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*Research Into Global Healthcare Tools*

# Modelling and Simulation Techniques for Supporting Healthcare Decision Making: A Selection Framework

MODELLING AND SIMULATION TECHNIQUES FOR SUPPORTING HEALTHCARE DECISION MAKING:
A SELECTION FRAMEWORK

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# Modelling and Simulation Techniques for Supporting Healthcare Decision Making: A Selection Framework

# Background

The development of this workbook has been led by a team of researchers from five UK universities with a grant from the UK Engineering and Physical Sciences Research Council (EPSRC). They are investigating the use of modelling and simulation in healthcare as part of the RIGHT (Research Into Global Healthcare Tools) project.

The workbook was developed following an extensive review of literature on the application of modelling and simulation in healthcare and other safety-critical industries, supplemented by the team's extensive expertise of modelling and simulation in healthcare. In order to produce this summary guide, thousands of articles were categorised according to the techniques used, when they were used, and with what resources.

This is the second version of the workbook and a corresponding web-based tool is also available through http://www.right-toolkit.org.uk/.

EPSRC

Engineering and Physical Sciences Research Council

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# Contents

# Who the Workbook is for

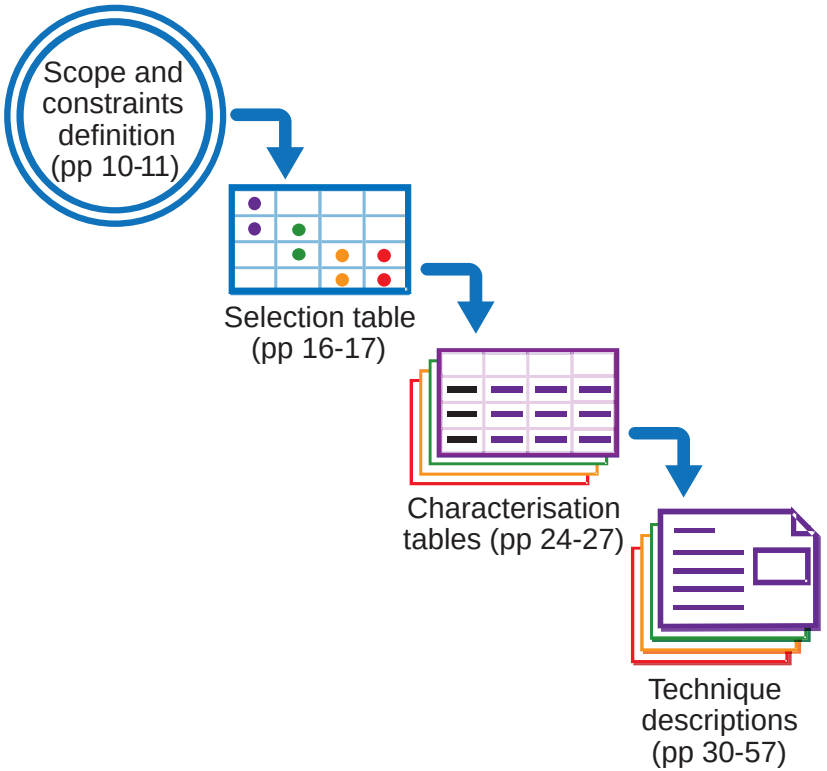
This workbook is intended to provide guidance for people who are making decisions in healthcare. It is aimed at anyone who wants to find out more about different modelling and simulation techniques – what they are, when to apply them, and what resources are required to use them. It will not only help decision makers commission more appropriate modelling work, but also assist professional modellers and business consultants to expand their modelling repertoire in order to meet the diverse needs of their clients.

The workbook is not a "how-to-do" guide to modelling and simulation, rather a "what-is-it" introductory guide. That said, the further reading section at the end of the workbook will help locate further details for each technique. The RIGHT research team would also welcome any contact regarding the applications of these techniques.

# How to Use this Workbook

The first part of the workbook introduce a framework for technique selection, containing summary questions for scope and constraints definition and tables for selection and comparison of potentially suitable techniques. The tables illustrate which set of modelling and simulation techniques are applicable, according to project life cycle stages and types of output. The techniques are also characterised by the minimum input resources required for each technique (time, money, knowledge and quantitative data).

