RIGHT

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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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

RIGHT

Research Into Global Healthcare Tools

Contents

Who the Workbook is for

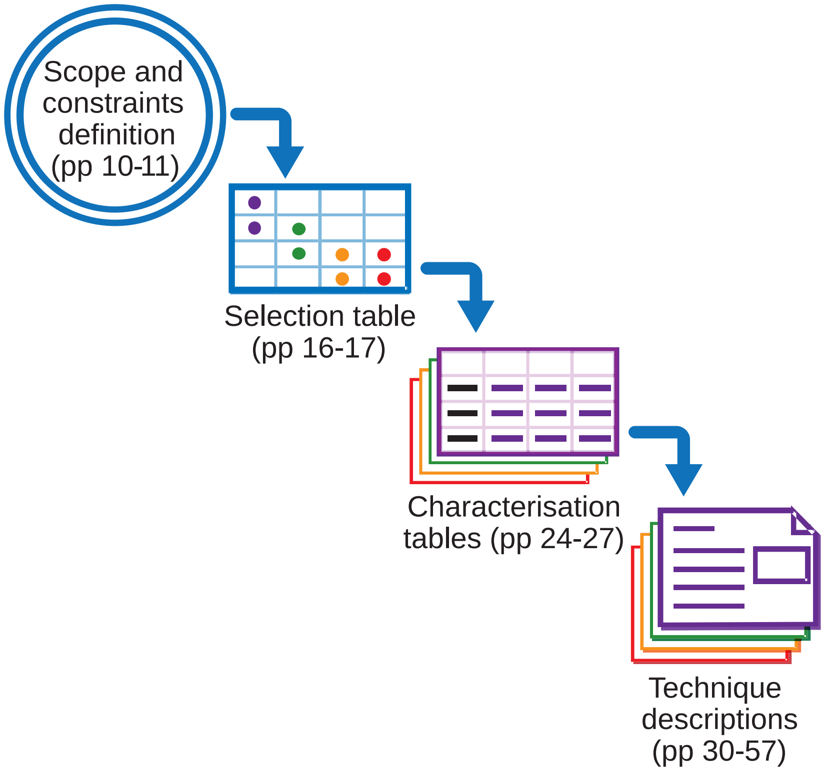
This workbook is intended to provide guidance for people who are making decisions in healthcare. It is aimed at anyone who wants to find out more about different modelling and simulation techniques – what they are, when to apply them, and what resources are required to use them. It will not only help 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).

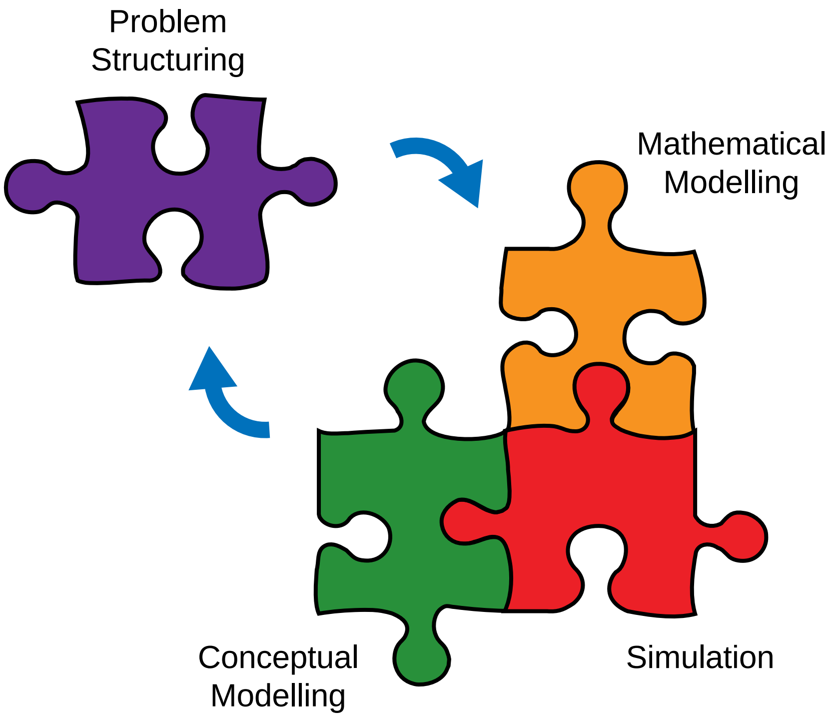
The second part of the workbook provides a descriptive summary of each technique, including a statement of the purpose, application, the inputs required and the outcome of each technique. Additional reading material is identified at the end of the workbook.



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.

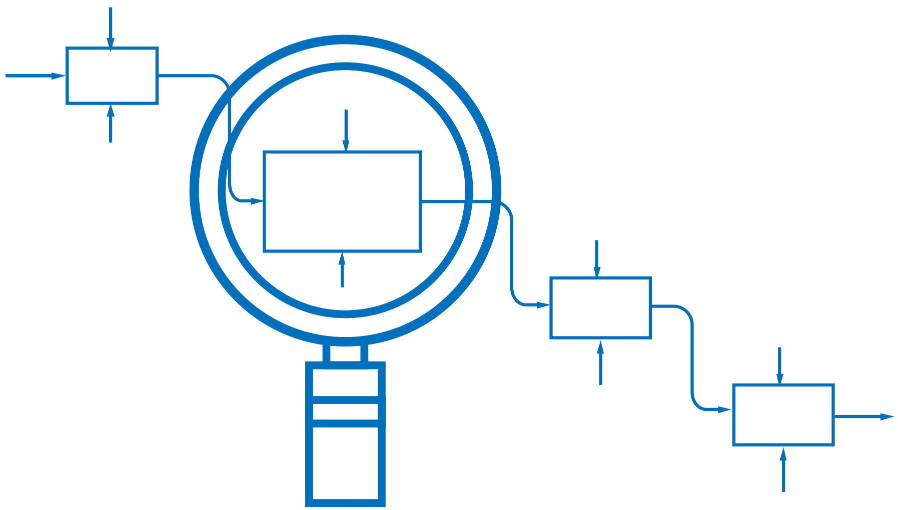
All the techniques are further characterised to illustrate when to apply them and to identify what resources are required. The scope and constraints of the problem situation need to be defined first before selecting suitable techniques.

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
	Communication Diagrams	7
	Data Flow Diagrams	8
	Influence Diagrams	9
	Information Diagrams	10
	Issue Maps	11
	State Transition Diagrams	12
	Swim Lane Activity Diagrams	13
Mathematical Modelling	Decision Trees	14
	Markov Modelling	15
	Multivariate Analysis	16
	Optimisation Techniques	17
	Petri Nets	18
	Queueing Theory	19
	Survival Analysis	20
Simulation	Agent Based Simulation	21
	Discrete Event Simulation	22
	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?



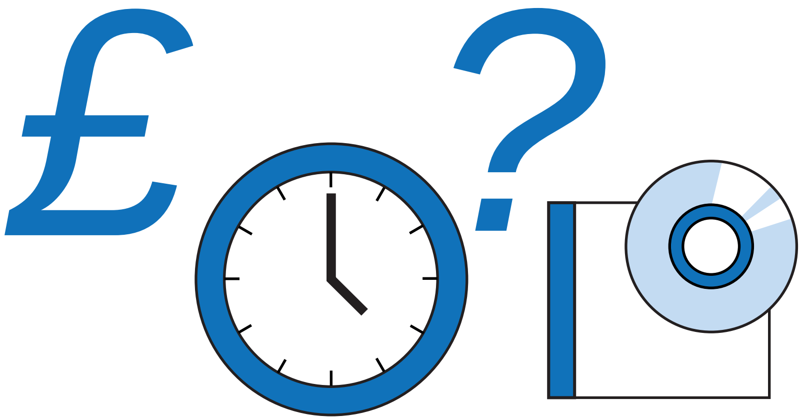
How to Define Constraints

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 18	15 18 27	22 24 25
5. Exact / very accurate		10 16 17	16	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.

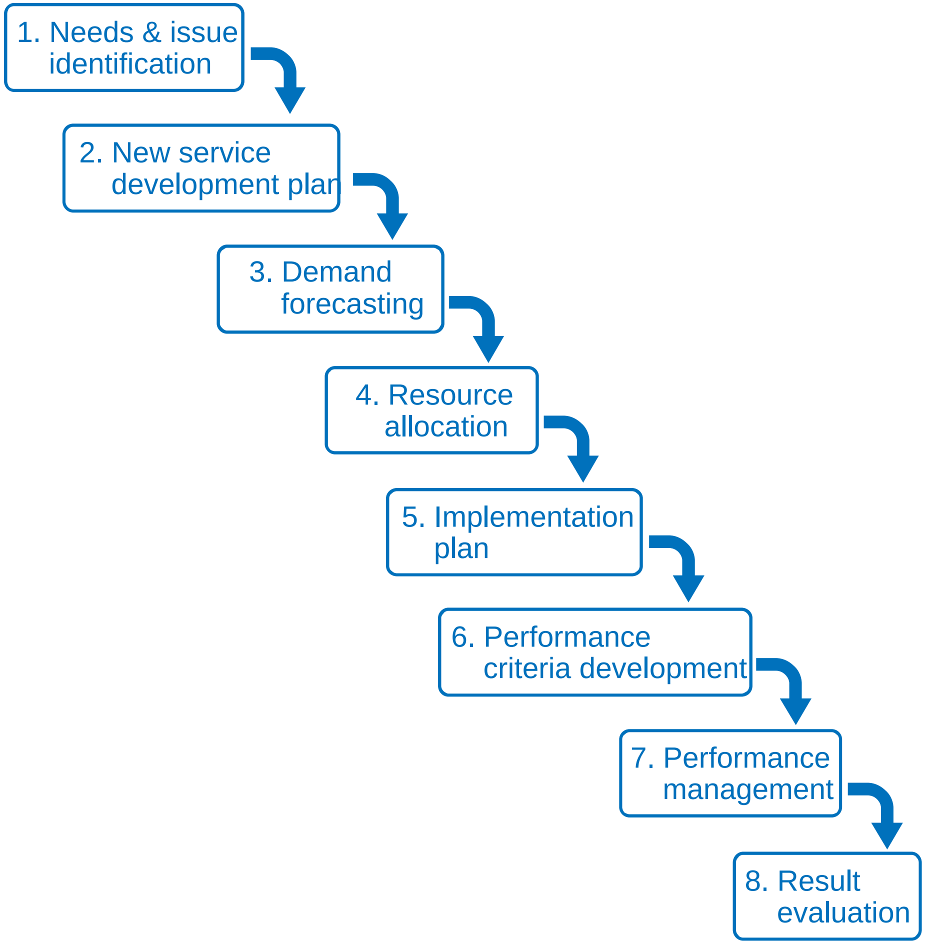
These techniques provide well-characterised view of *system interactions*.

