OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG INF FAKULTÄT FÜR INFORMATIK

Kickoff Lecture Simulation Project 2020

Last ItS lecture of term: 31.01.20, 11:15

Everyone who wants to participate in SimProj must attend!

Agenda of this meeting:

- Some more information on the course
- Binding registration for the course

SimProj can be counted as

- Bachelor FIN : *WPF FIN SMK* or *Wahlpflichtfach*

Master Students can do team projects

- DigiEng: Interdisciplinary Team Project
- DKE: Applications, Team Project

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Introduction to Simulation

Verification & Validation

Verification & Validation

It is VERY easy to make errors in a simulation project.

- Inaccurate measurements
- Incorrect assumptions
- Programming errors

Much may depend on simulation results

- Money, property, environment, human life

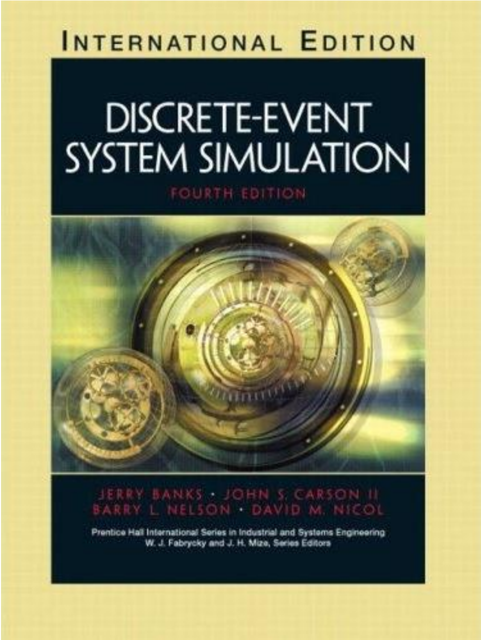
V&V are thus important parts of a simulation study

- They are difficult and expensive
- Only few people do them!

Background Reading

Relevant sections of the book:

- 10.1
- 10.2
- 10.3
- 10.4



Reminder: Verification & Validation

Validation

- Compare the real system to the simulation model.
- Does the model represent the real system accurately?
- *Building the right model*

Verification

- Compare the conceptual model with its implementation.
- Does the simulation program represent the conceptual model?
- *Building the model right*

