Report for the National Institute of Health and Clinical Excellence - Clinical Guidelines Technical Support Unit

Interim methods guide for developing service guidance 2013 – Appendix 2: Service Delivery Operational Research Methods Reference

The role of operational research in cost-effectiveness analysis of service delivery interventions in healthcare

Contents:- *page*

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Appendix 2: Service Delivery Operational Research Methods Reference

EXECUTIVE SUMMARY

This report outlines the role and position of Operational Research (OR) in the development of NICE (National Institute for Health and Clinical Excellence) guidance for the cost-effectiveness analysis of service delivery interventions in healthcare.

OR represents a wide diversity of methods and has an established history of application in health services although many research outputs have not been implemented in practice. 'Soft' OR methods deal with the conceptualisation of systems and are often qualitative in nature, in contrast, 'hard' OR embodies more quantitative approaches which are mathematically based. A broad classification of OR methods is given which divides methods into the following categories: Problem Structuring Methods and Conceptual Modelling, Mathematical Approaches and Optimisation, and Simulation.

As NICE extends its role in assessing service delivery, OR practitioners are likely to have a central role in both developing guidance for the cost-effectiveness evaluation of such interventions and also in delivering these evaluations. Collaboration between healthcare OR specialists and health economists and statisticians will need to be fostered. In general, it is important to acknowledge the considerable challenges which are raised in this context.

The report concludes with a series of recommendations and observations by the author which highlight key issues in the area. These are classified under the following headings: the need for classification and segmentation, careful definition and scoping of issues, addressing the diversity of context in service delivery, the need for evolution and expectation management, presentational issues, the standards/flexibility trade-off, specification of inputs and outputs, and an interdisciplinary and multi-faceted approach.

INTRODUCTION (SCOPE AND PURPOSE)

The broad purpose of this short report is to outline the position and potential role of Operational Research (OR) within the general context of the requirement within NICE to develop guidance for cost-effectiveness evaluation of service delivery interventions in health care.

Since this report is designed to be read by those not expert in the domain of OR, an introduction to the field is given, as well as a summary outline of the various methods that it encompasses. Whilst a detailed account of these methods is well beyond the scope of this report, references are given to sources for more in-depth information about specific techniques.

The outline analysis of the range of OR methods shows how they can and have been applied in the health domain, along with an assessment of the relative strengths and weaknesses of each approach and the resource implications for adopting each. The specific relevance of each approach to cost-effectiveness analysis is also tentatively provided.

A key aspect of this report is to position OR relative to other disciplines such as health economics and statistics within the context of cost-effectiveness modelling for health care service delivery. It seems clear that all these disciplines (and others) will be required to address the challenging issues raised in this area.

Within the discussion section of the report, the author highlights a number of areas which seem important within the context of the report. These are necessarily based on the personal perspective of the author, and are included in order to raise awareness of issues which he believes to be central to this enterprise.

CONTEXTUAL BACKGROUND

Operational Research (OR) embodies a wide range of techniques which have been applied across a large number of domains. It is therefore best considered as an 'umbrella term' representing a wide diversity of approaches and applications. As a systematic approach OR has its roots in military and manufacturing sectors where it has been deployed extensively, often as a critical component of project planning and product development [1].

In the service sector, OR is a more recent addition but has a fast and growing level of interest and application[2]. In the health sector specifically, OR has been used across a wide field of application areas and at many different levels of decision making. Although its use in healthcare dates back to 1965 [3], the vast majority of research and development in this field has occurred over the last two decades [4-6]. One recurring theme in healthcare modelling has been the failure of many research outputs and innovations to achieve implementation in health practice [7]. This limitation has begun to be addressed through a number or recent initiatives such as MASHnet [8], PenCHORD [9] and the Cumberland Initiative [10]. A range of examples of modelling approaches with demonstrable impact on health service delivery can be found on the websites on these organisations and a selection is presented in Appendix B of this report.

TAXONOMY OF METHODS

The most fundamental distinction made when referring to OR generally is between so-called 'hard' and 'soft' methods, and much has been said about their relative virtues.[1] Broadly speaking 'hard OR' refers to mathematical and numerical models based in quantitative analysis. In contrast, 'Soft OR' commonly embodies a substantial qualitative element and is more focused on conceptualizing and visualizing systems in order to define key issues of concern. Both these facets of OR are important when considering the relevance of OR to service delivery intervention. It should also be stressed that hard and soft OR approaches can be combined, and indeed commonly complement one another within research projects.

There have been several attempts to classify operational research methods as deployed within healthcare. Brennan et al [11], for instance, provide a taxonomy based on the distinctions between individual and cohort based models for economic analysis and whether such models are required to capture interactions between elements. The RIGHT Project [12], analyses methods according to the following four categories: Problem structuring methods, Conceptual Modelling, Mathematical Modelling, and Simulation. Within these categories, twenty-eight separate techniques are listed, and for each of these the analysis outlines specific areas of application, level of expertise, time and resources likely to be required when deploying the technique. This provides an interesting breakdown of OR techniques, but arguably it over simplifies the field and relies upon the single dimension of method type as a basis for its classification. OR methods are often used in combination to address a particular issue at hand, and a more elaborate categorisation of OR in healthcare can be found in Brailsford et al [6] which analyses a sample of the research literature in healthcare modelling, using a multi-dimensional basis for classification according to health application area, level of implantation (e.g. strategic vs. operational), and method (or methods) deployed for a particular project.