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

Technique Selection Table

Problem structuring
Conceptual modelling
Mathematical modelling
Simulation

Type of output	Project Life Cycle Stage: 1. Needs and issues identification	2. New service development	3. Demand forecasting	4. Resource allocation
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
2. Trend analysis	28	14 28	28	9 11 13 14 24 26
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
4. Comprehensive system behaviour	1	1 10 14 15 17 18 20	15 18 20	14 15 17 18 20 21 22 24
5. Exact / very accurate		10 16 17	16	16 17 22 24

Technique Selection Table

Project Life Cycle Stage

Type of output	5. Implementation plan	6. Performance criteria development	7. Performance management	8. Performance evaluation
1. Just some insight	9 12 23	9 19	19	3
2. Trend analysis	24 26	14		24
3. System interaction	6 7 8 9 13 24 25	8 9 18	18	3 24 25
4. Comprehensive system behaviour	10 21 22 24 25 27	10 14 15 18	15 18 27	22 24 25
5. Exact / very accurate	10 22 24 25 27	10 16	16 27	16 22 24 25

Problem structuring
Conceptual modelling
Mathematical modelling
Simulation

How to Select Techniques

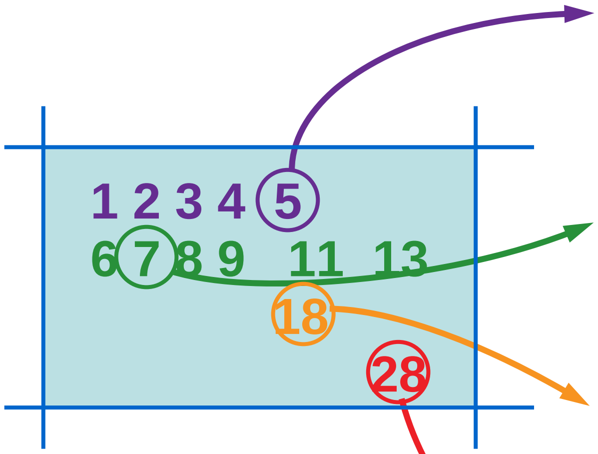
After selecting a set of potential techniques from the technique selection table on page 16-17, the selection of techniques are further refined by the *Technique / Input Required* tables on pages 24–27. These tables allow comparison of techniques by the required minimum input resources (*time*, *money*,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



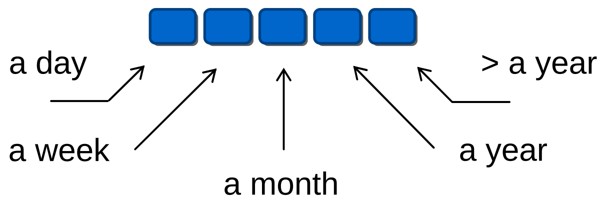
	Time	Money	Knowledge	Data
5. Strategic options development & analysis	a month	£1500	none	none
7. Communication diagrams	a week	£1500	limited	none
18. Petri Nets	a month	£15K	expert	statistics
28. System dynamics	a month	£50K	moderate	guesstimate

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)

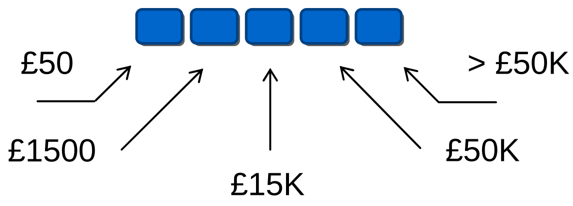


Technique Characterisation

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

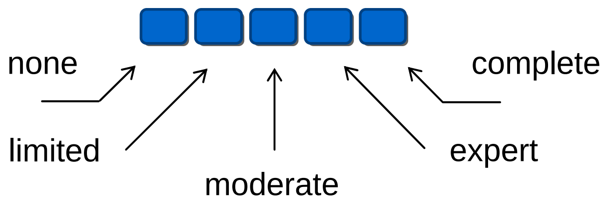


Technique Characterisation

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

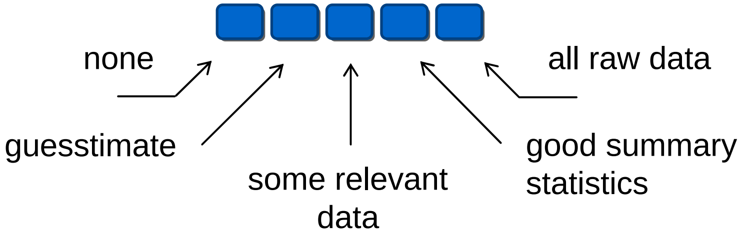


Technique Characterisation

Input Required – Quantitative data

What is the minimum amount of quantitative data this technique requires?

- **None**: I do not have any quantitative data
- **Guesstimate**: I can guess a number of variables and have a feel for some trends
- **Some relevant data**: I am an expert in the field and have access to expert views and some relevant statistics
- **Good statistics**: I have good summary statistics on all aspects of this service, including financial and operational histories
- **All types of raw data**: I can furnish any raw data that is required and have access to all relevant expertise



Problem Structuring Techniques

TECHNIQUE		**MINIMUM INPUT REQUIRED**			
No.	*Description*	*Time*	*Money*	*Knowledge*	*Data*
1	Drama Theory & Confrontational Analysis	a month	£1500	limited	none
2	Robustness Analysis	a year	£1500	none	none
3	Soft Systems Methodology	a month	£1500	none	none
4	Strategic Choice Approach	a month	£1500	none	none
5	Strategic Options Development & Analysis	a month	£1500	none	none

Conceptual Modelling Techniques

TECHNIQUE		MINIMUM INPUT REQUIRED			
No.	*Description*	*Time*	*Money*	*Knowledge*	*Data*
6	Activity Diagrams	a week	£1500	moderate	none
7	Communication Diagrams	a week	£1500	limited	none
8	Data Flow Diagrams	a week	£1500	moderate	none
9	Influence Diagrams	a month	£1500	moderate	none
10	Information Diagrams	a week	£1500	moderate	none
11	Issue Maps	a month	£1500	moderate	none
12	State Transition Diagrams	a week	£1500	moderate	none
13	Swim Lane Activity Diagrams	a week	£1500	moderate	none

Mathematical Modelling Techniques

TECHNIQUE		MINIMUM INPUT REQUIRED			
No.	*Description*	*Time*	*Money*	*Knowledge*	*Data*
14	Decision Trees	■■□□□ a week	■■□□□ £1500	■■■□□ moderate	■■■□□ some
15	Markov Modelling	■■■□□ a month	■■■□□ £15K	■■■□□ moderate	■■■■□ statistics
16	Multivariate Analysis	■■■□□ a month	■■■□□ £15K	■■■□□ moderate	■■■■■ raw
17	Optimisation Techniques	■■■□□ a month	■■■□□ £15K	■■■□□ moderate	■■■■■ raw
18	Petri Nets	■■■□□ a month	■■■□□ £15K	■■■■□ expert	■■■■□ statistics
19	Queueing Theory	■■□□□ a week	■■□□□ £1500	■■■□□ moderate	■■■□□ some
20	Survival Analysis	■■■□□ a month	■■■□□ £15K	■■■□□ moderate	■■■■■ raw