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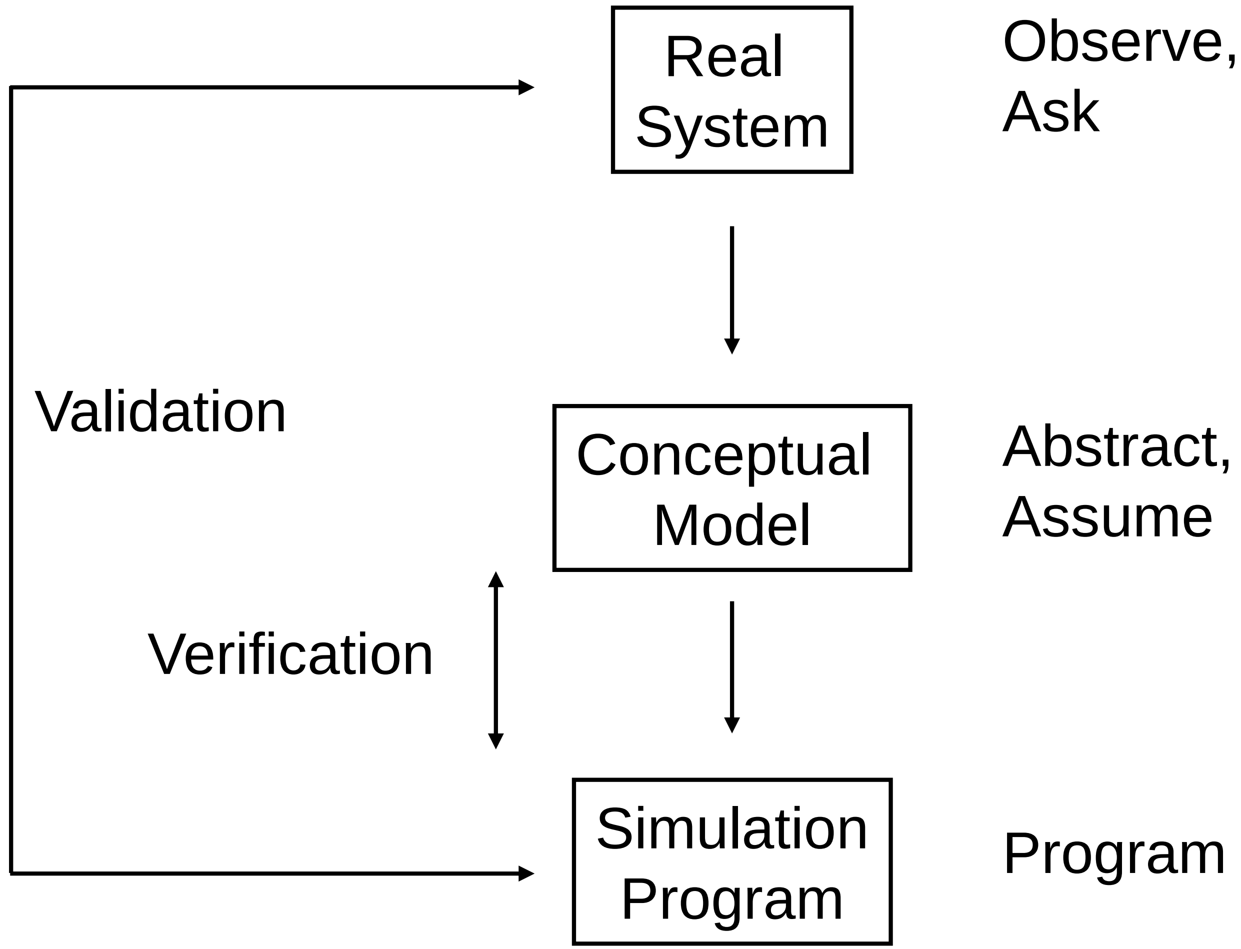
Reminder: Steps of a Simulation Study



Verification Methods

Both general and specific verification methods are available.

General methods of verification:

- Interactive debugging
- Let someone else check your program
- Trace values of variables
- Common sense
- Documentation
- Top–down programming
- Modular programming

(Standard methods of Software Engineering)

Verification Methods

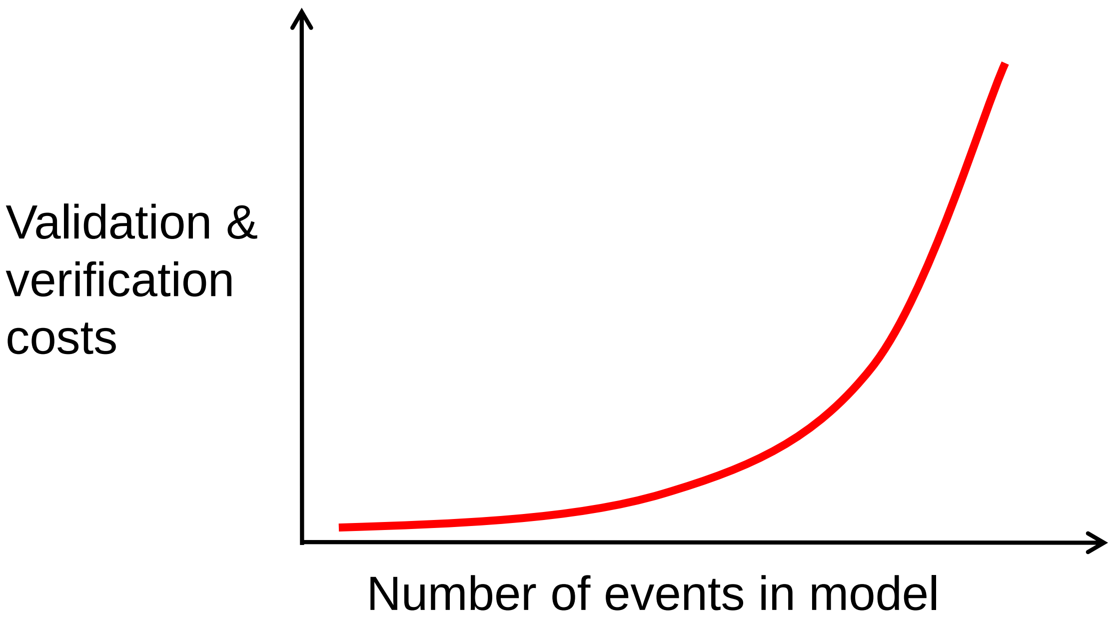
Simulation–specific aids to verification:

- Conservation laws
- Test simple cases which have known results
- Successive refinement ("start simple!")
(The final model should be as simple as possible, and as complex as necessary!)
- Plausibility checks
- Animation
- Sensitivity analysis

Verification Costs

Model complexity:

- The cost of verification (and validation) depends superlinearly on the model complexity:



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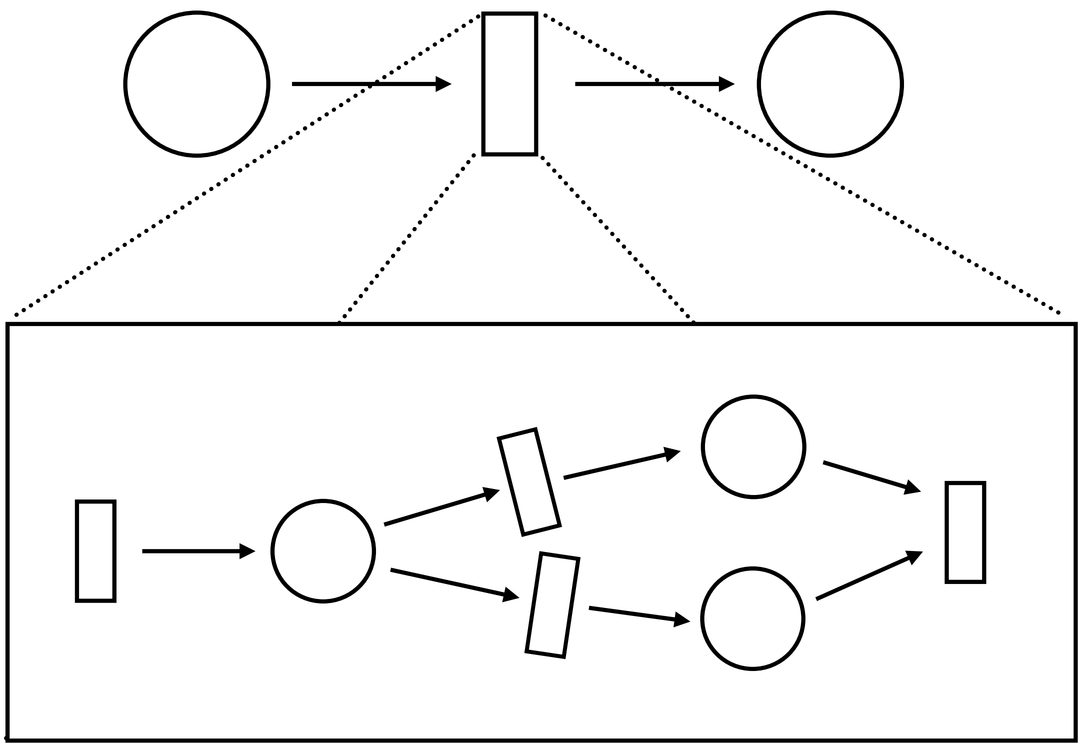
Successive Refinement



Validation

What are we trying to achieve?

- *"The model behaves exactly like the real system." (?!)*

This is impossible!

- (The model is always an approximation.)

Also: Validation is a destructive process.

- We can only prove that a model is wrong.
- We can never prove that it is correct.

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A Practical Definition of Validation

New definition of validation:

- *"The decisions that are made based on the simulation results are the same as if we had been able to use results from the real system instead."*

This means that validation is relative.