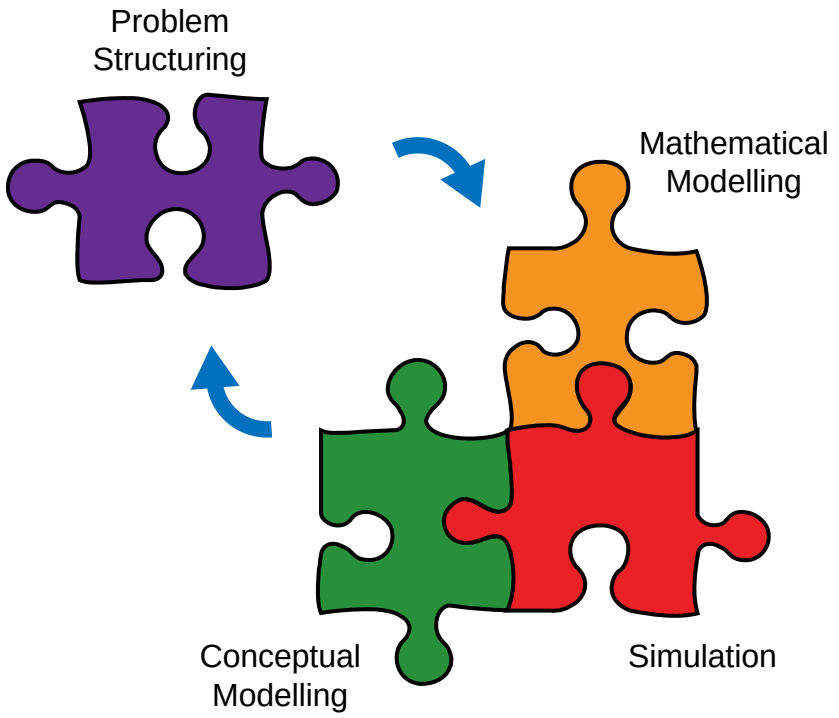
The second part of the workbook provides a descriptive summary of each technique, including a statement of the purpose, application, the inputs required and the outcome of each technique. Additional reading material is identified at the end of the workbook.



# Technique Selection

Modelling and simulation techniques often compliment each other rather than being mutually exclusive. As a result technique selection is usually a progressive and iterative process.

For example, when the problem situation is ‘messy’ and unclear, problem structuring techniques help to specify the challenge and bring understanding to how the system works. This may be sufficient in itself if the challenge is solely to gain some insight into a particular situation. Alternatively, such understanding can provide a good base for further analysis, leading to the selection of appropriate conceptual modelling, mathematical modelling or simulation techniques.



# Technique Selection



Twenty-eight techniques, commonly applied in manufacturing, aerospace, military and healthcare, were identified through analysis of thousands of research papers. These are categorised into four groups: *Problem Structuring Techniques*, *Conceptual Modelling Techniques*, *Mathematical Modelling Techniques* and *Simulation Techniques*. These techniques are numbered in alphabetical order within each group and each group is colour-coded in blue, green, orange and red respectively.

All the techniques are further characterised to illustrate when to apply them and to identify what resources are required. The scope and constraints of the problem situation need to be defined first before selecting suitable techniques.

| *Category* | *Techniques* | *Number* |
|---|---|---|
| Problem Structuring | Drama Theory & Confrontation Analysis | 1 |
| | Robustness Analysis | 2 |
| | Soft Systems Methodology | 3 |
| | Strategic Choice Approach | 4 |
| | Strategic Options Development & Analysis | 5 |
| Conceptual Modelling | Activity Diagrams | 6 |
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| | Queueing Theory | 19 |
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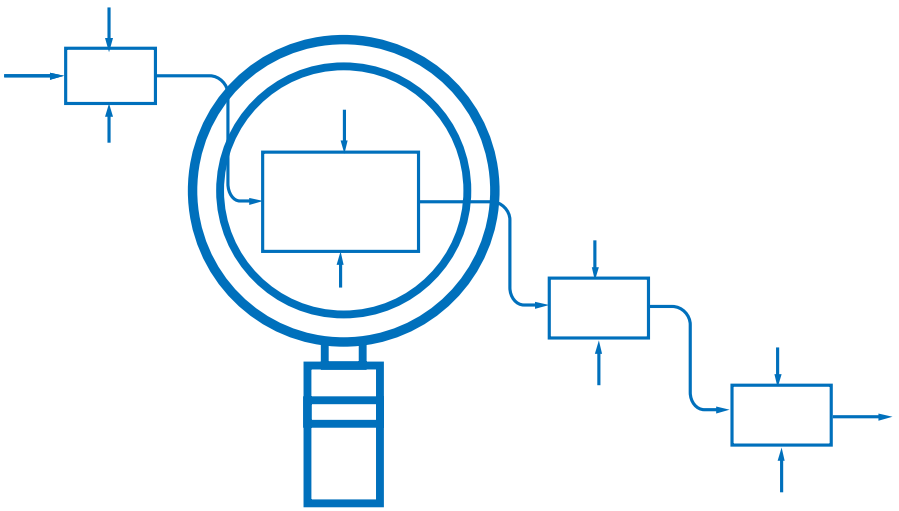
| | Gaming Simulation | 23 |
| | Hybrid Simulation | 24 |
| | Inverse Simulation | 25 |
| | Monte Carlo Simulation | 26 |
| | Real Time Simulation | 27 |
| | System Dynamics | 28 |