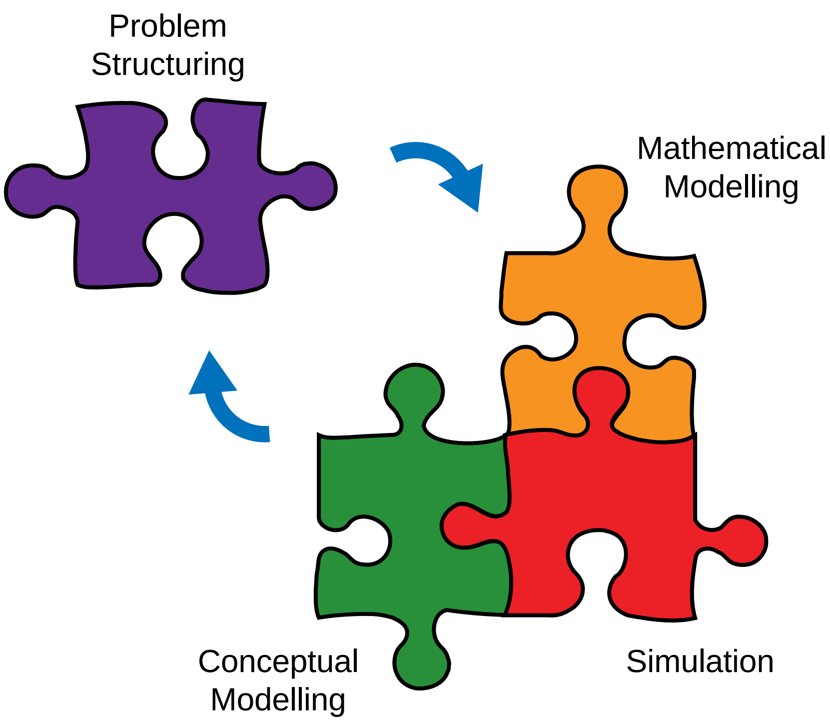
Simulation Techniques

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

	PCT's position	Social service's position	Patients' position	Threatened future
PCT (party)		→	→	
Discharge (option)	■	□	□	◆
Social Services	←			
free up beds	■	□	□	◇
refer to hospital	□	□	□	◆
Patient Groups	←			
file complaint	□	□	□	◇

KEY arrows: dilemma pressures away from agreed outcomes
filled-in shapes: selected options under that party's desired outcome or the threatened future
non-filled-in shapes: options non-desired under that player's desired outcome or the threatened future

Confrontation between multiple stakeholders

Minimum input requirements:

Time	Money	Knowledge	Data
■■■□□	■■□□□	■■□□□	■□□□□
a month	£1500	limited	none

Outputs expected:

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

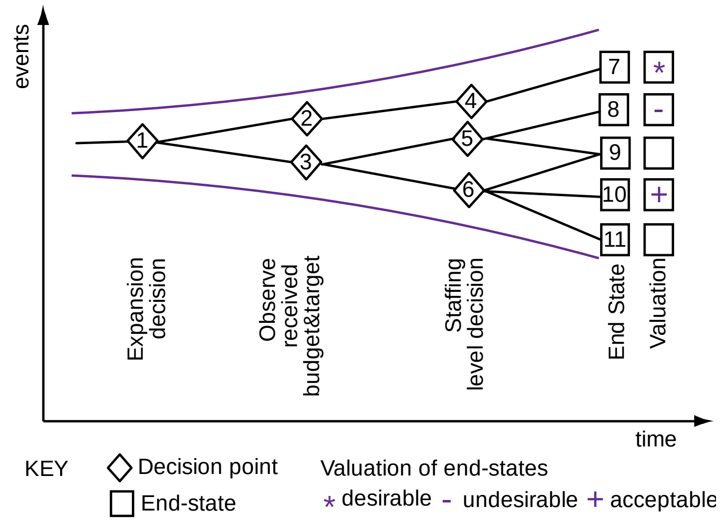
2 Robustness Analysis

Highly uncertain problem situations are quantitatively structured as a sequence of decisions in order to help maintain flexibility in attaining future goals.

In robustness analysis, a number of possible future scenarios are structured as a series of decision and implementation phases in which decisions are sequential. Robustness analysis focuses on maintaining flexibility to reach the organisation's goals and avoiding "catastrophic" outcomes as a result of decisions, their implications and changing environmental factors.

Main applications include:

- Business location decisions, company expansion planning, hospital location decisions and regional health planning



Service planning decisions and outcomes

Minimum input requirements:

Time	Money	Knowledge	Data
a year	£1500	none	none

Outputs expected:

- Better understanding of the options, their links, and their feasibility and acceptability

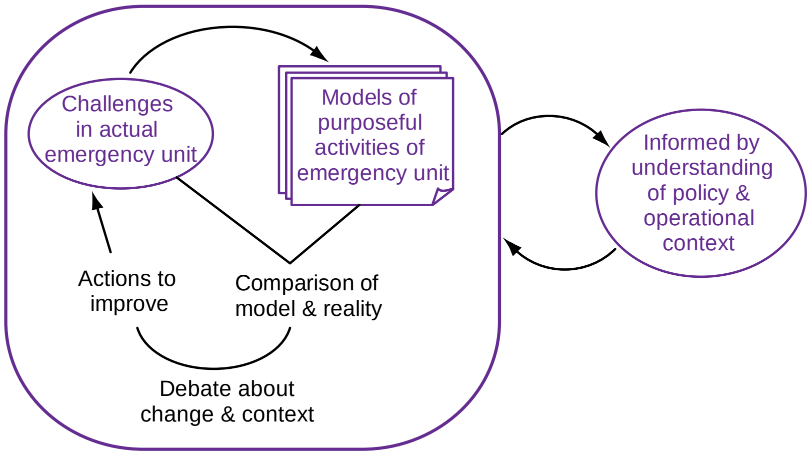
3 Soft Systems Methodology

Models of purposeful activity and observable reality are compared in order to explore a system and associated decisions.

The soft systems methodology assists a group of stakeholders to identify the purpose of their “system” and the problems they face. The technique is based around comparing different perspectives of the system to the reality observed. The aim is to assist the exploration of reality and develop some means to ‘accommodate’ the various stakeholders’ needs. Rich pictures are used in the early stage of SSM to represent a messy situation.

Main applications include:

- Project management (multiple stakeholders, conflicting goals and priorities, and unclear objectives)



System improvement of an emergency unit

Minimum input requirements:

Time	Money	Knowledge	Data
■■■□□	■■□□□	■□□□□	■□□□□
a month	£1500	none	none

Outputs expected:

- Understanding of complex problem situations
- Identification of ‘desirable and feasible’ changes in the system

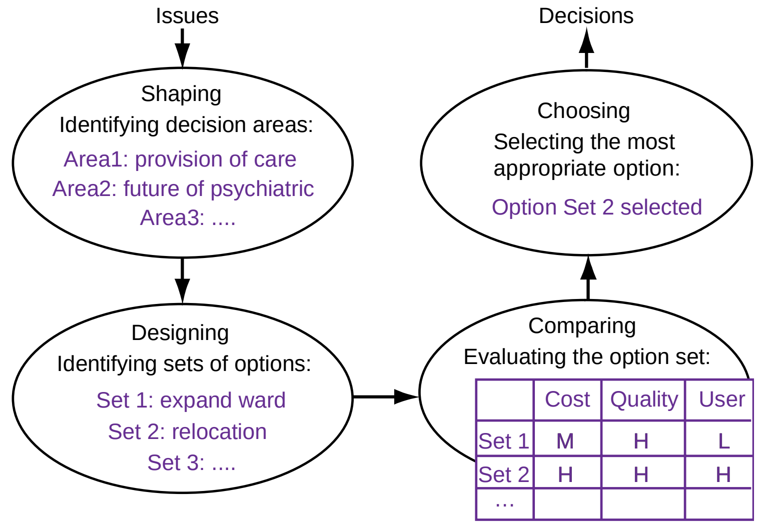
4 Strategic Choice Approach

The interconnectedness of decisions is explicitly addressed in order to help managers structure the problem, and consider possible courses of action in situations of uncertainty.

The strategic choice approach helps stakeholders to define their problem, identify potential solutions, compare them and select a preferred one. The approach uses visual tools to highlight the interconnectedness of decisions, but also focuses on identifying sources of uncertainty, including environmental factors, values, and other related domains. It is designed to be an interactive approach which can used without expertise.

Main applications include:

- Corporate strategic planning, local government decision making, organisational and inter-organisational decision making



Healthcare service planning

Minimum input requirements:

Time	Money	Knowledge	Data
a month	£1500	none	none

Outputs expected:

- Better understanding of the system and linkages
- Identification of 'desirable and feasible' changes in the system

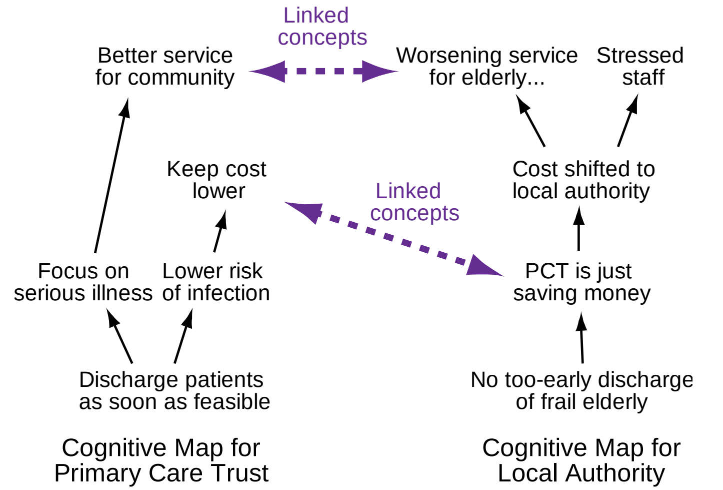
5 Strategic Options Development & Analysis

Aggregated cognitive maps are represented in order to identify clusters of key issues that must be addressed and a hierarchy of actions to take.

Strategic options development and analysis enables stakeholders to identify and incorporate each other's viewpoints into a rich, unified model of the problem. It is built around allowing stakeholders to express subjective perspectives of a situation and then mapping the definitions and perspectives of the problems. The identifying of interconnected issues and aggregating of individual cognitive maps enables discussion and negotiation about objectives, strategy and options.

Main applications include:

- Decision making at policy and strategic levels
- Used to produce influence diagrams which are basis for *System Dynamics* simulation (see page 57).