- We have to think about goals.

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Validation

Validation and goals:

- The model depends on the goal of the project.
- Different goals lead to different models.
- A model can be valid for one goal, but not for another.
- Perform validation with respect to goals of project.
- First job: decide what the goal of the project is.

Validation

Selective validity:

- A model can be valid for one goal, but not for others.
- A model can be valid for one item of output data, but not for others.
- A model can be valid for certain assumptions, but not for others.

Two–Step Validation

A two–step approach to validation:

1. Develop a model with high face validity.
2. Determine the quality of the simulation output.

Face Validity

What does "Face Validity" mean?

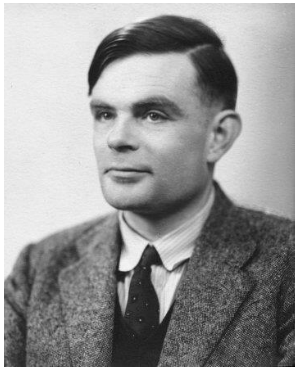
- Results appear reasonable to model users and experts.

Approaches:

- Use common sense (!)
- Involve experts in the calibration process
- Sensitivity analysis
- Use real data wherever possible
- Compare with theoretical results in simple cases
- Turing Test

Turing Test

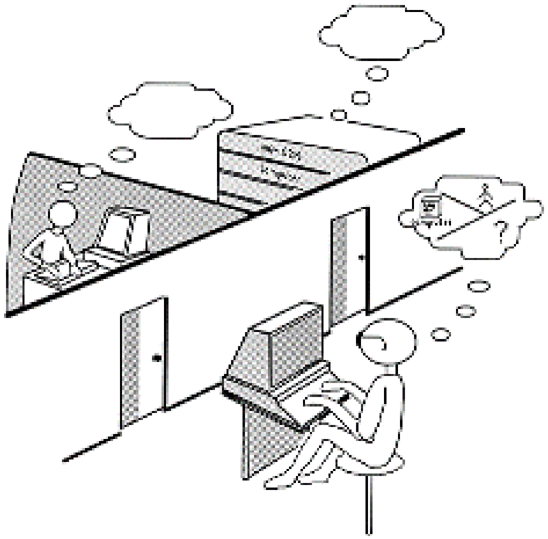
Alan Turing (1950)



- A test person communicates with two others.
- One is person, the other is a computer.
- Can the test person tell the difference?

Use in simulation:

- Show system results and simulation results to experts.
- Can they tell the difference?



Sensitivity Analysis

Sensitivity analysis measures …

- the dependency of output values on input parameters

Given:

- Output value O
- Input parameter I
- Sensitivity $S = dO \,/\, dI$

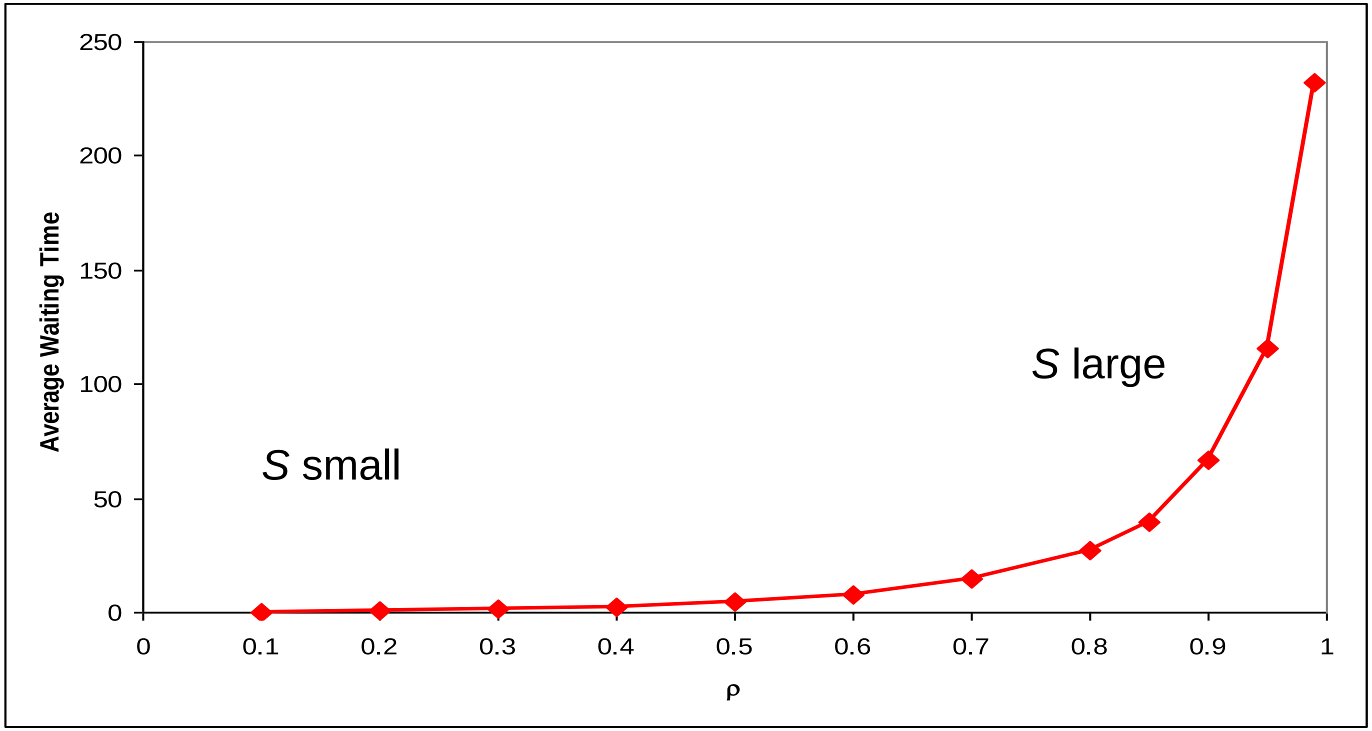
Example: Simple queue with a fixed arrival rate

- I: Service rate
- O: Average queue length

Sensitivity Analysis

Example: Queue in the bank, all activities exponential

- $O =$ average waiting time
- $I =$ arrival rate (service rate $= 1$)



Sensitivity Analysis

Uses of sensitivity analysis:

- Verification
- Guide future data collection
- Guide the level of model detail
  (If S is small –> low model detail is sufficient)
  (If S is large –> more detailed model is needed)
- Detect critical parameters

Quality of Simulation Output

Determine the quality of the simulation output.

The question we are interested in:

- *Can the simulation model predict the future of the system?*

Of course, this question cannot be answered.

However, sometimes a real system already exists.

We may then at least ask the question:

- *Does the simulation model "predict the past" of this system?*

Making Comparisons

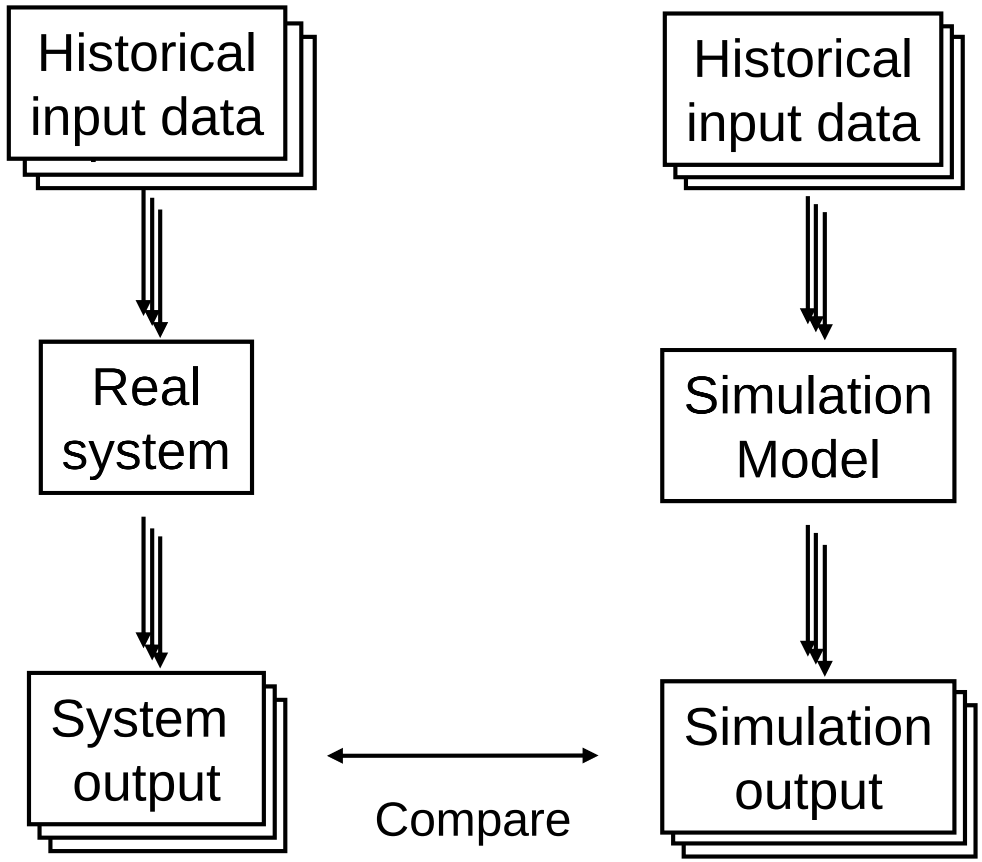
Idea:

- Validate model using data from real system.

There are two common approaches:

1. Use historical input data.
2. Use input–output transformations.

Using Historical Input Data



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Using Historical Input Data

"Historical Input Data" means raw, real data.

- (Actual arrival times etc., not sampled distributions)

Complete historical data must be available.

- (Nothing may be missing.)

Note:

- The simulator must be able to use raw input data.
- This is not always possible.

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Using Historical Input Data

Compute mean and variance of replications:

- Assume R measurements Z_r, $r = 1 \dots R$
- Run simulation using h.i.d. to obtain R values W_r
- Compute $d_r = Z_r - W_r$
- Compute $\bar{d} = d_r / R$
- Compute $S^2 = \frac{1}{R-1} \sum (\bar{d} - d_r)^2$

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Using Historical Input Data

Idea:

- We assume $d_r = Z_r - W_r \sim N(\mu, \sigma)$
- Null hypothesis: $H_0 : \mu = 0$
- Choose level of significance α
- Compute a confidence interval using

$$t_0 = \frac{\bar{d} - \mu}{S / \sqrt{R}}$$

- If $|t_0| > t_{\alpha/2, R-1}$ then reject H_0
- This is called a *paired t–test*