Appendix 2: Service Delivery Operational Research Methods Reference

For the purposes of this short report, we provide a categorisation in Table 1 below which outlines a range of the most commonly applied methods in healthcare OR, giving key references and typical areas of application. A more detailed analysis is provided in Appendix A, which additionally lists some of the strengths and weaknesses commonly attributed to each technique.

Table 1: Summary taxonomy of OR along with popular sub-areas and key reading

Problem Structuring Methods and Conceptual Modelling		
Example Technique	***Typical Areas of Application in Health***	***References***
Soft Systems Methodology (SSM)	• Performance Improvement • Outpatient Service Modelling • Determining study objectives	[13-15]
Strategic Options and Decision Analysis (SODA)	• Healthcare / Tele-health systems design	[15]
Strategic Choice Analysis	• Strategic employment relations	[15]
Validation	• Measuring patient / staff satisfaction • Measuring validity of trials	[16]
Mathematical Approaches and Optimisation		
Example Technique	***Typical Areas of Application in Health***	***References***
Mathematical Programming	• Resource allocation • Measuring performance / efficiency	[17]
Data Envelopment Analysis	• Measuring performance / efficiency • Assessing quality and patient satisfaction	[18, 19]
Meta-heuristics	• Scheduling • Staffing	[20, 21]
Vehicle Routing	• Dispatch and routing of emergency vehicles	[22]
Scheduling	• Theatre scheduling • Outpatient appointment scheduling	[20, 21]
Location Analysis / Facility Location	• Ambulance location analysis • Hospital / clinic placement	[23-25]
Queuing Theory	• Waiting time / utilisation analysis • System / Pathway Design • Appointment systems	[1, 26]
Simulation		
Example Technique	***Typical Areas of Application in Health***	***References***

Appendix 2: Service Delivery Operational Research Methods Reference

Discrete Event Simulation	• Redesign of clinical pathways • Visualising existing pathways • Waiting list and scheduling issues • Modelling impact on bed usage	[27-30]
System Dynamics	• Predicting impact of local system changes on wider health & social care systems • Identifying areas for policy focus • High-level systems thinking	[31-35]
Agent Based Simulation	• Modelling disease spread • Modelling uptake of interventions / technology • Disease screening modelling	[36]
Monte Carlo simulation	• Demand estimation • Disease transmission • Disease screening modelling	[37, 38]

POSITIONING OR

The extension of NICE evaluation to the area of service delivery will inevitably require the inclusion of operational researchers at various levels and in various capacities. OR practitioners have, over time, built up a considerable understanding of how to model service delivery in the health service, and this understanding will be crucial when extending the scope of analysis of cost-effectiveness. Despite this, the integration of cost elements within OR models of health is not a well-developed science, and there is still much work to do in terms of building links with other disciplines to create the necessary infra-structure for NICE-style evaluations. In particular, the collaboration between health economists and OR health modellers is of particular importance here. There is some evidence in recent years of an increasing convergence between these disciplines [39], but still much remains to be achieved. Nonetheless, attempts have been made to integrate aspects of each of these disciplines for cost-effectiveness evaluation for service delivery intervention [40]. Networks such as MASHnet - the UK Modelling and Simulation Healthcare Network [8] and The Cumberland Initiative [10] - may also play an important role in promoting greater collaboration between OR and health economics.

Within the context of the development of NICE guidance in this area, a clear need will be to determine the position of OR skills, and identify the level at which OR experts should feed into the process. Many OR techniques require moderate levels of training, but there is a good existing library of framework software which can allow non-expert users to build OR models with more limited training. Nevertheless, it might be important to develop hybrid skills which embody an understanding of both current OR practice as well as health economic skills.

DISCUSSION AND RECOMMENDATIONS

In this section a series of issues regarded by the author as central to the development of a viable system of cost-effectiveness of service delivery are outlined under sub-headings. This list is necessarily subjective and does not claim to be exhaustive, but hopefully is instructive in highlighting some of the key challenges.

The need for classification and segmentation

As already discussed, OR is a very broad field which embodies many approaches. Different OR techniques are suited to different areas of application in the health services and are relevant to different levels of application (e.g. strategic, operational, tactical).

As such, it is highly unlikely that a 'one-size fits all' approach will adequately address the requirement to develop cost-effectiveness analyses across the board for service delivery interventions in health. Rather, it is more likely that specific problems will require specific techniques (or a combination of techniques). The matching of intervention type to appropriate method will need to be addressed when developing NICE guidance and proper scoping of service delivery assessments will need to be considered carefully to ensure proper identification of the most appropriate OR tools.

In order to achieve this, it would be prudent to ensure that service type interventions are appropriately classified. An example of such a classification is given in the CG TSU paper by Tony Ades [41], which may provide a useful starting point for further discussion in the development of a taxonomy of interventions. This divides service delivery interventions into the four categories of: efficacy of early vs deferred treatment, uptake of interventions, organisation/integration of care, and increasing the availability of care.

Potentially, a clear and consistent classification framework could lead to the delineation of appropriate OR (and other) techniques for analysing the cost effectiveness impact for a range of service delivery interventions, as well as offering an indication of the data requirement and the way in which the outputs of such analyses could be presented (accounting for the importance of context variation etc). Such a framework could form an essential cornerstone for developing general guidance in this area.

