Aachen Summer Simulation Seminar 2014

Lecture 02
Simulation Studies - An Overview

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Motivation

• Introduce different life cycles used for simulation studies (for data and theory driven simulation)
• Further distinguish simulation paradigms in data and theory driven approaches
• Provide a complete example of a simulation study
Life Cycle of a Simulation Study

- Operations Research (data driven)
  - Discrete Event Simulation

Robinson (2004)

Balci (1990)
Oval symbols: Phases

Dashed arrows: Processes

Solid arrows: Credibility assessment stages
Processes

• Problem formulation (problem structuring / definition)
  – Communicated problem is rarely clear, specific, or organized
  – Initially communicated problem is translated into a formulated problem sufficiently well defined to enable specific research action

• Investigation of Solution Techniques
  – Sometimes communicated problem is formulated under the influence of a solution technique in mind
  – Important to identify all alternative techniques that can be used in solving the formulated problem
  – Chosen technique needs to be a sufficiently credible one which will be accepted and used by the decision maker(s)
COMMUNICATED PROBLEM

FORMULATED PROBLEM

PROPOSED SOLUTION TECHNIQUE
(Simulation)

INTEGRATED DECISION SUPPORT

SYSTEM AND OBJECTIVES DEFINITION

SIMULATION RESULTS

EXPERIMENTAL MODEL

COMMUNICATIVE MODEL(S)

PROGRAMMED MODEL

CONCEPTUAL MODEL

COMMUNICATIVE MODEL

Model Formulation

Model Qualification

Model Representation

Programming

Model V&V

Experiment Design Verification

Design of Experiments

Experimentation

Model Validation

Data Validation

Redefinition

Presentation Verification

Experimental Investigation

System and Objectives Definition Verification

Acceptability of Simulation Results

Feasibility Assessment of Simulation

Investigation of Solution Techniques

Problem Formulation

Formulated Problem Verification

DECISION MAKERS

Presentation of Simulation Results

System Investigation

System and Objectives Definition Verification

Acceptability of Simulation Results
Processes

• System investigation
  – Process of investigating the characteristics of the system that contains the formulated problem (for consideration in system definition and modelling)
    • Change characteristics: How often and how much the real system will change during the course of a simulation study
    • Environment characteristics: Consists of all input variables that can significantly affect its state
    • Counterintuitive behaviour characteristics: Some systems may show counterintuitive behaviour which we should try to identify for consideration in the model
Processes

• System investigation (cont.)
  • **Drift to low performance characteristics:** A system may show a drift to low performance due to the deterioration of its components over a period of time
  • **Interdependency and organisation characteristics:** In a complex system, many activities or events take place simultaneously and influence each other; needs to be examined before abstracting the real system for the purpose of modelling; decomposing the system into subsystems and subsystems into sub-subsystems
Processes

• Model formulation
  – Process by which a conceptual model is envisioned to represent the system under study
  – Robinson (2004): "The conceptual model is a non-software specific description of a simulation model describing the objectives, inputs, outputs, content, assumptions and simplification of the model"
  – Input data analysis and modelling
    • SDS: Model driven by rate changes defined through differential equations
    • DES and ABS: Model driven by input values obtained via sampling from probability distributions
Processes

• Model Representation
  – Process of translating the conceptual model into a communicative model (representation which can be communicated to other humans)
  – Typical representation formats:
    • SDM: Causal loop diagrams, stock and flow diagrams
    • DEM: Flow charts, activity cycle diagrams
    • ABM: UML + AgentUML
    • Specific mechanisms: Pseudo-code
  – Criteria for selection:
    • Applicability for describing the system under study
    • Technical background of the people to whom the model is communicated
    • Translatability into a programmed model
Processes

• Programming
  – Nowadays mainly Visual Interactive Modelling Systems (VIMS)
  – Software:
    • SDS: Dynamo, iThink/Stella, PowerSim, Vensim, ...
    • DES: Arena, SimIO, Simul8, Witness, ProModel, Extend, FlexSim, ...
    • ABS: AnyLogic, many academic tools focusing on specific research areas
    • Programming languages: GPSS, SIMAN, SIMSCRIPT, SIMULA, SLAM, ...
  – Survey available at OR/MS website (latest version from October 2013)
    • http://www.lionhrtpub.com/orms/surveys/Simulation/Simulation.html
Processes

• Design of experiment
  – Process of formulating a plan to gather the desired information at minimal cost and to enable the analyst to draw valid inferences
  • Obtaining accurate results
    – Run conditions: Warm up period, number of replications, run length
    – Variance reduction techniques: Obtain greater statistical accuracy for the same amount of simulation runs
  • Searching the solution space
    – Response-surface methodologies: Find the optimal combination of parameter values which maximize or minimize the value of a response variable
    – Factorial designs: Determine the effect of various input variables on a response variable
    – Ranking and selection techniques: comparing alternative systems
Processes