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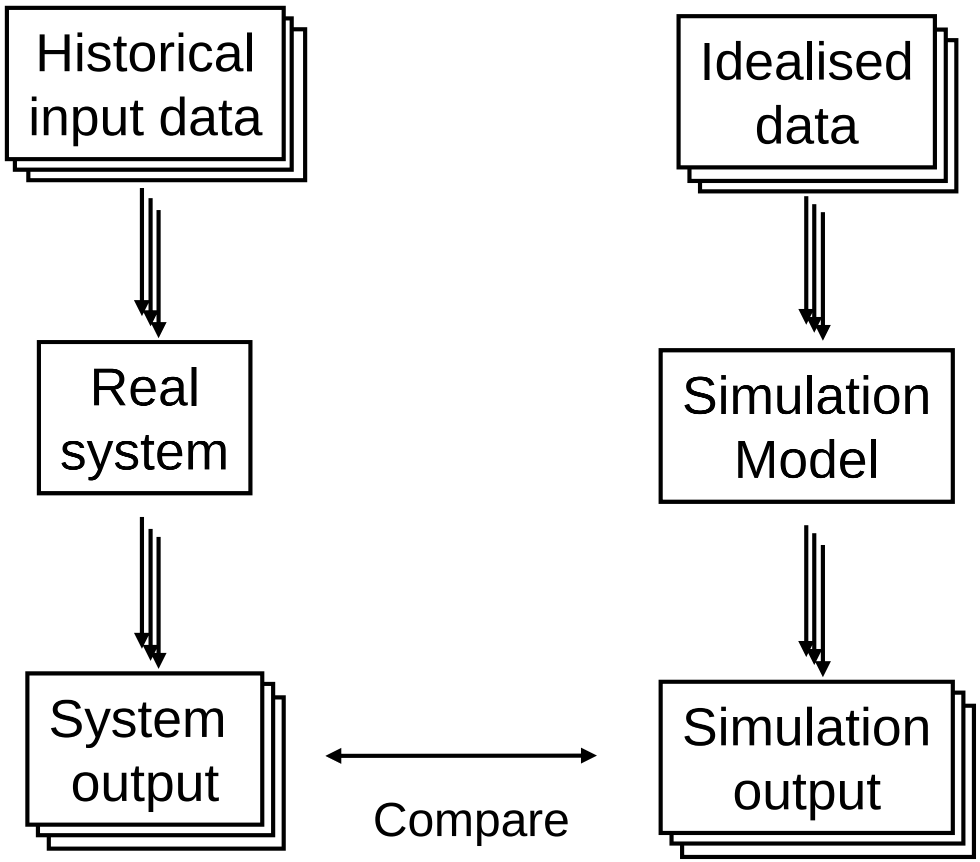
Input–Output Transformations



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Input–Output Transformations

Idea:

- We need R results Z_r, $r = 1 \ldots R$ from the real system
- Use random numbers in simulator
- Perform R replications to obtain Y_r
- Compute $\bar{Z} = \frac{1}{R}\sum Z_r$ and $\bar{Y} = \frac{1}{R}\sum Y_r$, $S^2 = \frac{1}{R-1}\sum (Y_r - \bar{Y})^2$
- Compute $t_0 = \frac{\bar{Z} - \bar{Y}}{S / \sqrt{R}}$
- Compute a confidence interval using
- Is 0 inside the confidence interval?

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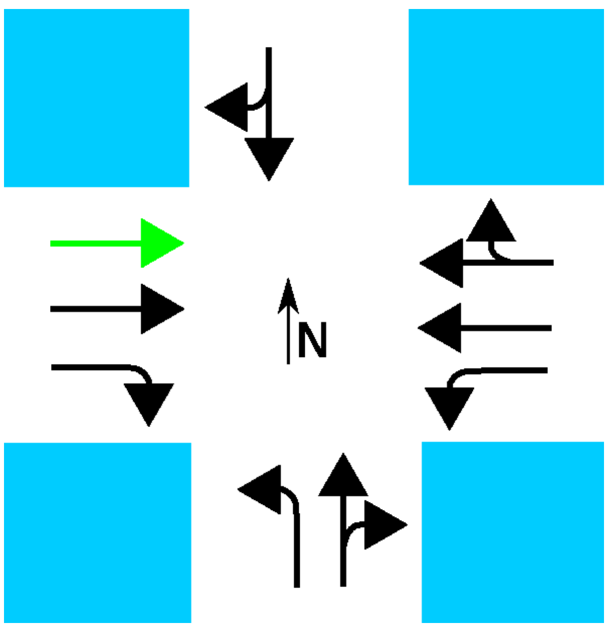
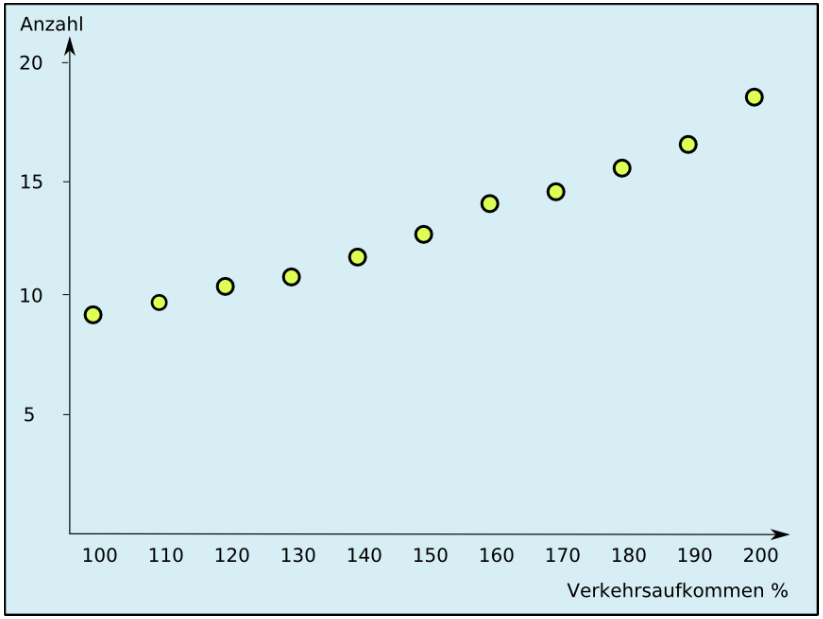
Example from Simulation Project