# How to Define Scope

Structuring your problem situation might be straightforward, but it could be unclear and messy at first. The following list of the questions (not exhaustive) is suggested to help you structure your problem situation in an iterative manner.

- **Boundary setting**: what is the scope of your problems?
- **Stakeholder definition**: who are involved in your problems?
- **Project lifecycle stages**: what project life cycle stages are you in?
- **Application areas**: what application areas does your problem belong to?



# How to Define Constraints

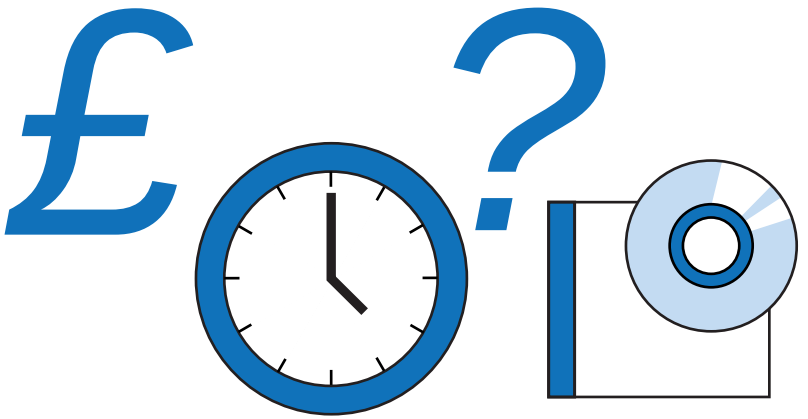


The following questions can help you define required outputs.

- **Level of insight**: what level of insight do you require?
- **Type of output**: what type of output do you require?

The following questions can help you define available input resources.

- **Time**: what is the maximum amount of time do you allow?
- **Money**: what is the maximum amount of money you can afford?
- **Knowledge**: what is the maximum amount of knowledge of the system/problem that you have, or could access?
- **Quantitative data**: what is the maximum amount of data that you have, or could access?



# How to Select Techniques

The workbook is designed to assist selection and comparison of techniques appropriate to supporting particular problem situations. This may be achieved, firstly, by using the *Technique Selection Table* on page 13. This table allows selection of a set of techniques by two criteria (*project life cycle stage* and *type of output*), as defined on pages 14–15.

**Example**: If the challenge is focussed at the stage of *new service development planning,* look down the column of '*2. New service development*' in the *Technique Selection Table* on page 13. If a good understanding of the system interactions is also required, look across the row of '*3. System interaction*' in the same table to find potential techniques that might support the problem situation.

The potential techniques include: four problem structuring techniques (1, 2, 3 and 5); six conceptual modelling techniques (6, 7, 8, 9, 11 and 13); one mathematical modelling technique (18); and one simulation technique (28).

