Aachen Summer Simulation Seminar 2014

Lecture 03
Introduction to Conceptual Modelling

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Motivation

• Define what a conceptual model is and how to communicate such a model
• Demonstrate how to develop a conceptual model
Introduction

- Importance of conceptual modelling (or model design)
  - The modeller along with the clients determines the appropriate scope and level of detail to model, a process known as conceptual modelling
  - Model design impacts all aspects of the study
  - A high proportion of the benefits of a simulation study is obtained just from the development of the conceptual model
    - For the development of the conceptual model we often seek answers to questions that have not previously been ask
    - Effective conceptual modelling may even lead to the identification of a suitable solution without the need for any further simulation work
Introduction

• What about the following argument:
  – The emergence of modern simulation software has reduced or even removed the need for conceptual modelling?
    • The modeller can move straight from developing an understanding of the real world problem to creating a computer model
    • The software allows rapid model development and prototyping but it does not reduce the level of decision making about the model design

• What about the following argument:
  – Power and memory of modern hardware and the potential of distributed software has increased the need for conceptual modelling?
    • Increase in complexity of simulation models; modellers build more complex models because software/hardware allows them to do so
    • Models are being developed that are far more complex than they need to be; careful model design is increasing in importance
What is a conceptual model?

• Definition (Robinson 2008a):
  – The conceptual model is a *non-software specific description* of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model.

• Conceptual modelling is more an art than a science; therefore it is difficult to define methods and procedures
What is a conceptual model?

• Key components of a conceptual model:
  – **Objectives:** The purpose of the model
  – **Inputs:** Elements of the model that can be altered
  – **Outputs:** Measures to report the results from the simulation runs
  – **Content:** Components represented in the model and their interconnections
  – **Assumptions:** Uncertainties and believes about the real world to be incorporated into the model
  – **Simplifications:** Reduction of the complexity of the model
What is a conceptual model?

• Basic conceptual model for booking clerk @ theatre:
  – **Objectives:** Serve 95% of customers in less than 10 minutes
  – **Inputs:** Arrival rates, service rates, number of clerks
  – **Outputs:** % of customers queuing for less than 10 minutes; histogram of waiting time for each customer in the queue; clerk utilisation
  – **Content:** Personal enquirers; phone callers; inter arrival time distribution; service time distribution; queuing priority
  – **Assumption:** Unlimited queues (we do not know space availability)
  – **Simplifications:** Queuing discipline (no jockeying, balking, leaving)

• Remember:
  – Assumptions are a facet of limited knowledge or presumptions
  – Simplifications are a facet of the desire to create simple models
What is a conceptual model?

Oval symbols: Phases
Dashed arrows: Processes
Solid arrows: Credibility assessment stages
What is a conceptual model?

• Requirements of a conceptual model:
  – Validity
  – Credibility
  – Utility
  – Feasibility

• What do these terms mean?
What is a conceptual model?

• Requirements of a conceptual model (Robinson 2004):
  – **Validity**: A perception, on behalf of the modeller, that the conceptual model will lead to a simulation model that is sufficiently accurate for the purpose at hand
  – **Credibility**: A perception, on behalf of the clients, that the conceptual model will lead to a simulation model that is sufficiently accurate for the purpose at hand
  – **Utility**: A perception, on behalf of modeller and clients, that the conceptual model will lead to a simulation model that is useful as an aid to decision making within the specified context
  – **Feasibility**: A perception, on behalf of modeller and clients, that the conceptual model will lead to a simulation model
Model complexity and accuracy

• Aim: Keep the model as simple as possible to meet the objectives of the simulation study

• Advantages of simpler models:
  – They can be developed faster
  – They are more flexible
  – They require less data
  – They run faster
  – Results are easier to be interpreted
Model complexity and accuracy

- 80/20 Rule
  - 80 percent of accuracy is gained from only 20% of complexity; beyond this there is diminishing returns from increasing levels of complexity
  - Increasing the complexity (scope and level of detail) too far might even lead to a less accurate model since the data and information are not available to support the detail being modelled
Model complexity and accuracy

• **80/20 Rule**
  – 80 percent of accuracy is gained from only 20% of complexity; beyond this there is diminishing returns from increasing levels of complexity
  – Increasing the complexity (scope and level of detail) too far might even lead to a less accurate model since the data and information are not available to support the detail being modelled

• **It is important to consider both, constructive simplicity and transparency.**
  – Constructive simplicity: Attribute of the model
  – Transparency: Attribute of the client
Methods of model simplification

• Simplification entails reducing the scope and the level of detail in a conceptual model
  – Scope reduction: Removing components and interconnections that have little effect on model accuracy
  – Detail reduction: Representing more simple components and interconnections while maintaining a satisfactory level of model accuracy

• Remember:
  – Most effective approach to simplification is to start with the simplest model possible and gradually add to its scope and level of detail; once a point is reached in which the study objectives can be addressed, then no further details should be added
Methods of model simplification

• Methods (*scope or level of detail reduction?*)
  – Aggregation of model components
    • Black box modelling
    • Grouping entities
  – Excluding components and details
  – Replacing components with random variables
  – Excluding infrequent events
  – Reducing the rule set
  – Splitting models