Different but linked viewpoints on patient discharge

Minimum input requirements:

Time	Money	Knowledge	Data
■■■□□	■■□□□	■□□□□	■□□□□
a month	£1500	none	none

Outputs expected:

- Better understanding of messy problems and stakeholders' positions
- Stakeholders' agreement on key solutions

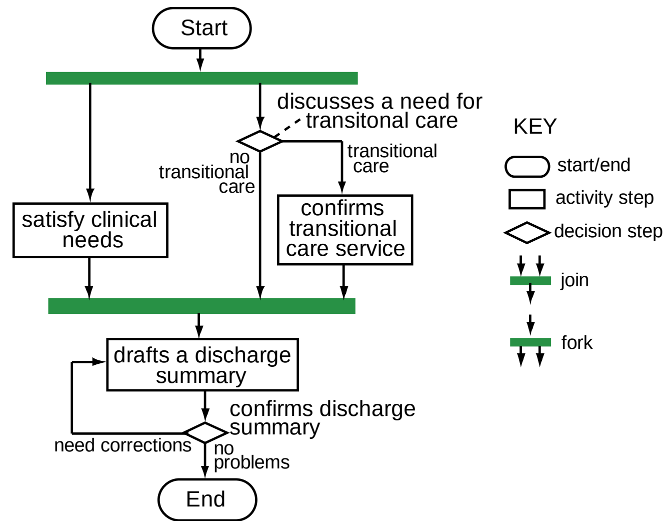
6 Activity Diagrams

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:

Time	Money	Knowledge	Data
■■□□□	■■□□□	■■■□□	■□□□□
a week	£1500	moderate	none

Outputs expected:

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

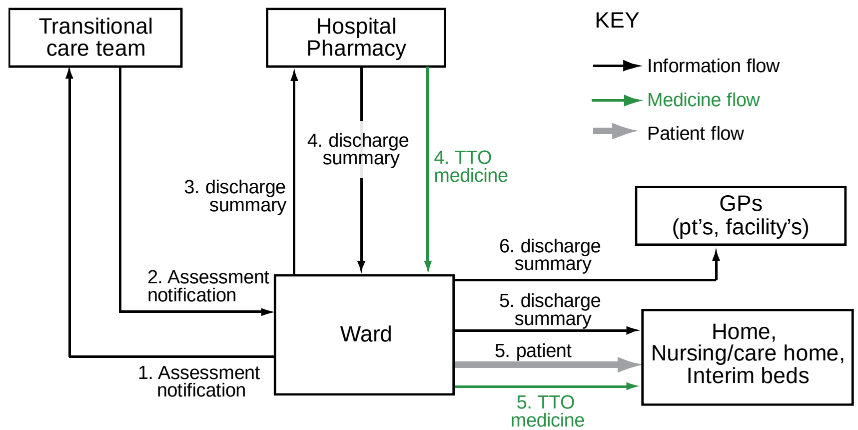
7 Communication Diagrams

Information and material flows between 'stakeholders' are represented in order to understand how stakeholders interact with each other.

Communication diagrams consist of stakeholders (individuals, teams or organisations) and the flow of messages and materials between them. Labels are placed on the flows to show the order in which the messages are sent. Communication diagrams are particularly helpful to describe interactions between trusts, departments, teams and individuals.

Main applications include:

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



Communication flows in a patient discharge process

Minimum input requirements:

Time	Money	Knowledge	Data
a week	£1500	limited	none

Outputs expected:

- General understanding of system interactions
- System requirements and design specifications at operation level

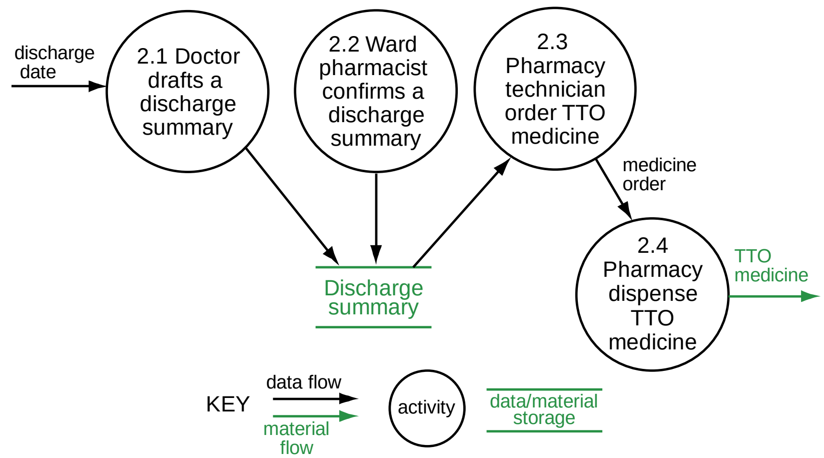
8 Data Flow Diagrams

Information (or material) inputs and outputs between 'activities' are represented in order to understand how information (or material) is processed and where information is stored.

Data flow diagrams were originally developed to describe the flow of data through an information system. They consist of three key elements: processes (circles), data flows (lines) and data stores (boxes without vertical lines); and are particularly helpful in describing data-driven processes, e.g. human-machine interactions.

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:

Time	Money	Knowledge	Data
a week	£1500	moderate	none

Outputs expected:

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

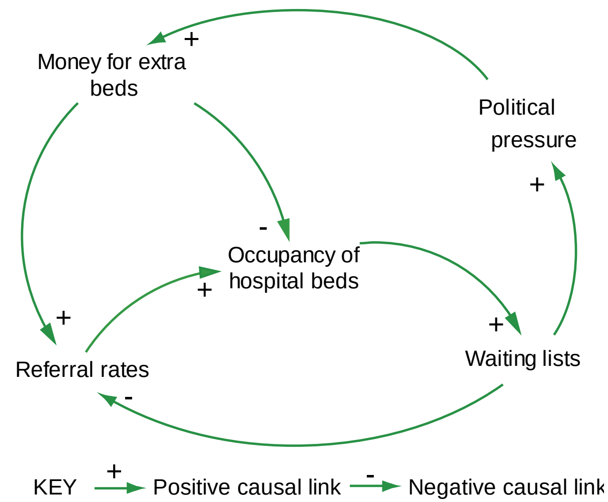
9 Influence Diagrams

The variables that define a situation, and the important relationships between them, are represented visually in order to facilitate a high-level qualitative analysis of the interdependencies between the variables and the implications of changing one or more of them.

The most common influence diagram, i.e. a causal loop diagram (CLD), represents the feedback structure of systems using a set of nodes (variables) and arrows (negative and positive influences), and allows the interdependencies and impacts of change to be considered. They can be used as the basis of *System Dynamics* (see page 57).

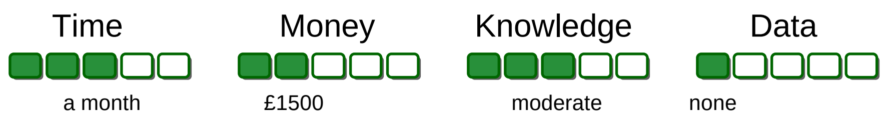
Main applications include:

- Evaluation of unintended effects of policy such as epidemic intervention policies or policies on the delivery of community care



Relationships between variables influencing waiting lists

Minimum input requirements:



Outputs expected:

- High-level qualitative understanding of the variables and causes of a system's dynamic behaviour

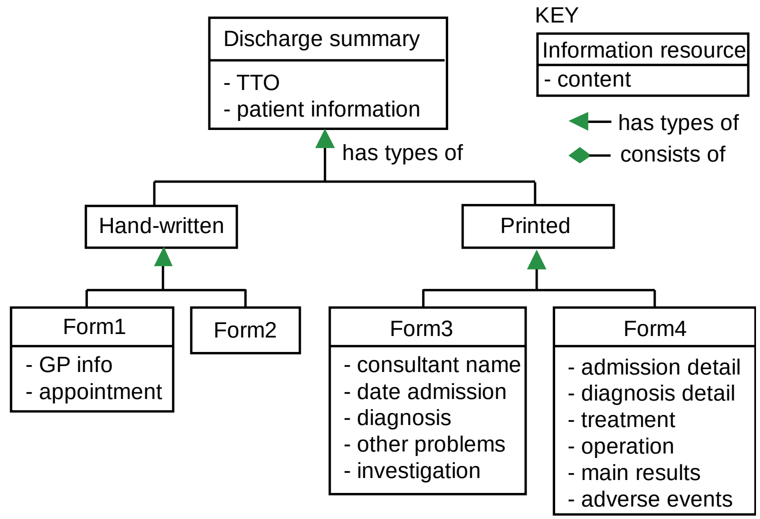
10 Information Diagrams

Information or document structures are represented diagrammatically in order to understand how information is, or documents are classified.

Information diagrams consist of two key elements: information resources (boxes) and hierarchical inter-relationships between them (lines). It is a type of entity relationship diagram, which represents a conceptual database model. Relationship types are described by two basic types: aggregation (consists of) and generalisation (has types of). Information diagrams are particularly helpful in describing documentation issues (document standardisation level and electronic document usage level).