# How to Select Techniques



**Project Life Cycle Stage**

| Type of output | 1. Needs and issues identification | 2. New service development | 3. Demand forecasting | 4. Resource allocation | 5. Implementation plan | 6. Performance criteria development | 7. Performance management | 8. Performance evaluation |
|---|---|---|---|---|---|---|---|---|
| 1. Just some insight | 1 2 3 4 5 9 11 28 | 1 2 3 4 5 9 11 12 19 23 28 | 19 28 | 9 11 12 19 | 9 12 23 | 9 19 | 19 | 3 |
| 2. Trend analysis | 28 | 14 28 | 28 | 9 11 13 14 24 26 | 24 26 | 14 | | 24 |
| 3. System interaction | 1 3 4 5 9 11 28 | **1 2 3 5 6 7 8 9 11 13 18 28** | 18 28 | 18 24 | 6 7 8 9 13 24 25 | 8 9 18 | 18 | 3 24 25 |
| 4. Comprehensive system behaviour | 1 | 1 10 14 15 17 18 20 | 15 18 20 | 14 15 17 18 20 21 22 24 | 10 21 22 24 25 27 | 10 14 15 | 15 18 27 | 22 24 25 |
| 5. Exact / very accurate | | 10 16 17 | | 16 17 22 24 | 10 22 24 25 27 | 10 16 | 16 27 | 16 22 24 25 |

Problem structuring
Conceptual modelling
Mathematical modelling
Simulation

**These techniques are applicable to the *new service development* stage.**

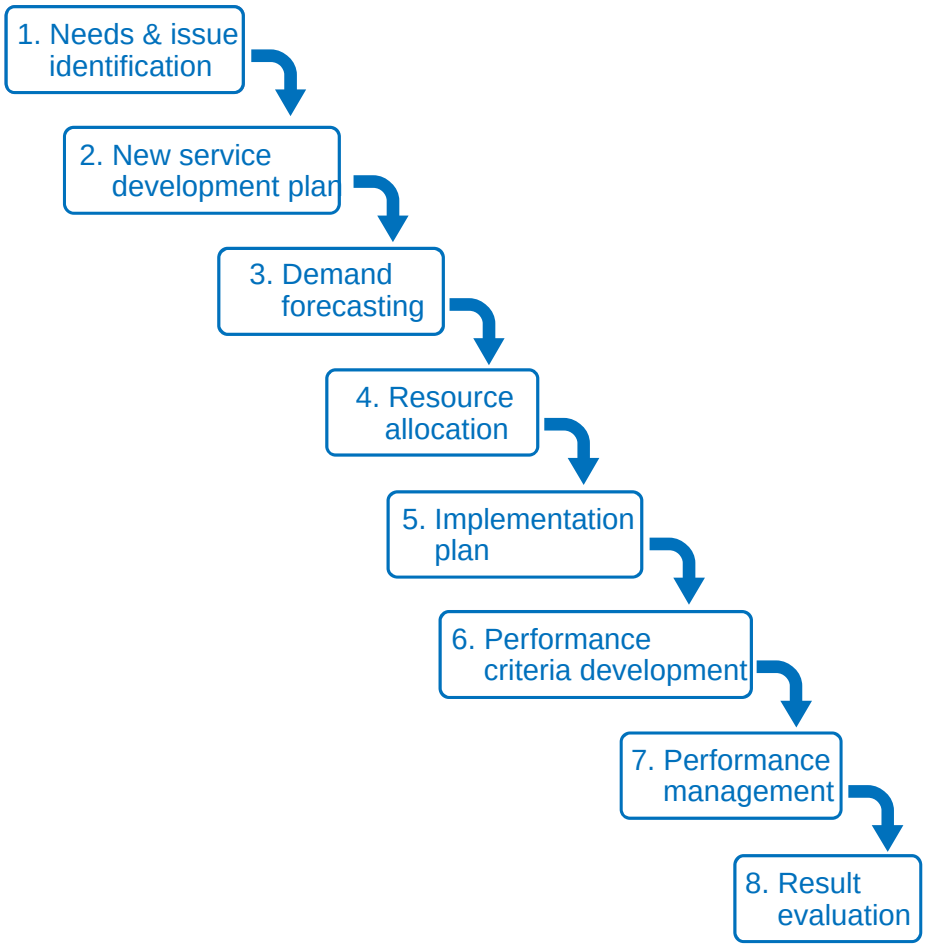
**These techniques provide well-characterised view of *system interactions*.**

# Technique Selection Criteria

## Project Lifecycle Stages

To which of these stages does your problem belong?

1. **Identify issues and needs** for health services
2. **Plan new service development** to meet those needs
3. **Forecast the demand** for health service
4. Secure and **allocate resources** (people, money and time) for delivering services
5. Develop **plans of the way resources will be actually used (implementation)** for health care delivery
6. **Develop performance criteria** (standards, targets) for health care delivery
7. **Manage the performance** of health care delivery
8. **Evaluate the results** of health care delivery



# Technique Selection Criteria



## Type of Output

What type of output do you require from techniques?