• Experimentation
  – What-if analysis
    • Making changes to the model’s inputs, running the model, inspecting the results, learning from the results, making changes to the model’s inputs ...
  – Different purposes of experimentation
    • Comparison of different operating policies, evaluation of system behaviour, sensitivity analysis, forecasting, optimisation, determination of functional relations
  – Output analysis (for stochastic simulation)
    • Analysis of results from single scenario (mean and standard deviation)
    • Comparing alternative scenarios (using confidence intervals to test difference between results from two scenarios)
Processes

- Histograms of the same mean but different levels of variability

Robinson (2004)
Processes

- **Redefinition**
  - Maintaining the model for further use
    - Updating the model so that it represents the current form of the system
    - Altering it for obtaining another set of results

- **Presentation of simulation results**
  - Process of interpreting simulation results and presenting them to the decision makers for their acceptance and implementation
  - Implementation:
    - Putting the solution into practice
    - Implementing the model
    - Implementation as a learning aid
Verification and Validation

• Verification and validation are continuous processes that are performed throughout the life cycle of the simulation study

• Verification
  – Substantiating that the simulation model has been transformed from one form into another as intended with sufficient accuracy
  – Deals with "building the model right"

• Validation
  – Substantiating that the simulation model, within its domain of applicability, behaves with satisfactory accuracy consistent with the study objectives
  – Deals with "building the right model"
Life Cycle of a Simulation Study

- Business + Economics + Social Science (theory driven)
  - System Dynamics Simulation and Agent-Based Simulation

Life Cycle of a Simulation Study

• Data driven agent-based simulation

Hassan et al (2008)
Life Cycle of a Simulation Study

- Comparing data driven and theory driven approaches

<table>
<thead>
<tr>
<th>Operations Research</th>
<th>Business, Economics, Social Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical basis</td>
<td>Theoretical basis</td>
</tr>
<tr>
<td>Improving the real world</td>
<td>Thinking about the real world</td>
</tr>
<tr>
<td>Data collection and analysis</td>
<td>Dynamic hypothesis</td>
</tr>
<tr>
<td>Validation: Sufficient accuracy for purpose</td>
<td>Plausibility: Seeming reasonable or probable</td>
</tr>
<tr>
<td>Implementing findings</td>
<td>Learning + understanding</td>
</tr>
</tbody>
</table>

after Robinson (2011)
Paradigms: Update

Data driven: Data for model formulation (in Social Sciences can be quantitative and qualitative); data for model validation
Theory driven: Theories for model formulation; data for model validation
Simulation Project Time-Scales

• Cochran et al. (1995):
  – Surveyed: Simulation users in industrial settings

<table>
<thead>
<tr>
<th>Duration</th>
<th>Count</th>
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<tbody>
<tr>
<td>1 week or less</td>
<td>4</td>
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<tr>
<td>1 week to 1 month</td>
<td>20</td>
</tr>
<tr>
<td>1 to 3 month</td>
<td>31</td>
</tr>
<tr>
<td>3 to 6 month</td>
<td>16</td>
</tr>
<tr>
<td>More than 6 month</td>
<td>29</td>
</tr>
</tbody>
</table>
Case Study

Modelling the Cargo Screening Process at the Ferry Port in Calais
Problem Formulation

- Location: Calais Ferry Port (France)
- Problem: Illegal immigration
- 900,000 lorries/year
- 3500 positive lorries ~ 0.4%
Problem Formulation

1. The lorry was carrying carbon powder made from lignite, a form of coal. It is used to clean pollutants from a plant which burns compacted sewage to generate electricity. The lignite is diluted with other chemicals and water to make the cleaning solution as it is pumped out of the truck.

2. The men opened the hatches on top of the tanker and lowered themselves in with their bags. There was plenty of space inside as the tanker was not filled completely. Once inside, they put blankets over the powder to sit and sleep on.

3. The lorry driver left a chemical works in Cologne yesterday and is believed to have travelled just under 300 miles to Calais, crossing to Dover. He continued his journey towards the Crossness sewage works in Bexley via the M2.
System Investigation

Controlled by Calais Chamber of Commerce (CCI)

Controlled by UK Border Agency
System Investigation

• Inspection Sheds
  – Heartbeat Detector
  – CO2 Probe
  – Visual Inspection
  – Canine Sniffers

• Drive Through
  – Passive Millimetre Wave Scanner
## System Investigation

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of lorries entering Calais harbour</td>
<td>900,000</td>
</tr>
<tr>
<td>Total number of positive lorries found</td>
<td>3474</td>
</tr>
<tr>
<td>Total number of positive lorries found on French site</td>
<td>1,800</td>
</tr>
<tr>
<td>Total number of positive lorries found on UK site</td>
<td>1,674</td>
</tr>
<tr>
<td>… In UK Sheds</td>
<td>890</td>
</tr>
<tr>
<td>… In UK Berth</td>
<td>784</td>
</tr>
</tbody>
</table>
Model Representation (French Side)

Red font = example
Model Representation (UK Side)