Main applications include:

- Information system requirements definition, document standardisation



Four different discharge summaries used in a hospital

Minimum input requirements:

Time Money Knowledge Data

a week £1500 moderate none

Outputs expected:

- General understanding of information structure
- System requirements and design specifications at operational level

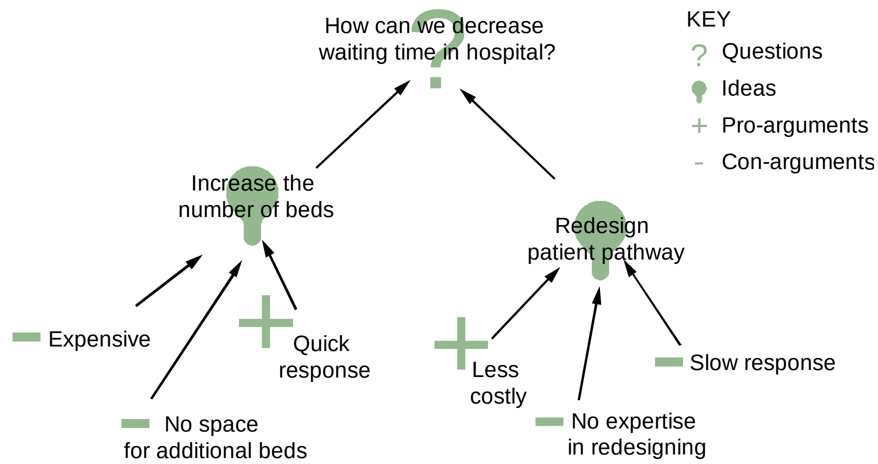
11 Issue Maps

The logical structure among questions, ideas and arguments (pros, cons) are represented graphically in order to understand the context of a complex issue.

Issue maps are based on a modelling language called IBIS (Issue Based Information System), which uses just three basic elements — questions, ideas, and arguments — to capture the structure of the complex issues. Issue maps provide an open and systematic way to clarify diverse perspectives, conflicting interpretations and goals, and inconsistent information.

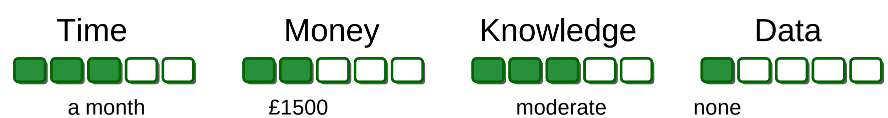
Main applications include:

- Any problem or question with complex and argumentative issues
- Organisational problems, e.g. policy negotiation, cost reduction, system (re)design



Issues around how to decrease waiting times in a hospital

Minimum input requirements:



Outputs expected:

- Better understanding of complex and contentious issues

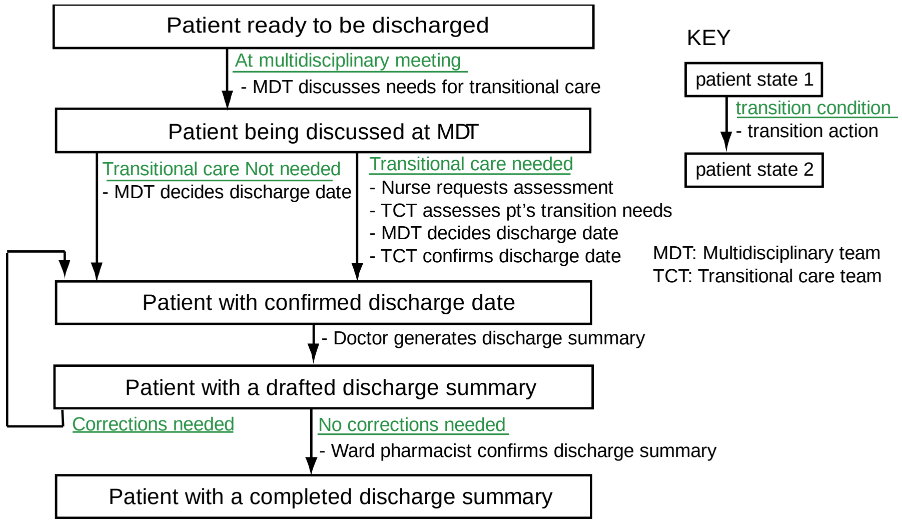
12 State Transition Diagrams

Patient states along with transition conditions and actions are represented in order to understand how patient states change through care processes.

State transition diagrams were originally developed to define the way in which a system's behaviour changes over time by showing the system's states, transition conditions and transition actions. In health care, the diagrams are used to describe patients' states in term of their clinical or administrative stages, which can effectively provide patients' centred perspective of care processes.

Main applications include:

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



A simplified patient discharge process

Minimum input requirements:

Time	Money	Knowledge	Data
2/5	2/5	3/5	1/5
a week	£1500	moderate	none

Outputs expected:

- General understanding of system operation
- System requirements and design specifications

Conceptual Modelling

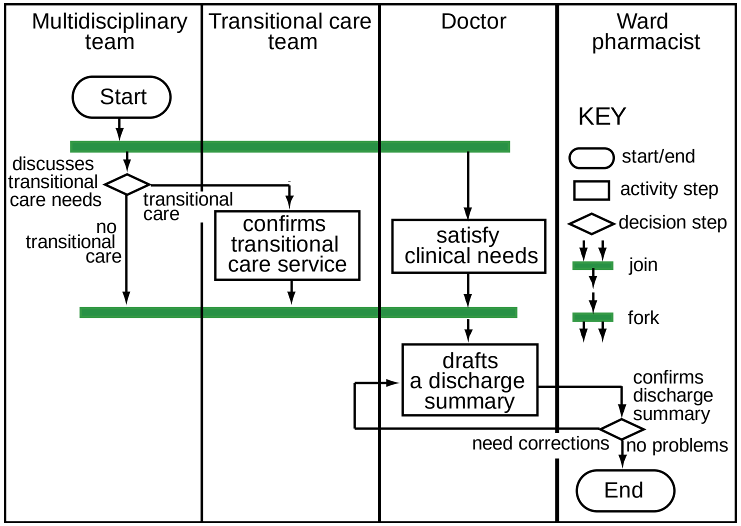
13 Swim Lane Activity Diagrams

The distribution of activities among the stakeholders participating in the process is represented in order to clarify roles and responsibilities of activities.

Swim lane activity diagrams are the enhanced activity diagrams that describe a process, but with explicit responsibility represented by 'swim lanes'. Swim lanes are arranged either horizontally or vertically to group the sub-processes according to the responsibilities.

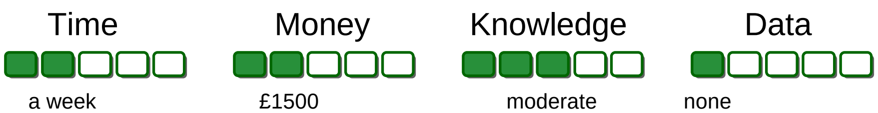
Main applications include:

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



A simplified patient discharge process

Minimum input requirements:



Outputs expected:

- General understanding of the workflow and responsibilities
- System requirements and design specifications

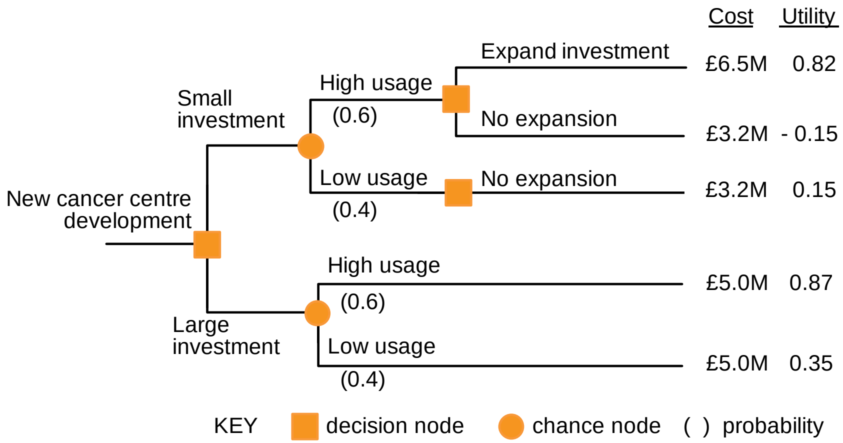
14 Decision Trees

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

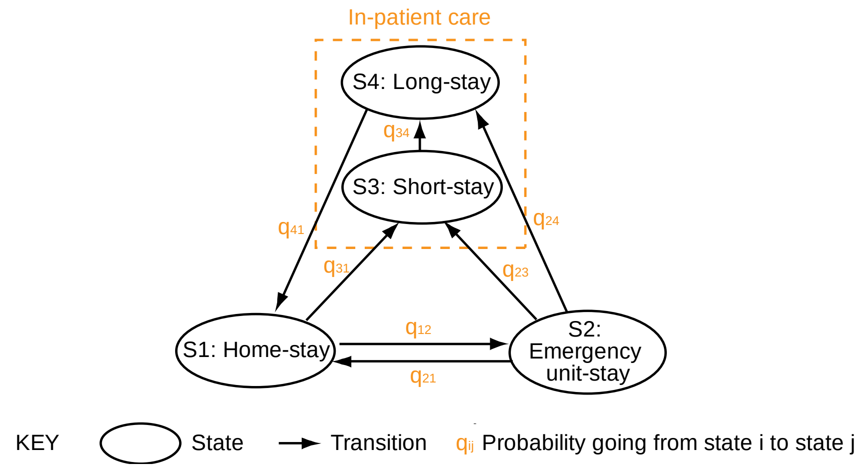
15 Markov Modelling

A series of states of objects or people, and their transitions over time, are mathematically modelled in order to estimate system characteristics.

Markov modelling often uses *State Transition Diagrams* (see page 52) to represent both states (e.g. clinical stages) and transitions. The key feature of Markov models is the 'memoryless' property which means that their next state depends only on their current state, not on the history that led them there. This makes it possible to formulate problems in a straightforward manner and to produce exact solutions.