1. **Just some insight**: this technique provides some general insight into causes and effects
2. **Trend analysis**: this technique provides some simple what-if analysis and predict any adverse outcomes and patient flows
3. **System interactions**: this technique provides relatively well-characterised view of my system and how it interacts with the rest of the healthcare system
4. **Comprehensive system behaviour**: this technique provides the comprehensive behaviour of the system and make accurate predictions in terms of intended and unintended outcomes
5. **Exact/very accurate**: this technique provides an accurate real-time representation of my system running to support an operational decision

# How to Select Techniques

After selecting a set of potential techniques from the technique selection table on page 16-17, the selection of techniques are further refined by the *Technique / Input Required* tables on pages 24–27. These tables allow comparison of techniques by the required minimum input resources (*time*, *money*, *knowledge* and *data*) as defined on pages 20–23.

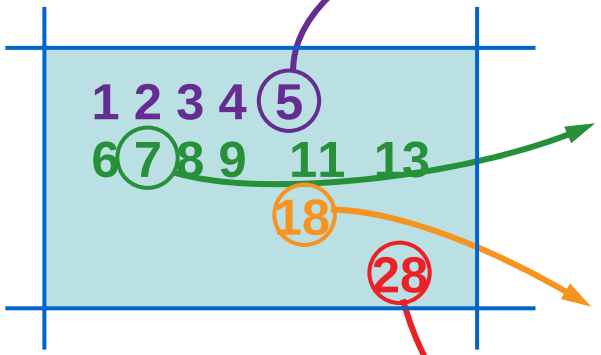
At any stage, a more detailed summary of each technique may be found at the second part of this book using the reference number provided in the tables.

**Example**: The Techniques by the minimum Input resources table help us compare constraints on the use of these techniques as shown on page 19. For example, 28. System Dynamics requires at least a month to execute and £50k to purchase hardware, software and expertise. This technique would be inappropriate to support a decision which need to be made in a couple of weeks with very limited budget. Given such constraints, it becomes clear that 7. Communication Diagrams, which requires only a week to execute and £1,500 to purchase hardware, software and expertise, might be more appropriate.

The application of this process enables the selection of techniques most suited to the needs and constraints of the particular decision process.

# How to Select Techniques





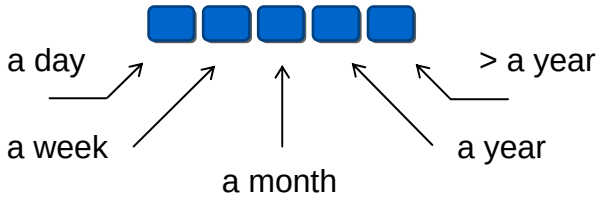

| | *Time* | *Money* | *Knowledge* | *Data* |
|---|---|---|---|---|
| **5. Strategic options development & analysis** | a month | £1500 | none | none |
| **7. Communication diagrams** | a week | £1500 | limited | none |
| **18. Petri Nets** | a month | £15K | expert | statistics |
| **28. System dynamics** | a month | £50K | moderate | guesstimate |

# Technique Characterisation

## Input Required – Time

What is the minimum amount of time this technique requires with expertise available?

- **a day**: my deadline is tomorrow (emergency decision/crisis)
- **a week**: my deadline is in a week's time or the decision is required urgently
- **a month**: my deadline is in a month's time or the decision is required soon
- **a year**: my deadline is in a year's time (operational level problem)
- **> a year**: I have more than a year to come to a decision (strategic decision)



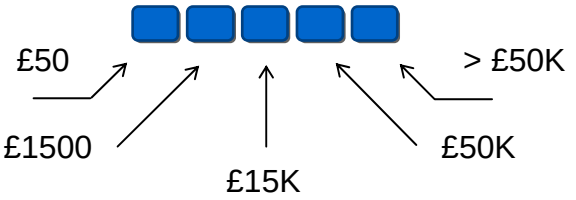
# Technique Characterisation



## Input Required – Money

What is the minimum amount of money this technique requires to purchase hardware, software and expertise?