Sensitivity Analysis of Intersection Model

- Development of queue length with increasing traffic volume gives a reasonable result:





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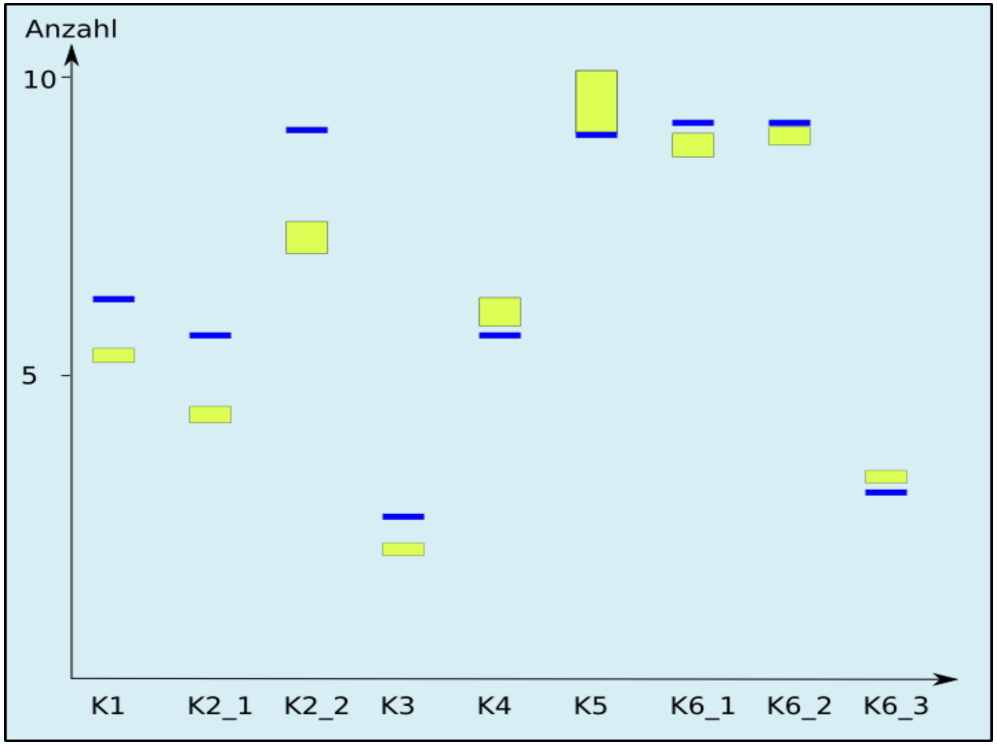
Example from Simulation Project

Input–Output Transformation of queue length for all lanes

- Mean value of measured queue length (blue bar)
- Confidence intervals of simulation results (green box)



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Learning Goals

Questions to test your knowledge:

- What is verification?
- What is validation in a simulation project?
- What is the Turing test?
- How would you perform a validation using input–output transformations?
- What is sensitivity analysis and what is it used for?
- Name and explain some validation methods for simulation models