Appendix 2: Service Delivery Operational Research Methods Reference

Careful definition and scoping of issues

As stressed above, proper classification and scoping of issues for NICE service delivery assessments is likely to be crucial. Given the challenges involved, this process will need to be carefully defined within the guidance and given the emphasis which it requires. Although this needs to be considered extensively, scoping could potentially encompass key elements of the process such as classification of intervention type (as discussed above), identification of appropriate approaches, identification of necessary data sources as well as the skills and resources needed and specification of outputs.

Addressing the diversity of context in service delivery

A commonly cited issue with regard to service delivery in health services is the wide range of different contexts under which implantation can occur. This issue relates closely to the central tension often seen in health care modelling projects between the need for generic approaches (to enable general and consistent policy guidance to be advanced) and specific solutions (which are able to take account of context, and hence be more flexible and directly relevant to the specific circumstances of implementation).

It is likely that the outputs from a service delivery intervention assessment will need to account for the diversity of implementation context within its specific recommendations. This implies that recommendations may need to be nuanced, much in the way that current NICE clinical guidance commonly distinguishes between different sub-groups of patients when assessing costs and benefits.

The need for evolution and expectation management

The rigorous and systematic use of cost-effectiveness analysis for health service delivery intervention, as envisaged by NICE, is an emerging field with much still to be defined. Experience suggests that best practice in this field will need to develop over time. Clearly, initial processes will need to be designed, discussed, proposed and trialed, but effective guidance will rely upon time and experience of use before becoming fully fit for purpose. As such, it would be sensible to take an historical perspective about the way in which NICE guidance for clinical technology assessments has been developed over time. Against this background, it is important that the constraints are fully appreciated and expectations of the key stakeholders involved in the process are managed.

Presentational issues

The methods used to communicate outputs from analytical studies to policy stakeholders is a critically and often neglected area in research [42]. Within clinically based HTA, for example, certain basic graphical tools such as the Forest Plot in meta-analysis and the Cost-Effectiveness Acceptability Curve (CEAC) in economic analysis have become essential aspects of communication in the NICE appraisal committee process. Likewise, within service delivery assessment, presentational tools will need to form a key part of communicating central aspects of cost-effectiveness analysis to stakeholders. Communication and presentation of outputs will need to be thoroughly considered from the outset of guidance development in order that such outputs can be specified within the developed guidance.

The standards/flexibility trade-off

The requirement to develop general guidance on the national level for service delivery interventions is clearly an important aspiration, bringing with it potential benefits of a clearly articulated and standardised process that can be specified and monitored for all participants in the assessment exercise. However, there is an inevitable diversity of need both in terms of the different modelling approaches required for different types of service delivery intervention, and the diversity of contexts in which these interventions can be applied. A rigid and over-standardised specification of guidance could easily hide-bound the modelling process and limit necessary flexibility. How to 'square this circle' is a particular challenge that should not be underestimated in the context of NICE's aspirations, and will require careful consideration as guidance is developed in this area.

Specification of inputs and outputs

Unlike cost-effectiveness models for clinical interventions there is as yet no established hierarchy of evidence for service delivery modelling. In addition, randomised-controlled trial evidence is rarely (if ever) found for service delivery comparisons. It will therefore be essential to establish a clear framework to structure data for cost-effectiveness analysis of service delivery interventions in health. Considerable research effort is likely to be required to specify the appropriateness and validity of data sources, as well as the uncertainty associated with input parameters [43], to create a viable evidence base for economic modelling in this field.

Likewise clear guidance will be necessary to specify the model outputs from the analysis of service delivery comparisons. Specifically, it will be important to determine whether cost per QALY metrics will be required and/or possible. Clearly for allocative efficiency to be fully addressed within a strategic health policy context, outputs of this nature may be essential and it should be noted that some limited attempts have been made to derive such outputs [40]. However, in general, the task of deriving cost per QALY metrics from service delivery models may not be feasible especially given the diversity of contexts in which such interventions can be applied.

Appendix 2: Service Delivery Operational Research Methods Reference

An interdisciplinary and multi-faceted approach

It is clear that to properly satisfy the objectives of cost-effectiveness for health service delivery, an inter-disciplinary approach will be essential. This report focuses on the specific requirements within operational research. However, other disciplines such as health economics and statistics will inevitably need to engage with this challenge. More specifically it will be essential that those with expertise in health technology assessment, as previous practised in the clinical and public health domains, bring their expertise and experience to bear in this context. It is important to appreciate the multifaceted nature of the many processes involved in the policy making context of HTA. It is therefore essential that people with an understanding of the substantive process issues as well as the challenging research issues raised in this domain are engaged with the process of guidance development.