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Methods of model simplification

• Methods
  – Aggregation of model components [detail reduction]
    • Black box modelling
    • Grouping entities
  – Excluding components and details [scope reduction]
  – Replacing components with random variables [detail reduction]
  – Excluding infrequent events [scope reduction]
  – Reducing the rule set [detail reduction]
  – Splitting models [advantage: individual models run faster]

• Remember: Over-simplification can make a model less transparent and thereby reducing its credibility
Communicating the conceptual model

• Representing the conceptual model (examples):
  – System Dynamics (SD)
    • Causal loop diagrams; stock and flow diagrams
  – Discrete Event Simulation (DES)
    • Component list; process flow diagram; logic flow diagram; activity cycle diagram; combining Petri net and UML static structure diagrams (Pels and Goossenaerts 2007); class diagram to support OO DES
  – Agent Based Simulation (ABS)
    • UML + AgentUML (class, component, sequence, deployment, state chart, use cases, and activity diagrams) (Bommel and Müller 2008); coloured Petri nets (Jensen et al 2007)
Communicating the conceptual model

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Communicating the conceptual model

• DES Example: M/M/1/n Queue
  – A single server system with ...
    • A queue capacity of n
    • An infinite calling population
    • Poisson (random) arrival process (inter-arrival times are exponentially distributed) and service times are also exponentially distributed
Communicating the conceptual model

• DES Example: M/M/1/n Queue
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<table>
<thead>
<tr>
<th>Component</th>
<th>Detail</th>
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</thead>
<tbody>
<tr>
<td>Customers</td>
<td>Inter-arrival time (exponentially distributed)</td>
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<tr>
<td>Queue</td>
<td>Capacity</td>
</tr>
<tr>
<td>Service</td>
<td>Service time (exponentially distributed)</td>
</tr>
</tbody>
</table>
Communicating the conceptual model

• DES Example: M/M/1/n Queue

Process flow diagram

Activity cycle diagram

Logic flow diagram
How to develop a conceptual model

• Framework for conceptual modelling
  – Four key elements
    1. Develop an understanding of the problem situation
    2. Determine the modelling objectives
    3. Design the conceptual model: Inputs and outputs
    4. Design the conceptual model: The model content

• Remember that conceptual modelling is an iterative process!

• For more examples see Robinson (2004) Appendix 1+2
  – Online version available from the library catalogue
How to develop a conceptual model

1. Develop an understanding of the problem situation
   – Clients might not have a good understanding of the cause and effect relationships within the problem situation
   – Clients have different world view
   – While learning from clients the modeller needs to play an active role
   – Modeller needs to confirm his/her understanding by providing a description of the problem situation for the client

• Problem situation and understanding of it will both be changing during the simulation study
How to develop a conceptual model

• Case Study: Fast-Food Restaurant (Robinson, 2004):
  – A fast-food restaurant is experiencing problems with one of its branches in its network. Customers regularly complain about the length of time they have to queue at the service counters.
  – It is apparent that this is not the result of shortages in food, but a shortage of service personnel.
How to develop a conceptual model

2. Determining the modelling objectives
   – Modelling objectives determine the nature of the model
   – Modelling objectives determine level of abstraction and simplification
   – Modelling objectives are a reference point for model validation
   – Modelling objectives guide for experimentation

• The purpose of the modelling study is not the development of the model itself but to develop a tool to aid decision making

• Bad practice: Developing models that do not serve any useful purpose, e.g. models that are looking for a problem to solve
How to develop a conceptual model

2. Determining the modelling objectives (cont.)
   – Forming the objectives:
     • By the end of the study what do we hope to achieve?
       – What does the client want to achieve?
       – What level of performance is required?
       – What constraints must the client (modeller) work within?
     • Modeller should be willing to suggest additional objectives and to redefine or eliminate objectives suggested by the clients
     • It is important that the clients understands what a simulation model can and cannot do for them; managing the expectations of the client
How to develop a conceptual model

• Case Study: Fast-Food Restaurant
  – What does the client want to achieve?
  – What level of performance is required?
  – What constraints must the client (modeller) work within?

• Objective:
  – The number of service staff required during each period of the day to ensure that 95% of customers queue for less than 3 minutes for service.

• Constraint:
  – Due to space constraints, a maximum of six service staff can be employed at any one time.
How to develop a conceptual model

3. Design the conceptual model: Inputs and outputs
   – Experimental factors (inputs):
     • Often, they are the means by which it is proposed that the modelling objectives are to be achieved
     • They can be either qualitative or quantitative
     • They are often under control of the clients; however, also factors that are not under control of the client should be considered as this improves the understanding of the real system

   • Remember: If possible, the range over which experimental factors are to be varied as well as the method of data entry should be defined
How to develop a conceptual model

3. Design the conceptual model: Inputs and outputs (cont.)
   
   – Responses (outputs):
     
     • Measures used to identify whether the objectives have been achieved
     • Measures used to identify reasons for failure to meet objectives (e.g. bottlenecks)