@Routing
@Search_UK

DeepSearch_UK@
CO2Check_UK

@Search_UK
HBCheck_UK

OpenCheck_H
RemovePeople_H
100%
BorderAgency_UK

@DeepSearch_UK
OpenCheck_S
RemovePeople_S
100%
BorderAgency_UK

@Berth
WaitFerryArrival
Leave to Dover

random checks
CO2Check_F

random checks
OpenCheck_H
RemovPeople_H
100%
BorderAgency_UK
Programming
Programming

- Inspection sheds and berth activities
Presentation
Presentation
Experimentation
Experiment 1

- Detection Rate vs. Clandestines Detected
Experiment 2

• Objectives (service standards)
  – Less than 5% of lorries should spend more than 27.01 minutes in the system
  – The base detection rates should not be compromised

• Possible intervention
  – Allow lorries to pass without inspection when queues in front of the UK sheds are getting too long
## Experiment 2

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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</thead>
<tbody>
<tr>
<td>Traffic Growth (TG)</td>
<td>0%</td>
<td>10%</td>
<td>20%</td>
<td>0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Search Growth (SG)</td>
<td>0%</td>
<td></td>
<td>10%</td>
<td>20%</td>
<td></td>
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<tr>
<td>Lorries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Arrivals</td>
<td>900000</td>
<td>990000</td>
<td>1080000</td>
<td>900000</td>
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<td>Soft-sided</td>
<td>0.44</td>
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<td></td>
<td></td>
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<tr>
<td>Positive</td>
<td>0.00550</td>
<td>0.00500</td>
<td>0.00458</td>
<td>0.00550</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Search rate</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>UK Sheds</td>
<td>0.330</td>
<td>0.300</td>
<td>0.275</td>
<td>0.363</td>
<td>0.396</td>
<td></td>
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<tr>
<td>UK Berth</td>
<td>0.600</td>
<td>0.545</td>
<td>0.500</td>
<td>0.660</td>
<td>0.720</td>
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<tr>
<td>Detection Rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>France</td>
<td>0.41</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>UK Sheds</td>
<td>0.80</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>UK Berth</td>
<td>0.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Queue size restriction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>UK Sheds</td>
<td>off</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK Berth</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
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### Results

<table>
<thead>
<tr>
<th>Results</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Waiting times (avg)&quot;1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>0.858</td>
<td>1.019</td>
<td>1.268</td>
<td>0.863</td>
<td>0.859</td>
<td>0.860</td>
<td>0.863</td>
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<tr>
<td>UK Sheds</td>
<td>2.612</td>
<td>2.474</td>
<td>2.321</td>
<td>3.452</td>
<td>5.046</td>
<td>3.940</td>
<td>3.763</td>
</tr>
<tr>
<td>Overall</td>
<td>1.831</td>
<td>1.783</td>
<td>1.856</td>
<td>2.439</td>
<td>3.620</td>
<td>2.901</td>
<td>2.788</td>
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<tr>
<td>Time in system (avg)</td>
<td>18.099</td>
<td>18.085</td>
<td>18.155</td>
<td>18.517</td>
<td>19.274</td>
<td>18.893</td>
<td>18.834</td>
</tr>
<tr>
<td>Service problem</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>UK Sheds</td>
<td>0.019</td>
<td>0.019</td>
<td>0.020</td>
<td>0.036</td>
<td>0.068</td>
<td>0.052</td>
<td>0.049</td>
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<tr>
<td>UK Berth</td>
<td>0.676</td>
<td>0.676</td>
<td>0.677</td>
<td>0.744</td>
<td>0.812</td>
<td>0.803</td>
<td>0.801</td>
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<tr>
<td>Resource utilisation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>UK Sheds</td>
<td>0.808</td>
<td>0.808</td>
<td>0.809</td>
<td>0.868</td>
<td>0.915</td>
<td>0.914</td>
<td>0.914</td>
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<tr>
<td>UK Berth</td>
<td>1774.9</td>
<td>1765.5</td>
<td>1745.9</td>
<td>1780.5</td>
<td>1774.3</td>
<td>1757.5</td>
<td>1769.7</td>
</tr>
<tr>
<td>Positive lorries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>900.8</td>
<td>814.0</td>
<td>733.8</td>
<td>981.2</td>
<td>1078.0</td>
<td>1061.2</td>
<td>1042.8</td>
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<tr>
<td>UK Sheds</td>
<td>699.9</td>
<td>658.4</td>
<td>630.7</td>
<td>715.9</td>
<td>743.0</td>
<td>746.5</td>
<td>746.8</td>
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<tr>
<td>Missed</td>
<td>1590.1</td>
<td>1697.2</td>
<td>1797.0</td>
<td>1480.7</td>
<td>1365.7</td>
<td>1361.7</td>
<td>1358.1</td>
</tr>
</tbody>
</table>
Next Step

- Develop a combined DES/ABS version of the model
Summary

• What did you learn?
Comments or Questions?
References

- Balci (1990) Guidelines for successful simulation studies
- Cochran et al (1995) Simulation project characteristics in industrial settings
- Richardson and Pugh (1981) Introduction to System Dynamics Modeling with DYNAMO
- Robinson (2011) Are ABS and OR commensurable paradigms (ORSimSIG presentation)