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Appendix 2: Service Delivery Operational Research Methods Reference

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Appendix A: Taxonomy of methods

Conceptual Modelling and Problem Structuring Methods

Technique	**Soft Systems Methodology (SSM)**	**References**	[13, 15, 44]
Summary	SSM compares different stakeholder's perspectives of a system to build up a picture of key relationships and interactions to assist understanding. It lends itself to complex systems and 'messy' problems where there may be no consensual agreement and values may differ between individuals. Tools such as 'Rich Pictures' are used in the early stages of SSM to systematically and iteratively work towards an understanding of system characteristics.		
Strengths	• Can be used in a highly structured manner or elements of the approach can be selected and combined with bespoke approaches to problem structuring; • Designed to work with multiple problem stakeholders; • Application in a wide variety of domains • Provides a highly structured problem to feed into more quantitative modelling • Can help stakeholders reach a decision on action without the need for quantitative modelling • Provides structured approaches to describing systems e.g. C.A.T.W.O.E		
Weaknesses	• Modeller skills are different from traditional skills used for quantitative modelling. • Inexperienced modellers need to be cautious of purely relativist thinking; • Validation of qualitative models is complex;		
Appropriate application areas	• Performance Improvement • Outpatient Service Modelling • Determining study objectives		
Resource requirements	• Facilitation skills: large workshops and small groups • Interview training/experience • Building recognisable qualitative models of stakeholder perceptions; • As with other PSMs modellers must be aware of their own role and influence in the decision making process; as such, skill is needed in the choice and justification of using SSM and engagement with appropriate stakeholder groups; • As with other PSMs modellers should consider working with a more experienced SSM practitioner to learn to successfully conduct action research.		

Appendix 2: Service Delivery Operational Research Methods Reference

Technique	**Strategic Options Development & Analysis (SODA)**	**References**	[15]
Summary	SODA uses cognitive maps to aggregate and identify clusters of key issues and hierarchically organise necessary actions. Each user's perspective is integrated into a unified model of the system or problem being addressed. This allows interconnected issues to be highlighted and facilitates discussion and negotiation around strategic options.		
Strengths	• Aids decision making at the strategic level; • Initial workshop used to identify issues of strategic importance to organisations; • Makes extensive use of cognitive mapping to build a groups view of a system • Highly successful at structuring group decision making processes • Software available to aid live cognitive mapping (Banxia Decision Explorer and Banxia Group Explorer) • Approaches attempts to minimise *group think*, encourages input from all stakeholders; • Establishes and prioritises options for action;		
Weaknesses	• Modeller skills are different from traditional skills used for quantitative modelling. • Inexperienced modellers need to be cautious of purely relativist thinking;		
Appropriate application areas	• Performance Improvement • Outpatient Service Modelling • Determining study objectives		
Resource requirements	• Facilitation skills: large workshops and small groups • Interview training/experience • As with other PSMs modellers must be aware of their own role and influence in the decision making process; as such, skill is needed in the choice and justification of using SODA and engagement with appropriate stakeholder groups; • As with other PSMs modellers should consider working with a more experienced SSM practitioner to learn to successfully conduct action research.		

Appendix 2: Service Delivery Operational Research Methods Reference

Technique	**Strategic Choice Analysis (SCA)**	**References**	[15]
Summary	SCA allows users to define a problem area, identify and compare plausible solutions, and then select solutions based on defined criteria. It uses a range of interactive and visual tools to present the interconnectedness of a system and display issues of uncertainty, environmental influences and values.		
Strengths	• Clearly defined stages of problems structuring: • Builds understanding of system and linkages • Identifies feasible changes within a system • Addresses sources of uncertainty in decision process		
Weaknesses	• Largely qualitative approach which lacks clear metrics as outputs • May need to be combined with other methods to give more precise results		
Appropriate application areas	• Strategic Planning and decision making • Inter-organisational issues		
Resource requirements	• Facilitation skills: large workshops and small groups • Interview training/experience • As with other PSMs modellers must be aware of their own role and influence in the decision making process; as such, skill is needed in the choice and justification of using SODA and engagement with appropriate stakeholder groups; • As with other PSMs modellers should consider working with a more experienced SSM practitioner to learn to successfully conduct action research.		

Appendix 2: Service Delivery Operational Research Methods Reference

Optimisation and Mathematical Approaches

Technique	Meta-heuristic search	References	[20, 21]
Summary	In general terms an optimisation problem involves maximising or minimising an objective function by choosing inputs from a range of values subject to a number of constraints. The more complex the optimisation problem the more likely solution will involve a heuristic search technique as opposed to mathematical. Meta-heuristics provide a general purpose algorithm to guide the search for good solutions that approach optimality. Examples include local search approaches, such as steepest decent or simulated annealing, and evolutionary algorithms that breed and mutate good solutions in order to find optimal solutions.		
Strengths	• Provide near optimal solutions to optimisation problems that cannot be solved by a computer within polynomial time. • General search approaches that can be applied to multiple optimisation problems. • Several algorithms e.g. simulated annealing, ant colony optimisation and Genetic algorithms are based on physical and natural processes and have intuitive explanations.		
Weaknesses	• In some circumstances it may be simpler to develop a bespoke heuristic approach; • Knowledge of programming and algorithm analysis required;		

Appropriate application areas	• Scheduling
	  o E.g. Allocation of patient to nurses for home visits
	  o E.g. Outpatient clinic appointments
	  o E.g. vehicle routing of home visit
	• Location Analysis / Facility Location		

Resource requirements	• Algorithm analysis skills (determining execution time and storage requirements) • Programming and software engineering skills • Advantageous to have knowledge of mathematical approaches to optimisation.		

