Simulation in a Nutshell

Game Theory meets Object Oriented Simulation
Special Interest Group

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Introduction to Simulation

• **System:**
  – Collection of parts organised for some purpose
  – Defining a system requires setting boundaries

• **Model:**
  – Some form of abstract representation of a real system intended to promote understanding of the system it represents.
  – A model is a static representation of the system

• **Simulation:**
  – The process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operation of the system
Introduction to Simulation

• What do you use simulation for?
  – To predict system performance
  – To compare alternative system designs
  – To determine the effects of alternative policies on system performance

• Simulation vs. other modelling approaches: Pros and cons?
  – Advantages:
    • Modelling variability; less restrictive assumptions; transparency; creating knowledge and understanding; visualisation, communication, interaction
  – Disadvantages:
    • Expensive; time consuming; data hungry; requires expertise; overconfidence
Introduction to Simulation

• Modelling and simulation paradigms?
  – System Dynamics Modelling (SDM) and Simulation (SDS)
    • Modelling: Causal loop diagrams; stock and flow diagrams
    • Simulation: Deterministic continuous (differential equations)
  – Discrete Event Modelling (DEM) and Simulation (DES)
    • Modelling: Process flow diagrams; activity cycle diagrams
    • Simulation: Stochastic discrete (flow oriented approach)
  – Agent Based Modelling (ABM) and Simulation (ABS)
    • Modelling: UML (class diagrams + state chart diagrams) + Equations
    • Simulation: Stochastic discrete (object oriented approach)
  – Mixed Method Modelling (MMM) and Simulation (MMS)
Introduction to Simulation

- Process oriented world view
  - SD (OR/MS + Business)
    - Theory driven
  - Traditional DES (OR/MS)
  - Object Oriented DES (OR/MS)
  - Agent Oriented DES (ABM + DES) (OR/MS)

- Object oriented world view
  - ABM/S (Business + Social Science + Economics)
    - Theory driven
  - ABM/S (Social Science)
    - Data driven

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 study life cycle

- Data driven:
Simulation study life cycle (theory driven)

• Theory driven:

  Communicate the model

  Formulate the question

  Analyze the model

  Assemble hypothesis

  Implement the model

  Choose model structure

  Parametrize the model

Grimm and Railsback (2005)
Simulation (Modelling) Methods

- **System Dynamics:**
  - System Dynamics (SD) is a methodology and computer simulation modelling technique for framing, understanding, and discussing complex issues and problems.
  - The basis of the methodology is the recognition that the structure of any system is just as important in determining its behaviour as the individual components themselves.
  - It is mostly used in long-term, strategic models and assumes high level of aggregation of the objects being modelled.
  - The range of applications includes business, urban, social, ecological types of systems.
Simulation (Modelling) Methods

- System Dynamics:
  - Example: Advertising for a durable good

- Causal loop diagram
- Stock and flow diagram
Simulation (Modelling) Methods

- System Dynamics:
  - Example: Bass diffusion model
Simulation (Modelling) Methods

• Discrete Event:
  – Objects of the system

  • **Entities**: Individual system elements whose behaviour is explicitly tracked; organised in classes and sets; distinguishable by attributes
    – **Classes**: Permanent groups of identical or similar entities (e.g. bus passengers)
    – **Sets**: Temporary groups of identical or similar entities (e.g. passengers on a particular bus, passengers waiting in a queue)
    – **Attributes**: Items of information to distinguish between members of a class (e.g. index) or to control the behaviour of an entity (e.g. entity type)

  • **Resources**: Individual system elements but not modelled individually; treated as countable items (e.g. number of passengers waiting at a bus stop)
Simulation (Modelling) Methods

• Discrete Event:
  – Operations of entities
    • Over time entities co-operate and hence change state
      – **Event**: Instance of time in which a significant state change occurs
      – **Activity**: Operations which are initiated at an event, transforming the state of the entities
    • Entity states:
      – **Active state**: Involves the co-operation of different classes of entities; duration can be determined in advance, usually by taking a sample from an appropriate probability distribution if the simulation is stochastic
      – **Dead state**: No co-operation, entity waits for something to happen; duration cannot be determined in advance
Simulation (Modelling) Methods

• Discrete Event:
  – Example: Process flow diagram of booking clerk model (in AnyLogic)
Simulation (Modelling) Methods

