. Do not fall in love with data
5. Model building may feel like muddling through

Factors why complex models are used: “Show off”, “Possibility” , “include all” syndrome, lack of understanding of the system, unclear simulation objectives *et.c.*

Example: Buying a car

Which criteria are important when buying a car?

How would a systems engineer go about to buy a car?

Example: Buying a car

Is the question well-posed? Is it a car we need or are other means of communication valid?

Should we buy the car, or lease it?

What is the time horizon?

What purpose is the car supposed to serve?

Constraints/desired objectives: loading capacity, driving performance, comfort, fuel ecenomy, safety aspects, parking abilities, insurance premiums, second hand value, maintenance, disposal, eco-friendliness, status, *et.c.*

Simulation

Why should you use simulation?

Analytic results from models are often less time-consuming and suitable for optimization, but

- fewer restrictive assumptions are required in simulations, especially different probilistic distributions and individual properties of elements are easy to implement
- transient (time-dependent) solutions are easier to simulate
- simulations are flexible to test “What happens if?”
- sometimes analytical solutions are “impossible” to obtain
- simulations can be used to verify a model and its assumptions

Simulation types

Classified according to

- Stochastic or deterministic
- Steady-state or dynamic
- Continuous or discrete, or discrete event
- Local or distributed

Simulation Projects

Steps of simulation projects (ORMS 12.4) (*cf.* HL 20.5)

1. Identify the problem
2. State your objective
3. Identify, collect and prepare input data
4. Formulate the model
5. Verify and validate the model
6. Experiment and analyze the results
7. Conclusions and recommendations

Car buying example

1. Identify the problem.
   A company needs to speed up transports
2. State your objective
   Find the least expensive transportation means for a flow of goods from A to B with bounds on time and environmental effects, for the next five years.
3. Identify, collect and prepare input data
   Determine values, investment costs, for cars/vehicles of different type and age that satisfy the speed and environmental constraints. Find statistics about machine failures for the vehicles and costs of repair and replacement or change of vehicle.
4. Formulate the model
   Determine a model that keeps track of the current vehicle, its age and value, and using the statistics determine the generated maintenance/replacement cost and any costs for strategic decisions to change vehicle.

Car buying example continued:

5. Verify and validate the model
   Test the model, maybe first without repairs and then check how this factor changes the result.

6. Experiment and analyze the results
   Test a number of vehicle management plans and compare the results. Weigh costs against robustness and other factors.
   Compare to the cost for leasing a car.
   Compare to the cost for using a shipping service.

7. Conclusions and recommendations
   Determine the best plan, and alternative solutions that are observed to perform well in other aspects.

Basic building blocks of simulations

(IOR 20.1)

1. Define the *states of the system*
2. Identify the *possible states* of the system
3. Identify the possible *events* changing the states
4. Determine formulas for *state transitions* based on the possible events
5. Define a *simulation clock* that keeps track on simulated time
6. Design a *random generator* for the events