Appendix 2: Service Delivery Operational Research Methods Reference

<table>
<tr><td>Technique</td><td>Mathematical programming</td><td>References</td><td>[17]</td></tr>
<tr><td>Summary</td><td colspan="3">Optimisation involves maximising or minimising an objective function by choosing inputs from a range of values subject to a number of constraints. A well-known mathematical approach to optimisation taught on most quantitative undergraduate courses is linear programming where the objective function and constraints all take a linear form. More complex problems include integer or mixed-integer programming (some or all variables must take integer values), non-linear optimisation, stochastic programming and robust optimisation.</td></tr>
<tr><td>Strengths</td><td colspan="3">• Problems are clearly formulated as a system of equations in order to optimise some measure of performance while taking account of known constraints
• Wide range of techniques: linear programming, integer programming, non-linear programming, dynamic programming, data envelopment analysis (DEA), stochastic programming and robust optimisation;
• Linear programming, in particular, is simple to understand;
• Where the distributions of parameter can be estimated, parameter uncertainty can be tackled through stochastic programming;</td></tr>
<tr><td>Weaknesses</td><td colspan="3">• Mathematical programming techniques are only useful when problem is well-defined;
• Strong mathematical skills required for stochastic programming.</td></tr>
<tr><td>Appropriate application areas</td><td colspan="3">• Scheduling
    o E.g. Allocation of patient to nurses for home visits
    o E.g. Outpatient clinic appointments
    o E.g. vehicle routing of home visit
• Location Analysis / Facility Location
    o E.g. hospital location;
    o E.g. Placement, number and size of outpatients clinics in the community;
    o E.g. Theatre scheduling
• Comparison of unit (e.g. hospital) productivity and efficiency (e.g. by DEA).</td></tr>
<tr><td>Resource requirements</td><td colspan="3">• Knowledge of mathematical programming software (e.g. xpress MP)
• Strong mathematical skills;</td></tr>
</table>

Appendix 2: Service Delivery Operational Research Methods Reference

Computer Simulation Methods

Technique	Discrete Event Simulation (DES)	References	[27, 28, 45]
Summary	DES is typically used to evaluate competing options for improvement to systems or identify interventions that may improve performance. For example, within healthcare simulation may be used to evaluate the impact of alternative staff schedules on the four hour wait in an emergency room. DES is a suitable tool when a substantial stochastic and queuing element is involved in the problem and hence is related to queuing theory. Application areas within healthcare tend to be more focused on individual units such as outpatient clinics, operating theatres and emergency departments		
Strengths	• Ability to express as queuing system, which is relevant for a number of healthcare systems • Facilitates easier dissemination of model processes to non-modellers • Able to easily accommodate variability and fluctuations in demand • Can compare scenarios easily • Easily able to identify system bottlenecks		
Weaknesses	• Not relevant for some systems to be expressed as queuing systems; workarounds to this can be clumsy • Requires framework software, or programming expertise • Unable to express processes that run in parallel easily (e.g. patients' simultaneous disease progression and appointment attendance) • Difficult to express interactions between individuals within the system, and individual behaviours and motivations • Tendency for models to quickly become very detailed. This provides a substantial validation and testing effort compared to a less detailed analytical or optimisation model • Complex models can have substantial runtimes that will need to be overcome by IT solutions (such as grid computing) or analysis methodology (such as meta-modelling or bootstrapping).		
Appropriate application areas	• Clinical pathway redesign and analysis • Visualisation of existing clinical pathways • Exploring waiting list reduction interventions • Modelling impact on bed occupancy • Whole hospital simulation		
Resource requirements	• Expertise in DES framework software such as Simul8, Witness or Arena and Scenario Analysis can allow non-experts to produce Discrete Event Simulations with moderate training; • However, most models will require some programming and automated support for rigorous analysis is limited • It is advisable for users to have an understanding of the event and time processing mechanisms, simulation output analysis methodology, programming and statistical analysis. • Conceptual or maths expertise in queuing theory is advantageous;		

Appendix 2: Service Delivery Operational Research Methods Reference

Technique	**System Dynamics (SD)**	**References**	[31-35]
Summary	SD conceptualises a system as a series of feedback loops and delays that influence system behaviour over time. These loops may, for example, involve passing of information, patient flows, resource levels, disease progression or inventory levels. Time progression in SD is “continuous” and operates by discrete time-slicing (equally size time intervals). Output from models is deterministic in the sense that it is the long term behaviour of the system that is studied as opposed to the short term stochastic fluctuations. SD models are typically represented using causal loop diagrams[31] that illustrate the effect and polarity of influence that variables have within a system have on each other (these may be used as a PSM in the early stages of the work). Within healthcare SD is well suited to modelling “systems of care” incorporating differing healthcare organisations and their effect on each other.		
Strengths	• Focus on long term system performance due to feedback and delays in information/patients/processes/inventory • Can capture how processes in, outputs from, and potential improvements in systems can impact other systems • Can identify potential qualitative effects without quantitative data, as long as relationships between system components are adequately understood and captured • Models can be built very quickly using framework software • Models are easily understood by non-modellers • Very low computational overheads • Can easily capture flows through a system		
Weaknesses	• Not designed to represent lower-level detailed processes within a system • Deterministic by default; more difficult to incorporate variability • Requires framework software to build SD models		
Appropriate application areas	• Predicting the impact of changes in one part of the system (e.g. pathway redesign in hospital department) on system as a whole (whole hospital, health and social care system) • Helping to focus on particular aspects of a system that could bring about most impact • Larger-scale policy decision making (e.g. regional commissioner decision-making)		
Resource requirements	• Moderate training overheads to build System Dynamics models • Rapid model development achievable with framework software • Rapid results due to low computational overheads		