- **Agent-Based:**
  - In Agent-Based Modelling (ABM), a system is modelled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules.
  - ABM is a mindset more than a technology. The ABM mindset consists of describing a system from the perspective of its constituent units. [Bonabeau, 2002]
  - ABM is well suited to modelling systems with heterogeneous, autonomous and pro-active actors, such as human-centred systems.
Simulation (Modelling) Methods

• Agent-Based:
  – What do we mean by "agent"?
    • Agents are objects with attitude!
  – Properties:
    • Discrete entities
      – With their own goals and behaviours
      – With their own thread of control
    • Autonomous
      – Capable to adapt
      – Capable to modify their behaviour
    • Proactive
      – Actions depending on motivations generated from their internal state
Simulation (Modelling) Methods

• Agent-Based:
  – The agents can represent individuals, households, organisations, companies, nations, ... depending on the application.
  – ABMs are essentially decentralised
    • There is no place where global system behaviour (dynamics) would be defined; instead, the individual agents interact with each other and their environment to produce complex collective behaviour patterns.
Simulation (Modelling) Methods

- Agent-Based:
  - Example: Blob World
Simulation (Modelling) Methods

- Multi method: System Dynamics + Agent-Based
  - Supply chain: System Dynamics
  - Consumer market: Agent-Based
Simulation (Modelling) Methods

• **Contrasting the different simulation methods:**
  – System Dynamics Simulation (continuous, deterministic)
    • Aggregate view; differential equations
  – Traditional Discrete Event Simulation (discrete, stochastic)
    • Process oriented (top down); one thread of control; passive objects
  – Agent Based Simulation (discrete, stochastic)
    • Individual centric (bottom up); each agent has its own thread of control; active objects
  – Multi-Method Simulation
Case Study

Department Store Management Practices

For more details see: Siebers and Aickelin (2011)
Case Study: Context

• Case study sector
  – Retail (department store operations)

• Developing some tools for understanding the impact of management practices on company performance
  – Operational management practices are well researched
  – People management practices are often neglected

• Problem:
  – How can we model proactive customer service behaviour?
Case Study: Modelling

• The system
  – Two departments (A&TV and WW) at two department stores

• Knowledge gathering
  – Informal participant observations
  – Staff interviews
  – Informational sources internal to the case study organisation

• Simulation modelling method
  – Combined DES and ABS (queuing system with active entities)
Communication layer

Let entities interact + communicate

Direct interactions
Network activities

Agent layer

Replace passive entities by active ones

Active entities
Behavioural state charts

DES layer

Passive entities
Queues
Processes
Resources
Case Study: Modelling

STORE

Entering

Queuing at till
(for refund)

Being served at till
(refund decision)

Browsing

Being served at till
(refund decision)

Queuing at till
(to buy)

Queuing for help

Being helped

Being served at till
(refund decision)

Leaving

Staff Resource Pool
Case Study: Modelling

Customer #3 State-Chart
Customer #2 State-Chart
Customer #1 State-Chart

Customer #3 State-Chart:
- Queuing at till (for refund)
- Seeking refund
- Seeking help
- Queuing for help

Customer #2 State-Chart:
- Being served at till (refund decision)
- Browsing

Customer #1 State-Chart:
- Contemplating (dummy state)
- Queuing at till (to buy)

Staff #3 State-Chart:
- Serving

Staff #2 State-Chart:
- Waiting

Staff #1 State-Chart:
- Being served at till (buying)
Case Study: Implementation

- Software: AnyLogic v5 (later translated into v6)
  - Multi-method simulation software (SD, DES, ABS, DS)
  - State charts + Java code
Case Study: Implementation

• Knowledge representation
  – Frequency distributions for determining state change delays

<table>
<thead>
<tr>
<th>Situation</th>
<th>Min.</th>
<th>Mode</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leave browse state after …</td>
<td>1</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>Leave help state after …</td>
<td>3</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Leave pay queue (no patience) after …</td>
<td>5</td>
<td>12</td>
<td>20</td>
</tr>
</tbody>
</table>

  – Probability distributions to represent decisions made

<table>
<thead>
<tr>
<th>Event</th>
<th>Probability of event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Someone makes a purchase after browsing</td>
<td>0.37</td>
</tr>
<tr>
<td>Someone requires help</td>
<td>0.38</td>
</tr>
<tr>
<td>Someone makes a purchase after getting help</td>
<td>0.56</td>
</tr>
</tbody>
</table>

```java
boolean x = (Math.random() < 0.37) ? true : false;
```
Case Study: Implementation