- **£50**: my budget is less than £50
- **£1500**: my budget is less than £1500
- **£15k**: my budget is less than £15k
- **£50k**: my budget is less than £50k
- **> £50k**: my budget exceeds £50k

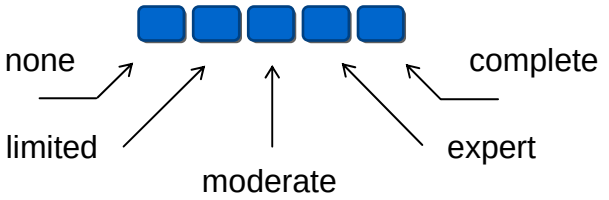


# Technique Characterisation

## Input Required – Knowledge

What is the minimum amount of knowledge of the problem this technique requires?

- **None**: I have no prior knowledge of this problem
- **Limited knowledge**: I understand some aspects of this problem, but not others
- **Moderate knowledge**: I have access to relevant expertise relating to this problem, but my views of the wider implications are not clear
- **Expert knowledge**: I have access to expertise regarding this problem
- **Complete knowledge**: I have access to a team of experts capable of understanding this problem



# Simulation Techniques

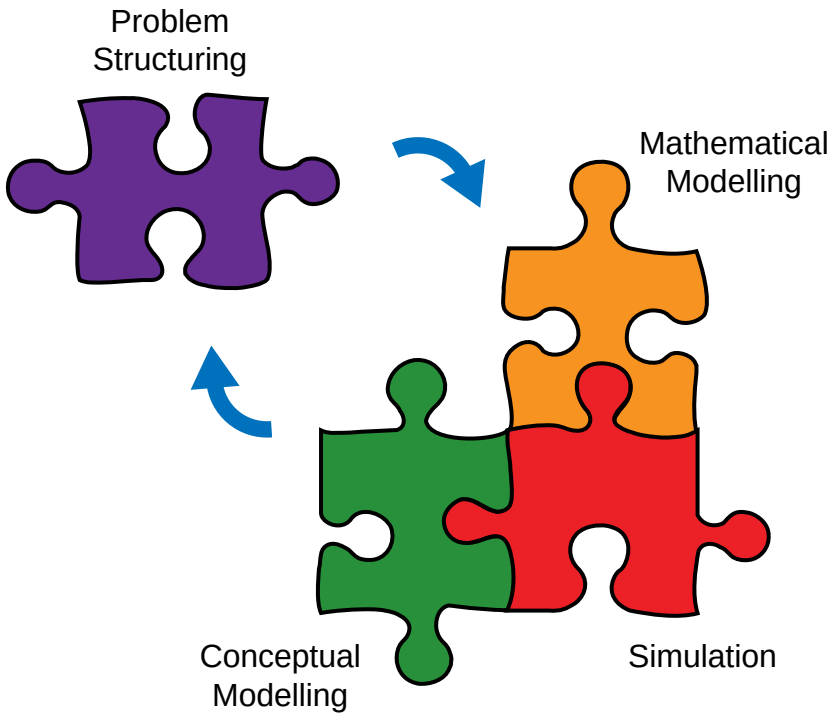


| TECHNIQUE | | MINIMUM INPUT REQUIRED | | | |
|---|---|---|---|---|---|
| No. | *Description* | *Time* | *Money* | *Knowledge* | *Data* |
| 21 | Agent-Based Simulation | a year | £50K | moderate | statistics |
| 22 | Discrete Event Simulation | a year | £50K | moderate | statistics |
| 23 | Gaming Simulation | a month | £15K | limited | guesstimate |
| 24 | Hybrid Simulation | a year | £50K | moderate | statistics |
| 25 | Inverse Simulation | a year | £50K | expert | statistics |
| 26 | Monte Carlo Simulation | a month | £50K | moderate | raw |
| 27 | Real-Time Simulation | a year | £50K | expert | raw |
| 28 | System Dynamics | a month | £50K | moderate | guesstimate |

# Technique Descriptions

Modelling and simulation techniques often compliment each other rather than being mutually exclusive. As a result technique selection is usually a progressive and iterative process.

In this workbook, twenty eight individual techniques are presented covering four different categories: problem structuring; conceptual modelling; mathematical modelling; and simulation.



# Technique Descriptions



A brief description of each technique is given in this section; along with example applications, a typical diagram, minimum input requirements and outputs expected.