Appendix 2: Service Delivery Operational Research Methods Reference

Technique	**Agent-Based Simulation (ABS)**	**References**	[36]
Summary	ABS conceptualises a problem as an environment made up of interacting agents. Agents may, for example, represent patients, healthcare professionals or healthcare organisations with a series of defined attributes (for example a patient may have attributes for age, sex, history of smoking, hypertension and stage of disease progression) and interactions rules (for example, a patient scheduler may seek to prioritise screening patients who are high risk of developing a disease). Due to these interaction rules ABS is often thought to be a bottom up modelling approach where the behaviour of the overall system emerges as a result of the interacting agents. Potential application areas in healthcare may be the spreading of diseases, such as MRSA, throughout a hospital due to the interactions of staff and infected patients.		
Strengths	• Can explicitly model individuals within a system, complete with their own individual behaviours and motivations • Can capture the dynamics of how individuals within a system interact with each other, both explicitly and implicitly • Can offer confidence to clinicians about the validity of the model, as these stakeholders typically think in a patient-centric way • Can simultaneously simulate parallel processes for individuals within a system (e.g. disease progression and screening appointment attendance)		
Weaknesses	• Very high computational overheads – even moderately complex models can take a long time to run • Building models, even with the assistance of framework software, requires at least a moderate amount of programming expertise • Can be difficult to get larger-scale system processes to 'emerge' unless all non-trivial influencing low level factors are captured • Despite a strong uptake in the biological sciences (to model ecological systems), uptake in operational research has been slow and limited to a narrow subset of application areas. This may in part arise from misunderstandings about the similarities between Agent-Based Simulation and more traditional Discrete Event Simulation approaches		
Appropriate application areas	• Disease spread modelling (e.g. flu epidemic) • Intervention uptake modelling • Screening simulation (combination of screening and disease progression)		
Resource requirements	• Significant expertise needed to build models; particularly in the level of complexity that is appropriate for the problem. • Slow model development due to detailed intricacies • Very slow results due to high computational overheads		

Appendix 2: Service Delivery Operational Research Methods Reference

<table>
<tr><td>Technique</td><td>Monte Carlo Simulation</td><td>References</td><td>[37, 38]</td></tr>
<tr><td>Summary</td><td colspan="3">In Monte-Carlo simulation systems are typically represented using random numbers (or pseudo-random numbers) to sample from representative distributions to model system variability. In a patient pathway model, for instance, random sampling can be used to represent progression from one disease state to another. Monte-Carlo simulation is often combine with Markov Chain models in the so-called MCMC framework to model alternative care pathways or treatment options. This approach is commonly used in health technology modelling.</td></tr>
<tr><td>Strengths</td><td colspan="3">• Can use Excel as a platform increasing portability between users
• Easy to build and relative simplicity
• Familiarity within Health Technology Assessment community
• Good for working through population-level changes
• Can be combined with Markov Chains for a coherent approach
• Easy to understand (can be expressed using simple flow charts)</td></tr>
<tr><td>Weaknesses</td><td colspan="3">• No ‘memory’ (cannot capture dynamics / behaviours that are dependent upon previous events in the model)
• Difficult to simultaneously capture smaller-scale and larger-scale processes
• ‘Decision’ points in system are expressed as deterministic transition probabilities
• Details of the model can be difficult to convey (particularly in more complex systems) because of mathematic complexity</td></tr>
<tr><td>Appropriate application areas</td><td colspan="3">• Systems that can be best expressed in terms of transitions between states
• Population-level problems/ Cohort modelling
• Demand estimation
• Cost-effectiveness analysis (eg using Bayesian analysis approach)
• Disease transmission/ Disease screening modelling
• Financial risk analysis
• Treatment pathway modelling and disease progression modelling (without any parallel processes captured)</td></tr>
<tr><td>Resource requirements</td><td colspan="3">• Knowledge of sampling and pseudo random number generators;
• Knowledge of probability theory;
• Knowledge of output analysis methodology;
• Programming skills;
• Experience in modelling with Microsoft Excel and add-ins such as @Risk or Crystal Ball can be advantageous;
• Moderate mathematical expertise needed to build models</td></tr>
</table>

	• Relatively slow to build models • Results are effectively instant once model has been built

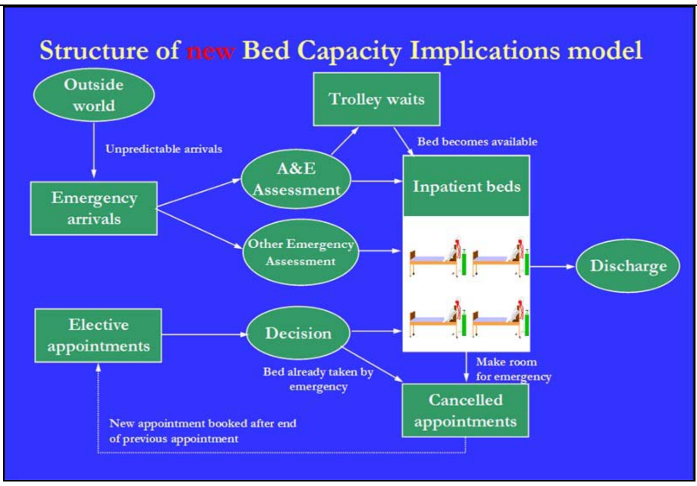
Appendix B: Case study examples of modelling healthcare delivery

CASE STUDIES SUMMARIES

Case study examples are one of the most instructive ways to examine modelling and simulation approaches in healthcare planning. The following case studies have been chosen to illustrate a range of different methods, differing funding bases, and of areas of implementation. In all cases the models have been used to support real health decision making at the strategic level.