- Implementation of customer types

<table>
<thead>
<tr>
<th>Customer type</th>
<th>Likelihood to</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>buy</td>
</tr>
<tr>
<td>Shopping enthusiast</td>
<td>high</td>
</tr>
<tr>
<td>Solution demander</td>
<td>high</td>
</tr>
<tr>
<td>Service seeker</td>
<td>moderate</td>
</tr>
<tr>
<td>Disinterested shopper</td>
<td>low</td>
</tr>
<tr>
<td>Internet shopper</td>
<td>low</td>
</tr>
</tbody>
</table>

```
for (each threshold to be corrected) do {
    if (OT < 0.5) limit = OT/2 else limit = (1-OT)/2
    if (likelihood = 0) CT = OT – limit
    if (likelihood = 1) CT = OT
    if (likelihood = 2) CT = OT + limit
}
```

where:
- OT = original threshold
- CT = corrected threshold
- likelihood: 0 = low, 1 = moderate, 2 = high
Case Study: Implementation

• Implementation of staff proactiveness
  – Non-cashier staff opening and closing tills proactively depending on demand and staff availability
  – Expert staff helping out as normal staff

• Other noteworthy features of the model
  – Realistic footfall and opening hours
  – Staff pool (static)
  – Customer pool (dynamic)
  – Customer evolution through internal stimulation (triggered by memory of ones own previous shopping experience)
  – Customer evolution through external stimulation (word of mouth)
Case Study: Implementation

• Performance measures
  – Service performance measures
    • Service experience
  – Utilisation performance measures
    • Staff utilisation
    • Staff busy times in different roles
  – Level of proactivity
    • Frequency and duration of role swaps
  – Monetary performance measures (productivity and profitability)
    • Overall staff cost per day
    • Sales turnover
    • Sales per employee
    • ...

GTMS-SIG
Case Study: Implementation

Department: Audio & TV (A&TV)  Sunday: Shop open for 8 hours

- red: cashier  - green: normal staff member  - blue: expert staff member  - magenta: section manager  - yellow: department manager  - cyan: advisor
- lighter colours: free  - darker colours: serving  - very dark colours: supporting (expert advice)

<table>
<thead>
<tr>
<th>Real</th>
<th>Planned</th>
<th>Run Time:</th>
<th>0</th>
<th>21</th>
<th>0</th>
<th>5</th>
<th>52</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers in store: 27</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- browsing 9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- seeking help 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- queueing for help 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- standard: 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- expert: 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- refund author: 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Getting help: 7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- standard: 7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- expert: 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- refund author: 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wait at till: 6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- to pay: 6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- for refund: 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- served at till: 3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- for refund: 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average arrival rate per hour: 73 (73)

Overall: 862255 100%
- leave happy (transaction or refund): 291013 34% 1 2
- leave not waiting for help: 2494 3% 1992 12%
- leave not waiting for expert help: 826 1% 197 43%
- leave not waiting to pay: 10855 13% 3001 28%
- leave without finding anything: 42902 50% 0 0%
- leave unhappy (no refund): 0 0%

Customers left: 862255 100%
- satisfied (≥ 0): 61507 72% 51920 35188 43% 101576
- don’t know (≥ 0): 10574 12% 40552 47%
- not satisfied (≥ 0): 13957 16% 41554 10066 12% -20736

Overall refunds: 0 100%
- refunds accepted: 0 0%
- refunds denied: 0 0%
- leave not waiting for refund decision: 0 0%
- leave not waiting for authorisation decision: 0 0%
- total decisions by cashier: 0 100%
- overall decisions by authorised person: 0 100%

Finite population:
- shopping enthusiasts: 400
- solution demanders: 3208
- service seekers: 3200
- disinterested shoppers: 400
- internet shoppers: 800

Important parameters:
- replication number: 3
- probability that refund is granted by cashier: 0.8
- probability that refund is granted by authorisation: 0.7
- probability that staff stay with customer: 0
- points required to become an expert: 100000
- word of mouth adoption fraction: 0.5
- word of mouth contact ratio: 0