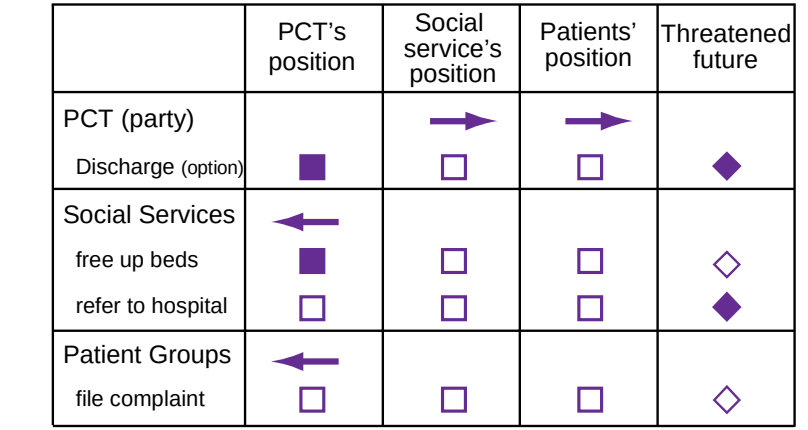
# 1 Drama Theory & Confrontation Analysis

*Stakeholders interests and power relationships are identified and modelled in order to manage dilemmas and conflict.*

Confrontation analysis provides a way of structuring situations involving parties with conflicting interests and identifying the dilemmas for different participants. Options Boards are used as the main tools for modelling confrontations and developing winning courses of action. The aim of this technique is to identify ways of getting stakeholders with different objectives and emotional responses to work together.

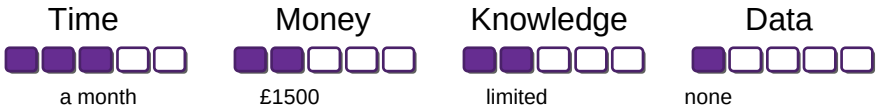
Main applications include:

- Conflicts in which decisions are subject to strong emotion, reputation and conflicting incentives
- Frequently applied to military, industrial and healthcare conflicts




Confrontation between multiple stakeholders

Minimum input requirements:




Outputs expected:

- Better understanding of the responses and incentives faced by the stakeholders in a conflict
- Effective engagement strategies in a conflict

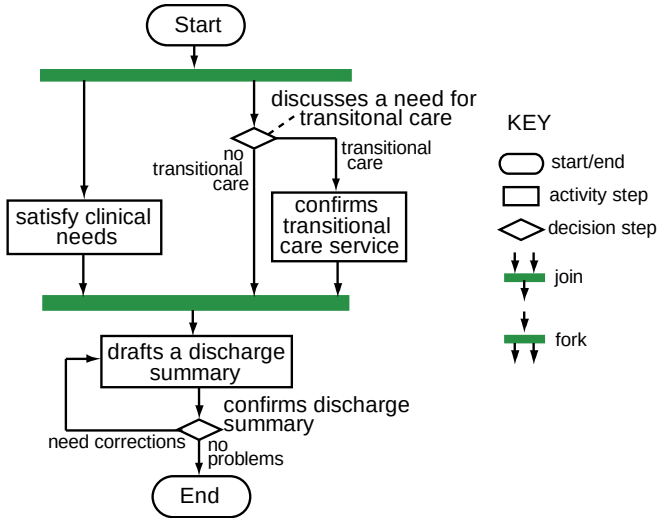
# 6 Activity Diagrams

*The sequence of activities is diagrammatically represented in order to document or (re)design a process.*

Activity diagrams are very similar to traditional flow charts. The diagrams consist of initial/final nodes, activity steps, decision steps and joins/forks which allow the modeller to describe activities occurring sequentially or simultaneously. Activity diagrams are very easy to build and read, and they are particularly helpful in understanding an overall process. With some additional notations, activity diagrams can be used as conceptual models for *Discrete Event Simulation* (see page 35).

Main applications include:

- System (re)design at an operational level
- Communication of procedures/standards, system requirements definition and operational risk analysis




A simplified patient discharge process

Minimum input requirements:


Outputs expected:

- General understanding of the workflow
- System requirements and design specifications at operation level