Main applications include:

- System (re)design at an operational level
- Disease stage modelling to evaluate implications of interventions, e.g. length of stay and cost



Multiple care settings and their network

Minimum input requirements:

Time	Money	Knowledge	Data

a month	£15K	moderate	statistics

Outputs expected:

- Better understanding of system characteristics
- Estimation of implication of interventions

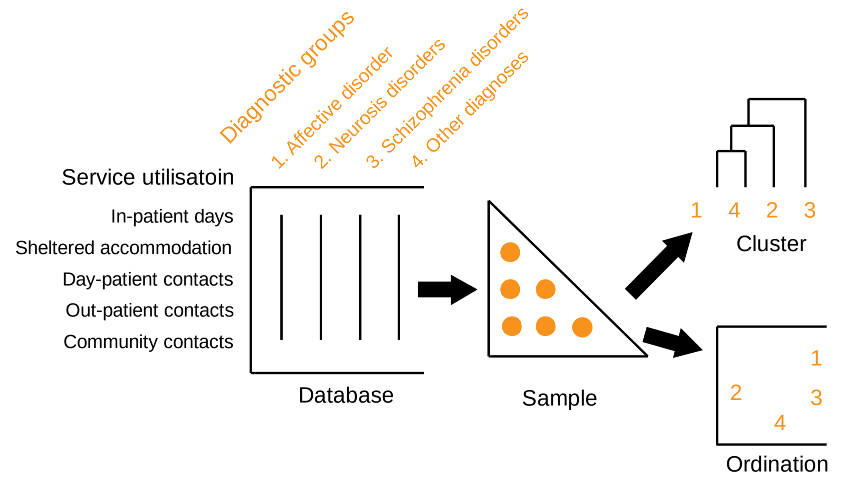
16 Multivariate Analysis

Multiple variables are analysed using a range of statistical techniques in order to reduce the complex mix of multiple variables or to understand the relationships between them.

Multivariate analysis is used to help analyse relationships between variables or to predict outcomes based on particular levels of input, using methods such as regression and ANOVA (Analysis of Variance). It is often used in systems design to investigate performance differences across a range of alternative designs. It can also be used to investigate performance variations within a single system and to support service improvements.

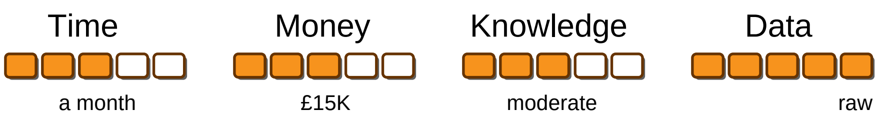
Main applications include:

- Science, engineering, medicine and commerce
- Production processes, market analysis, international tourism and healthcare



Service utilisation by diagnostic groups

Minimum input requirements:



Outputs expected:

- Better understanding of complex system variables (classification or summary information)

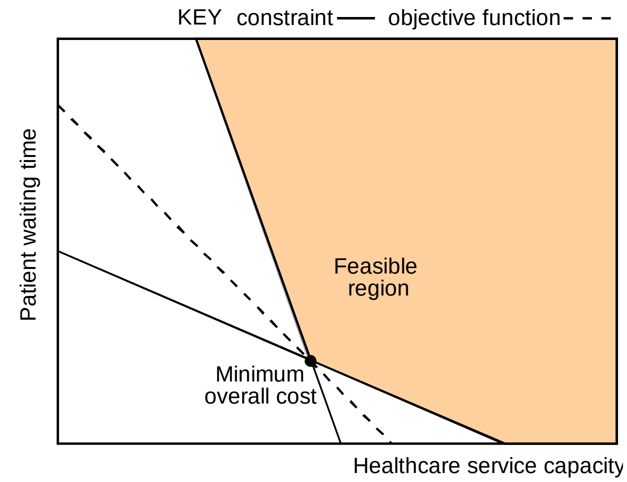
17 Optimisation Techniques

Problems are mathematically modelled using systems of equations in order to optimise some measure of performance while taking account of known constraints.

Mathematical programming, integer programming, goal programming, dynamic programming and a number of other approaches provide analytical solutions for optimisation problems. These techniques are useful where problems are mathematically well-defined, but may need a high computational demand. They require a single agreed numerical performance measure of outcome.

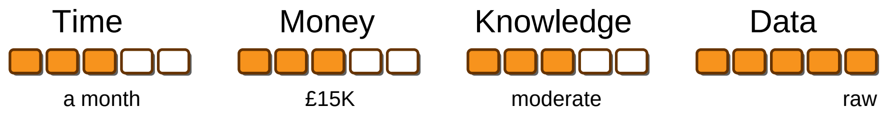
Main applications include:

- Strategic and operational-level decision making
- Hospital location decisions, operating theatre scheduling and workforce scheduling



Linear programming for cost minimisation

Minimum input requirements:



Outputs expected:

- Optimum quantitative values of various criteria, often relating to resource, constraints and costs
- Investigation of preferred courses of action

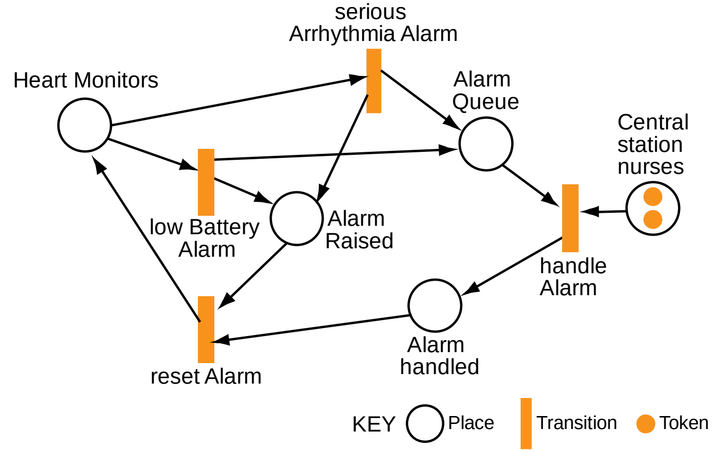
18 Petri Nets

System structures are modelled in order to estimate static and dynamic properties of the system.

Petri nets were introduced as a graphical and mathematical tool to model computer systems. They are well suited for modelling the concurrent behaviour of distributed systems such as distributed databases, banking systems, business processes and telecommunications systems. Petri nets model systems using four types of modelling elements, namely: places; transitions; arcs; and tokens (material, information and resource).

Main applications include:

- System (re)design at an operational level
- Logistics, capacity planning, production planning, supply chain management and project management



A dialysis machine monitoring system

Minimum input requirements:

Time	Money	Knowledge	Data

a month	£15K	expert	statistics

Outputs expected:

- General understanding of system behaviour

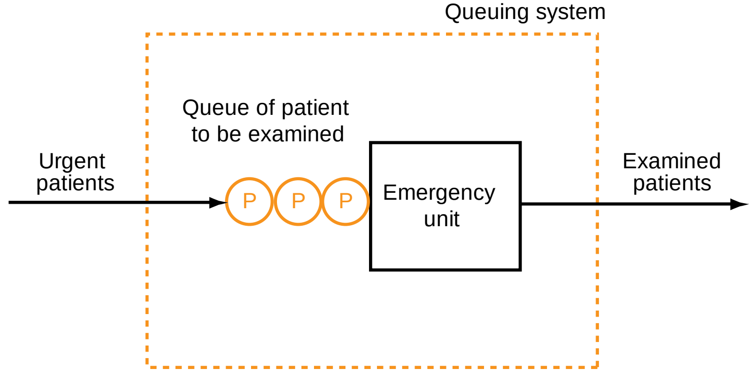
19 Queueing Theory

System performance measures associated with waiting are analysed in order to understand the relationship between congestion and delay, and thus enable service redesign.

Queueing theory is the mathematical study of queues. System characteristics, such as the average number of users, the average waiting time in the queue, and the expected number waiting or receiving service can be calculated. It is also possible to derive probabilities of the system being full or empty, of having to wait or not, and how long it takes to receive service. Knowledge of these system characteristics provides management information to help improve performance.

Main applications include:

- Telecommunications, traffic control, predicting computer performance, hospital waiting lists, airport traffic and airline ticket sales



Patient queueing for an Emergency Unit

Minimum input requirements:

Time	Money	Knowledge	Data

a week	£1500	moderate	some

Outputs expected:

- Better understanding of queues, bottleneck and resource utilisation
- Identification of optimal system operation

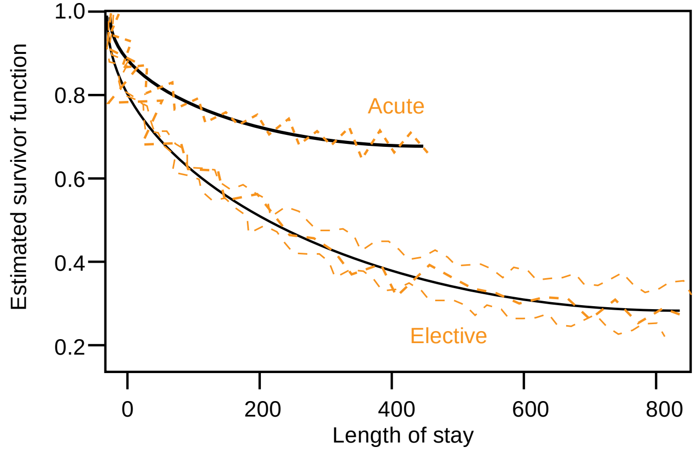
20 Survival Analysis

Death of biological organisms or failure in mechanical systems are statistically predicted in order to compare effectiveness.

Survival analysis is used to study complex relationships between events and the factors that influence those events. It can be used to determine quantitatively the impact of an input variable (e.g. a treatment) on an outcome variable (survival) which represents the time interval between events. It can be used to address questions such as how many people will survive after certain events, and how certain factors or settings increase or decrease the odds for survival.