Case Study 1.

Title:	**The Bed Capacity Implications Model (BECIM)**		
Initiator/s:	David Bensley, Dept. of Health	**Date:**	2005
Funding:	Department of Health	**Reference/s:**	[46]
Purpose:	It enables hospital trusts to investigate their current policies and the impact of changes to bed occupancy, elective booking level, elective cancellations, and emergency admission trolley waits.		
Method:	Discrete Event Simulation (implemented in Simul8)		
Details:	BECIM is a user friendly generic model, generally applicable to any hospital or a ward. It is a strategic model, for use in planning the medium to longer term rather than detailed day to day planning. The model is a learning tool not an operations model. For instance, the model can assist in: • Capacity planning. Identifying the consequences of policy associated with bed capacity. • The process of reforming emergency cares. • The introduction of an all-booked elective appointments system.		

	 Structure diagram of the BECIM bed capacity model
Outcomes:	***National Application*** At a Strategic level BECIM has been used to assist in achieving A&E trolley wait targets, for assisting in capacity plans for the Spending Review and for modelling unpredictable or unforeseen events, to estimate the effects of sudden changes in demand on capacity. It has proved to be a very helpful tool in modelling the potential impact of large numbers of casualties on the NHS. For instance, the model has been used to explore the best ways to accommodate bursts of plane loads of casualties from Iraq, with a higher length of stay than the other emergency patients. It has been used for modelling the implications of introducing units dedicated to treating stroke patients, the implications of introducing an integrated 'falls management' policy and the capacity implications of introducing independent treatment centres ***Local application*** BECIM has been made available to trusts and Strategic Health Authorities as a learning tool to aid capacity planning for achieving NHS Plan targets. At Hospital Trust level the model has been used as a Board level communication tool illustrating the trade-offs between reduced length of stay and increased capacity in the process demolishing some myths about emergency admission pattern The model has been widely presented within Government, to the NHS as well as at National and International Conferences.

Case Study 2.

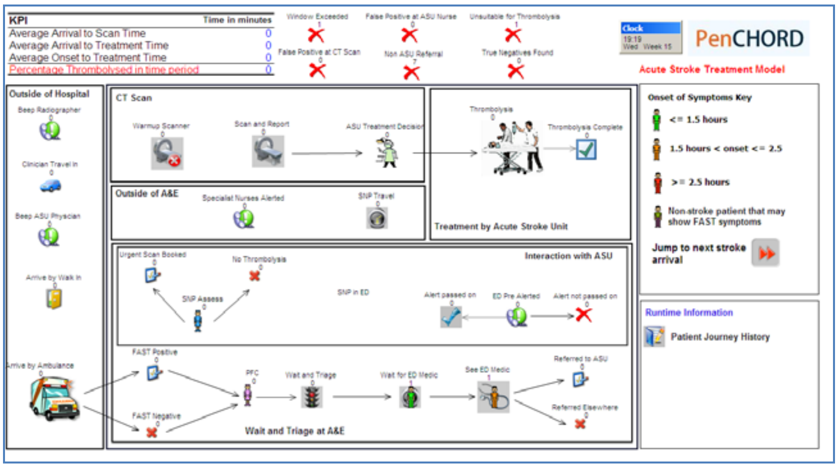
Title:	**Simulation of Thrombolysis for Stroke**		
Initiator/s:	Dr Thomas Monks and Dr Martin Pitt -University of Exeter Medical School, Dr Martin James – Royal Devon & Exeter NHS Foundation Trust	**Date:**	2012
Funding:	NIHR CLAHRC through PenCLAHRC and PenCHORD[9]	**Reference/s:**	[9, 47]
Purpose:	• To define a number of alternative pathways for emergency stroke care; • Evaluate pathways relative impact on: Percentage of acute strokes thrombolysed; Arrival to treatment times; Thrombolysed patients with favourable outcomes after 90 days; Scanning and assessment workload.		

<table>
<tr><td></td><td>

- Support implementation

</td></tr>
<tr><td>Method:</td><td>Discrete Event Simulation (implemented in Simul8)</td></tr>
<tr><td>Details:</td><td>

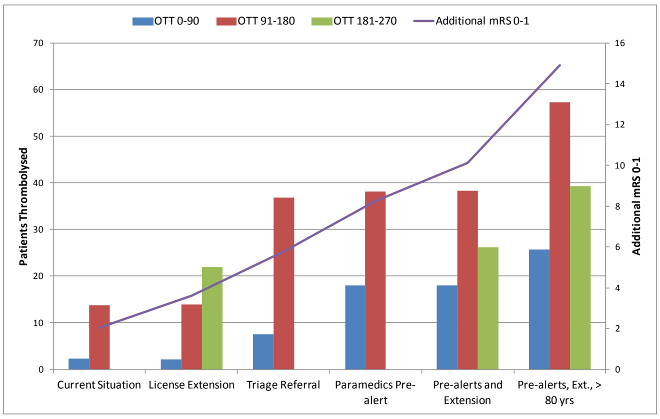
A DES model of the emergency pathway for patients with acute stroke was built to test a range of treatment scenarios. Key output metrics were the percentage of patients with acute ischaemic stroke receiving thrombolysis as well as the average onset to treatment time for these patients. The simulation was also designed to measure the effect of different care configurations on hospital services such as the CT scanning service.