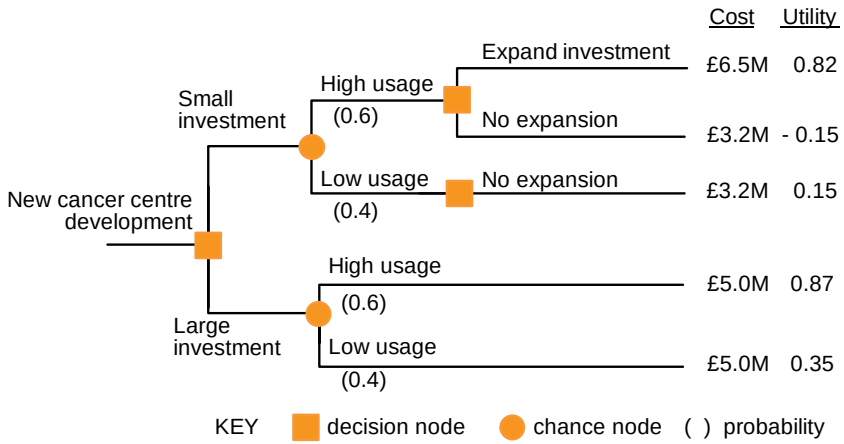
# 14 Decision Trees

*A complex decision problem is represented by a tree of interconnected decisions where the probabilities of the various events is calculated/ estimated in order to assist the choice of actions.*

Decision problems with multiple related choices can often be addressed using decision trees. A decision tree is based on a graphical technique that uses a tree structure to denote decisions and their likely consequences. Squares represent decisions and circles represent the chances of occurrences.

Main applications include:

- The evaluation of different strategies in the face of uncertainty
- Clinical decision-making, including comparing treatment policies (e.g. surgery vs medication)




Decision tree for new service development

Minimum input requirements:

| Time | Money | Knowledge | Data |
|---|---|---|---|
| a week | £1500 | moderate | some |

Outputs expected:

- General understanding of decision problems
- Structured, quantified decision-making support at operational and strategic levels

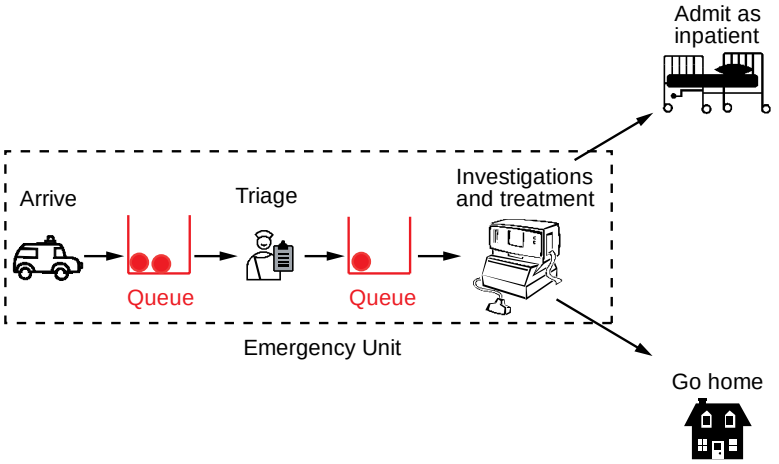
# 22 Discrete Event Simulation

*The operation of a system is represented as a chronologically-linked sequence of events in order to describe flows of people and/or material and explore the effects of any changes.*

Discrete event simulation is best suited to analysing systems that can be modelled as a series of queues and activities, for example, an Emergency Department or clinic. Individual patients are modelled as they pass through the system, allowing for variability and uncertainty in behaviour. This allows potential impacts to the system or patients to be estimated, and can help answer "what if" questions, before changes are made to the real system.

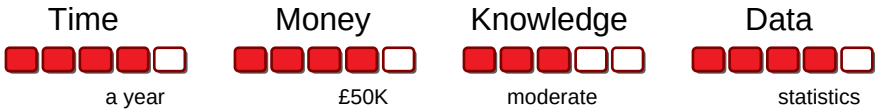
Main applications include:

- System (re)design at operational/strategic levels
- Scheduling, resource allocation, staffing, waiting list management and patient pathway design




Patient queueing through an emergency unit

Minimum input requirements:




Outputs expected:

- Quantitative estimation of system performance

# Further Reading

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# MODELLING AND SIMULATION TECHNIQUES FOR SUPPORTING HEALTHCARE DECISION MAKING: A SELECTION FRAMEWORK

This workbook is intended to provide guidance for people who are making decisions in healthcare. It is aimed at anyone who wants to find out more about different modelling and simulation techniques - what they are, when to apply them, and what resources are required to use them. It will not only help decision makers commission more appropriate modelling work, but also assist professional modellers and business consultants to expand their modelling repertoire to meet the needs of client most appropriately.

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