Main applications include:

- Estimation of the effectiveness of various treatment options (survival data-based estimation with respect to covariates, e.g. gender and age)



Survival function for different patient groups

Minimum input requirements:

Time	Money	Knowledge	Data
a month	£15K	moderate	raw

Outputs expected:

- Quantitative understanding of system survival corresponding to events

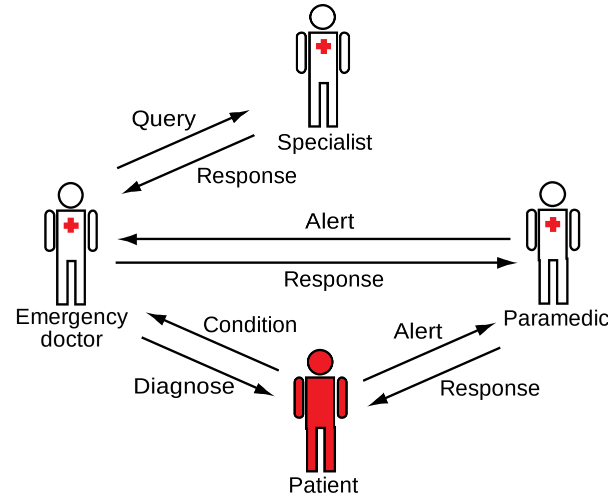
21 Agent-based Simulation

The system is modelled as a collection of autonomous decision-making entities, known as "agents", in order to explain and understand complex emergent behaviour patterns and the dynamics of the real-world system.

Each agent assesses its situation and makes decisions on the basis of a set of predefined rules. Agents execute behaviours which might be expected in the real-life system and allows the overall effect on the system to be estimated. This approach is well suited to complex problems, especially those with a large number of interactions between components.

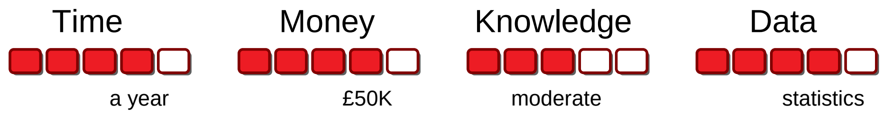
Main applications include:

- System (re)design at operational/strategic levels
- Traffic and customer flow management, stock market simulation, innovation adoption dynamics simulation or risk analysis



An interaction scenario around an emergency unit

Minimum input requirements:



Outputs expected:

- General understanding of system behaviour

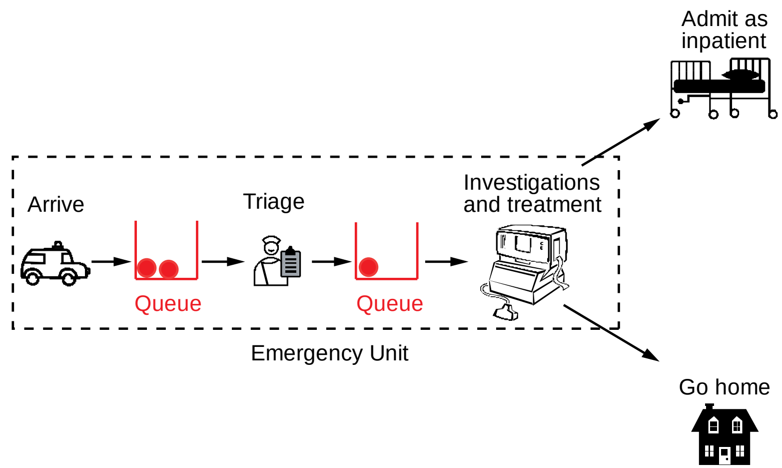
22 Discrete Event Simulation

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.

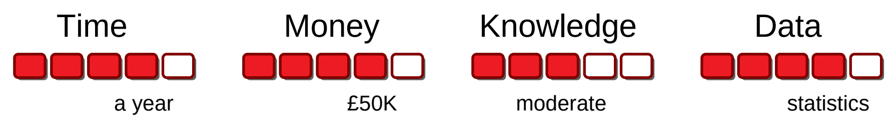
Main applications include:

- 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

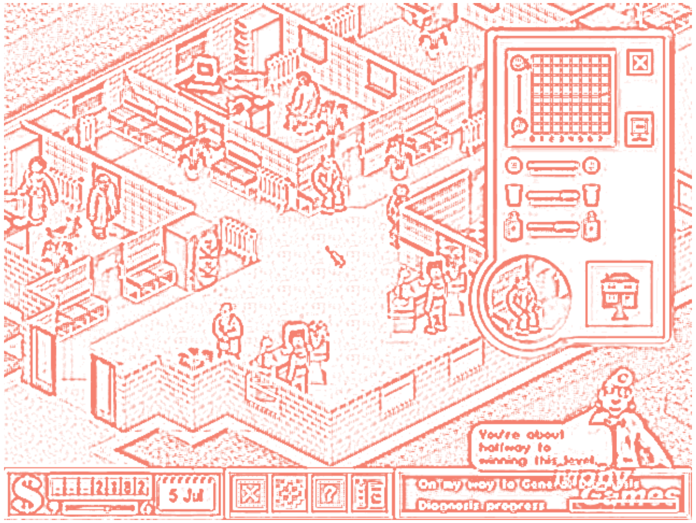
23 Gaming Simulation

A mixture of the current and hypothesised systems is analysed in the context of presumed future scenarios in order to evaluate future policies, strategies or concepts.

Interactive computer games have been used for decades in the aviation industry and the military to execute and assess the effectiveness of alternative strategies for responding to disastrous situations. Without losing actual lives, a great deal of practical experience can be gained through comparing different strategies, giving all parties clear guidance about what worked and what did not.

Main applications include:

- Preparing healthcare professionals for situations such as emergency management
- Strategic planning, policy making and operation management



Hospital management game – 'Theme Hospital'

Minimum input requirements:

Time	Money	Knowledge	Data
■■■□□	■■■□□	■■□□□	■■□□□
a month	£15K	limited	guesstimate

Outputs expected:

- Plan validation and training for new situations
- Low cost compared to the cost of using actual systems

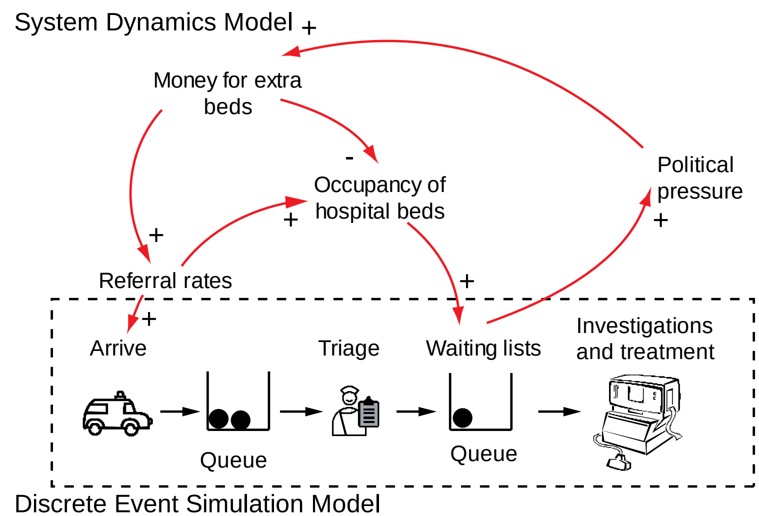
24 Hybrid Simulation

Two or more existing simulation techniques are combined in order to mitigate the drawbacks of the individual techniques.

The most common form of hybrid approach involves combining discrete and continuous time-handling approaches, for example *Discrete Event Simulation* (see page 35) and *System Dynamics (see page 57)*. Much current academic research focuses on combining two or more existing simulation methods in order to gain cumulative benefits from the individual techniques.

Main applications include:

- (Re)design of highly complicated systems at strategic/operational levels
- Production planning, supply chain management, traffic system management, and enterprise-wide decision making



Patient queueing and influencing factors

Minimum input requirements:

Time	Money	Knowledge	Data
a year	£50K	moderate	statistics

Outputs expected:

- Quantitative performance estimation of highly complicated systems in respect of qualitative measures

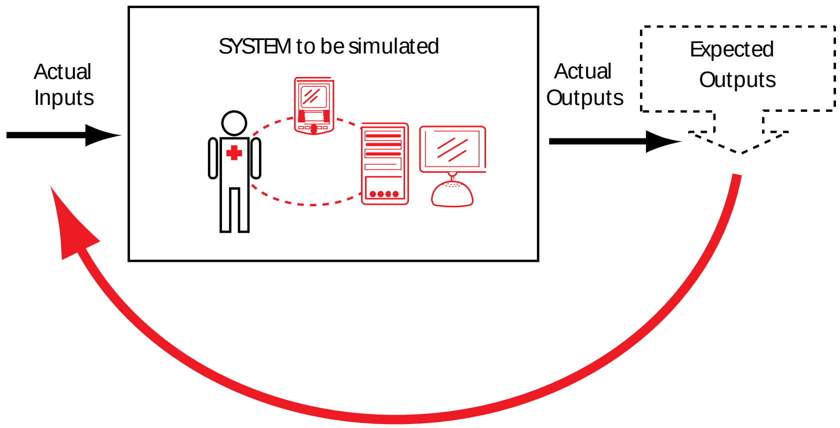
25 Inverse Simulation

The input time-history required to produce a given output time-history is calculated in order to determine the input variable from the prescribed output variable.