     • During the course of the simulation study review the experimental factors and responses when objectives are changing!
How to develop a conceptual model

• Case Study: Fast-Food Restaurant
  – Objective:
    • The number of service staff required during each period of the day to ensure that 95% of customers queue for less than 3 minutes for service.
  – Constraint:
    • Due to space constraints, a maximum of six service staff can be employed at any one time.
  – Experimental factors?
  – Responses?
How to develop a conceptual model

• Case Study: Fast-Food Restaurant
  – Objective:
    • The number of service staff required during each period of the day to ensure that 95% of customers queue for less than 3 minutes for service.
  – Constraint:
    • Due to space constraints, a maximum of six service staff can be employed at any one time.
  – Experimental factors:
    • Staff roster
  – Responses:
    • % of customers queuing for less than 3 minutes
    • Histogram of waiting time for each customer in the queue
    • Time series of mean queue size by hour
    • Staff utilisation
How to develop a conceptual model

4. Design the conceptual model: The model content
   - Model must be able to accept the experimental factors and to provide the required responses
   - Scope of the model must be sufficient to provide link between the experimental factors and responses
   - Scope of the model must also include any other processes that have a significant impact on the response
   - Level of detail must be such that it represents the components defined within the scope and their interconnections with sufficient accuracy
How to develop a conceptual model

4. Design the conceptual model: The model content (cont.)
   – Use rapid prototyping throw away models to decide about scope and level of detail

• Keep a record of all assumptions that are made during the design of the model content!!!
Methods of model simplification

- Case Study: Fast-Food Restaurant

<table>
<thead>
<tr>
<th>Model Scope</th>
<th>Detail</th>
<th>Decision</th>
<th>Justification</th>
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<tbody>
<tr>
<td>Customers</td>
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<td>Staff</td>
<td>Service</td>
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<td>Food preparation</td>
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<td>Cleaning</td>
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<td>Queue at service counter</td>
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<td>Tables</td>
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<tr>
<td>Kitchen</td>
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<thead>
<tr>
<th>Model Level of Detail</th>
<th>Detail</th>
<th>Decision</th>
<th>Comments (Details)</th>
</tr>
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<tbody>
<tr>
<td>Customers</td>
<td>Inter-arrival time</td>
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<td></td>
<td>Size of order</td>
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<td>Service staff</td>
<td>Service time</td>
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<td></td>
<td>Staff rosters</td>
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<td>Absenteeism</td>
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<td>Queues</td>
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<td></td>
<td>Capacity</td>
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<tr>
<td></td>
<td>Queue behaviour</td>
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<td></td>
<td>- jockey, balk, leave</td>
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<td></td>
<td>- join shortest queue</td>
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Methods of model simplification

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<tbody>
<tr>
<td>Customers</td>
<td>Include</td>
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<td>Flow through service process</td>
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<td>Staff</td>
<td>Service</td>
<td>Include</td>
<td>Required for response</td>
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<td>Food preparation</td>
<td>Exclude</td>
<td>Material shortage not significant</td>
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<tr>
<td></td>
<td>Cleaning</td>
<td>Exclude</td>
<td>Not related to speed of service</td>
</tr>
<tr>
<td>Queue at service counter</td>
<td>Include</td>
<td></td>
<td>Required for response</td>
</tr>
<tr>
<td>Tables</td>
<td>Exclude</td>
<td></td>
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<td>Kitchen</td>
<td>Exclude</td>
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<tr>
<td>Customers</td>
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<td>Include</td>
<td>Distribution</td>
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<td>Size of order</td>
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<td>Represented in service time</td>
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<td>Service staff</td>
<td>Service time</td>
<td>Include</td>
<td>Distribution</td>
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<td>Staff rosters</td>
<td>Include</td>
<td>Experimental factor</td>
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<td></td>
<td>Absenteeism</td>
<td>Exclude</td>
<td>Could be represented in staff rosters</td>
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<tr>
<td>Queues</td>
<td>Queuing</td>
<td>Include</td>
<td>Required for responses</td>
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<tr>
<td></td>
<td>Capacity</td>
<td>Exclude</td>
<td>Assumption: unlimited</td>
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<tr>
<td></td>
<td>Queue behaviour</td>
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<td></td>
<td>- jockey, balk, leave</td>
<td>Exclude</td>
<td>Not well understood</td>
</tr>
<tr>
<td></td>
<td>- join shortest queue</td>
<td>Include</td>
<td>Well understood</td>
</tr>
</tbody>
</table>
Graphical Representation
The role of data in conceptual modelling

• Data for model realisation are not required for conceptual modelling, but are identified by the conceptual model

• Sometimes it is difficult or even impossible to obtain adequate data making the proposed conceptual model problematic!

• What can you do in these cases?
  – Redesign the conceptual model and leave out the troublesome data
  – Estimate the data
  – Treat data as an experimental factor rather than a fixed parameter
Summary

• What did you learn?
Further Reading

- Robinson (2008a; 2008b)
- Bommel and Müller (2008)
- Robinson et al. (2010)

Acknowledgement

- The content of this presentation is a summary of Robinson (2004) chapter 5 and 6
Questions / Comments
References