Transactions: 291013
- Sales (€): 4,985,400
- Missed (€): 0,551,912

GTMS-SIG
Case Study: Experimentation

- **A&TV**: 2 cashiers, 4 normal staff, 4 expert staff

<table>
<thead>
<tr>
<th>Overall customers:</th>
<th>41235</th>
<th>100 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>- leave happy (transaction or refund):</td>
<td>12057</td>
<td>29 %</td>
</tr>
<tr>
<td>- leave not waiting for normal help:</td>
<td>930</td>
<td>2 %</td>
</tr>
<tr>
<td>- leave not waiting for expert help:</td>
<td>134</td>
<td>0 %</td>
</tr>
<tr>
<td>- leave not waiting to pay:</td>
<td>7468</td>
<td>18 %</td>
</tr>
<tr>
<td>- leave without finding anything:</td>
<td>20646</td>
<td>50 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transactions:</th>
<th>12057</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. Transaction [£]:</td>
<td>149.7</td>
</tr>
<tr>
<td>Sales [£]:</td>
<td>1,804,933</td>
</tr>
<tr>
<td>Missed [£]:</td>
<td>4,367,947</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customers left:</th>
<th>41235</th>
<th>122742</th>
</tr>
</thead>
<tbody>
<tr>
<td>*3</td>
<td>100 %</td>
<td></td>
</tr>
<tr>
<td>*4</td>
<td>100 %</td>
<td></td>
</tr>
<tr>
<td>*5</td>
<td>100 %</td>
<td></td>
</tr>
<tr>
<td>*6</td>
<td>100 %</td>
<td></td>
</tr>
<tr>
<td>- satisfied (&gt; 0):</td>
<td>24972</td>
<td>61 %</td>
</tr>
<tr>
<td>- don't know (= 0):</td>
<td>8085</td>
<td>20 %</td>
</tr>
<tr>
<td>- not satisfied (&lt; 0):</td>
<td>8178</td>
<td>20 %</td>
</tr>
</tbody>
</table>

*1 = number of people queueing for this service
*2 = % of those leaving the queue
*3 = considering accumulated history [number]
*4 = considering accumulated history [satisfaction growth]
*5 = experience per visit [number]
*6 = experience per visit [satisfaction growth]
Case Study: Experimentation

- A&TV: 3 cashiers, 6 normal staff, 1 expert staff

<table>
<thead>
<tr>
<th>Overall customers:</th>
<th>40960</th>
<th>100 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>- leave happy (transaction or refund):</td>
<td>16800</td>
<td>41 %</td>
</tr>
<tr>
<td>- leave not waiting for normal help:</td>
<td>1724</td>
<td>4 %</td>
</tr>
<tr>
<td>- leave not waiting for expert help:</td>
<td>761</td>
<td>2 %</td>
</tr>
<tr>
<td>- leave not waiting to pay:</td>
<td>1687</td>
<td>4 %</td>
</tr>
<tr>
<td>- leave without finding anything:</td>
<td>19988</td>
<td>49 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transactions:</th>
<th>16800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. Transaction [£]:</td>
<td>149.7</td>
</tr>
<tr>
<td>Sales [£]:</td>
<td>2,514,960</td>
</tr>
<tr>
<td>Missed [£]:</td>
<td>3,616,752</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Till queue length: mean: 2.15; max: 17.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal help queue length: mean: 1.56; max: 14.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customers left:</th>
</tr>
</thead>
<tbody>
<tr>
<td>40960</td>
</tr>
<tr>
<td>136411</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>- satisfied (&gt; 0):</th>
</tr>
</thead>
<tbody>
<tr>
<td>27979</td>
</tr>
<tr>
<td>152775</td>
</tr>
<tr>
<td>18512</td>
</tr>
<tr>
<td>50894</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>- don't know (= 0):</th>
</tr>
</thead>
<tbody>
<tr>
<td>7579</td>
</tr>
<tr>
<td>18924</td>
</tr>
<tr>
<td>-11610</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>- not satisfied (&lt; 0):</th>
</tr>
</thead>
<tbody>
<tr>
<td>5402</td>
</tr>
<tr>
<td>-16364</td>
</tr>
<tr>
<td>3524</td>
</tr>
</tbody>
</table>

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*5 = experience per visit [number]
*6 = experience per visit [satisfaction growth]
Questions or Comments
References

- Grimm and Railsback (2005) Individual-based modeling and ecology