Inverse simulation can be used for the solution of nonlinear problems, where interest is focused upon the actions needed to achieve a particular form of output. It can also provide useful insight into the ability of a human operator to provide the control necessary to achieve a particular response. For example, it can show when a task is likely to be beyond the capabilities of an operator due to factors such as reaction times and neuromuscular lags.

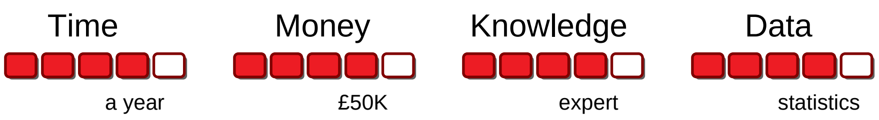
Main applications include:

- Aircraft flight control and pilot workload simulation
- Bed management and scheduling systems



Estimation of required human capability

Minimum input requirements:



Outputs expected:

- General understanding of operators' ability and corresponding system requirements

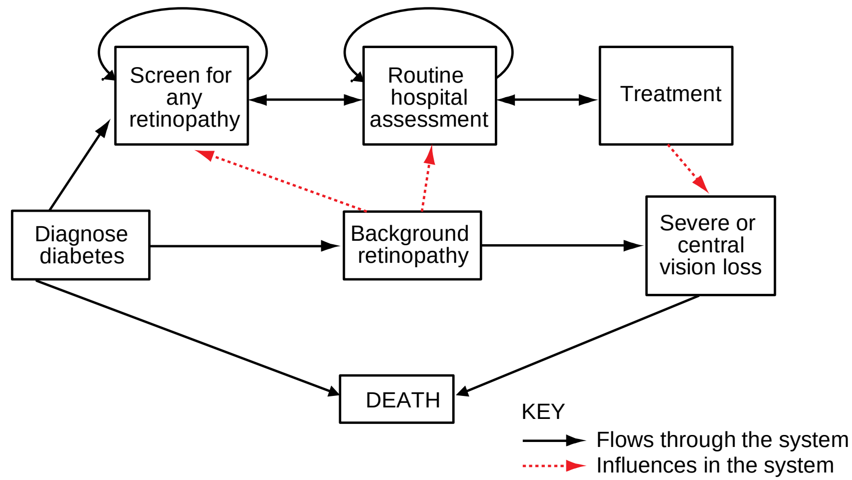
26 Monte Carlo Simulation

Systems are simulated using random or pseudo-random numbers in order to tackle mathematical problems which cannot be solved exactly by the use of analytical techniques or mathematical equations.

For example, patient progression through the stages of a disease like cancer can be modelled by randomly sampling the time each individual spends in a given state. This can be done in a spreadsheet with the use of add-ins such as *Crystal Ball* or *@Risk*. The effects of treatment can then be evaluated.

Main applications include:

- System (re)design at an operational level
- Disease stage modelling to evaluate implications of interventions, e.g. length of stay in various scenarios and transition times between stages



Screening for diabetic retinopathy

Minimum input requirements:

Time	Money	Knowledge	Data
a month	£50K	moderate	raw

Outputs expected:

- Better understanding of system characteristics
- Estimation of implication of interventions

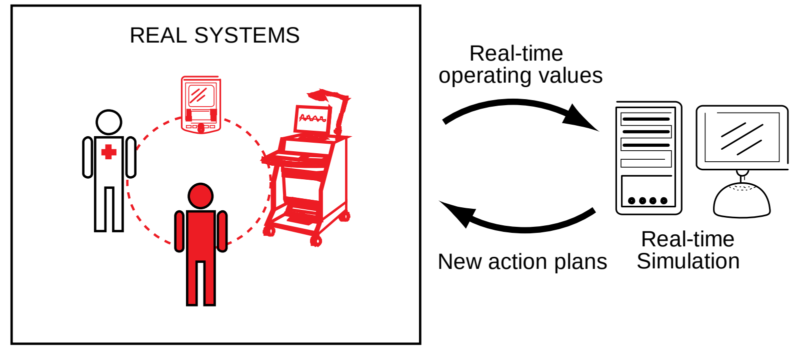
27 Real-time Simulation

System behaviour is predicted in response to operator actions and events via the use of real-time data.

Real-Time simulation is a powerful analytical tool that uniquely allows for the simulation of a sequence-of-operation using real-time data. It is well suited for identifying potential operating problems and their causes, virtually testing operator's actions and preventing system interruptions. The computational demands are high as this technique operates in real-time and in a distributed manner.

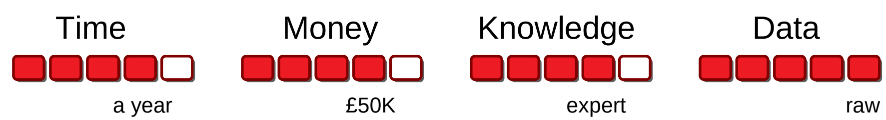
Main applications include:

- Real-time tactical planning and training
- Management or training for operation theatres and emergency unit



Real-time hospital planning

Minimum input requirements:



Outputs expected:

- Real-time understanding of actual scenarios and situations

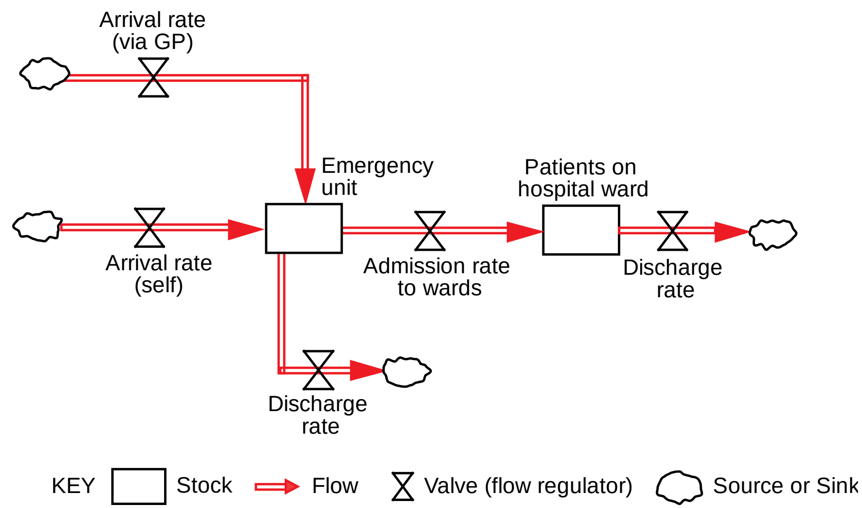
28 System Dynamics

Complex systems are modelled using causal-loop diagrams and stock flow diagrams in order to explore their dynamic behaviour.

System dynamics can be applied to any dynamic system to simulate its behaviour in a macroscopic, holistic way. For example, enabling more rapid discharge for patients from hospitals might increase the demand for social and community care. System dynamics allow the influences of one variable change on others to be identified, measured, tested as relevant, and anticipated in any given solution package.

Main applications include:

- System (re)design at policy and strategic levels
- Corporate strategy, disease dynamics, ecological and environmental issue simulation



A stock flow diagram for an emergency unit

Minimum input requirements:

Time	Money	Knowledge	Data
a month	£50K	moderate	guesstimate

Outputs expected:

- General understanding of system behaviour

Further Reading

1 Drama Theory & Confrontation Analysis

- Bennett P, Bryant J, Howard N (2001) Drama Theory and Confrontation Analysis. In Rosenhead J and Mingers J (eds.), Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict (2nd Ed.). John Wiley & Sons Ltd., pp. 225-248
- Bryant J (2006) Drama theory: dispelling the myths. Journal of Operational Research Society, **58**: pp. 602-613

2 Robustness Analysis

- Rosenhead J (2001) Robustness analysis: Keeping Your Options Open. In Rosenhead J and Mingers J (eds.) Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict (2nd Ed.). John Wiley & Sons Ltd., pp. 181-208

3 Soft Systems Methodology (SSM)

- Checkland PB (1999) Systems Thinking, Systems Practice: includes a 30-year retrospective. John Wiley and Sons Ltd.
- Rosenhead J, Mingers J (2001) Rational analysis for a problematic world revisited : problem structuring methods for complexity, uncertainty and conflict. John Wiley & Sons Ltd.

4 Strategic Choice Approach (SCA)

- Checkland PB (1999) Systems Thinking, Systems Practice: includes a 30-year retrospective. John Wiley & Sons Ltd.
- Rosenhead J, Mingers J (2001) Rational analysis for a problematic world revisited : problem structuring methods for complexity, uncertainty and conflict. John Wiley & Sons Ltd.

Further Reading

5 Strategic Options Development and Analysis (SODA)

- Eden C, Ackermann F (2001) SODA – The Principles. In Rosenhead J and Mingers J (eds.) Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict (2nd Ed.). John Wiley & Sons Ltd., pp.21-42

6 Activity Diagrams

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- Audit Scotland (2000) The map to success: using process mapping to improve performance. Accounts Commission, Edinburgh, UK. http://www.audit-scotland.gov.uk/docs/local/2000/nr_010201_process_mapping.pdf (Accessed October 2008)

7 Communication Diagrams

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8 Data Flow Diagrams

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- Ward PT, Mellor SJ (1985) Structured Development for Real Time Systems: Introduction and Tools. Prentice Hall
- Ward PT, Mellor SJ (1986) Structured Development for Real Time Systems: Essential Modelling Techniques. Prentice Hall
- Ward PT, Mellor SJ (1986) Structured Development for Real Time Systems: Implementation Modelling Technique. Prentice Hall

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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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