Screen shot of simulation model used in this study

The following six scenarios were tested compared using the simulation.

1. Base case: current operational practice
2. Extended thrombolysis license window (4.5 hours)
3. Early referral of patients by Triage nurses
4. Paramedics pre-alert on imminent stroke arrivals
5. Pre-alert system with license extension
6. Scenario 4 + eligibility extended to include > 80 yrs



Key outputs for each tested scenario

Outputs demonstrated the importance of paramedic pre-alert to the Stoke unit in terms of increasing patients thromboysed and reducing onset to treatment time.

</td></tr>
<tr><td>Outcomes:</td><td>

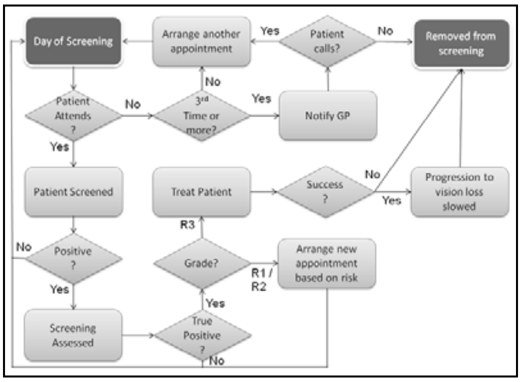
- Ruled out increased stroke nurse hours as a cost-effective option;
- Model provided a structured discussion with emergency department and

</td></tr>
</table>

	ambulance paramedics; • Early referral at triage was commenced at RD&E, Dec 2011 • Phone triage for suspected stroke patients travelling by ambulance commenced July 2012.

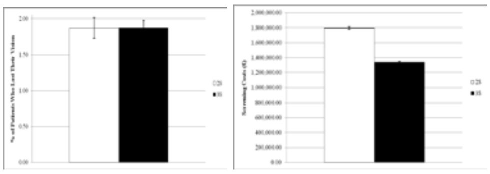
Case Study 3.

<table>
<tr><td>Title:</td><td colspan="3">Screening for Diabetic Retinopathy</td></tr>
<tr><td>Initiator/s:</td><td>Dr Daniel Chalk –University of Exeter Medical School,
Dr Bijay Patel – Royal Devon & Exeter NHS Found'n Trust</td><td>Date:</td><td>2012</td></tr>
<tr><td>Funding:</td><td>NIHR CLAHRC through PenCLAHRC and PenCHORD[9]</td><td>Reference/s:</td><td>[9, 48]</td></tr>
<tr><td>Purpose:</td><td colspan="3">To determine whether the screening interval for type 2 diabetic patients with no retinopathy can be safely extended from 1 year to 2 years until retinopathy is detected, thereby reducing service costs.</td></tr>
<tr><td>Method:</td><td colspan="3">Agent Based simulation (using Anylogic software)</td></tr>
<tr><td>Details:</td><td colspan="3">Anonymised patient data from Devon RD&E hospital for 3,537 patients and 33,810 screening episodes over 20 years was used in combination with retinopathy progression data from the literature to build the model. Each individual patient in the model attended screening and treatment appointments, and each patient's disease progressed over time. Patients in the model who progress to (and are identified as having) proliferative diabetic retinopathy are sent for treatment which, if successful, slows their rate of progression to sight loss. The model can test whether a proposed screening interval will increase the number of patients who lose their vision because they were not detected quickly enough, and a two-year screening interval for R0 (no retinopathy) patients was tested.



Schematic of model pathway used for study

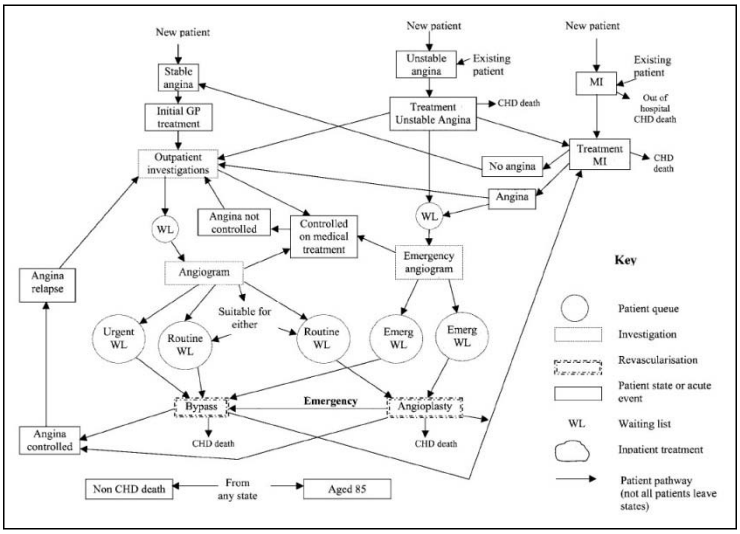
The model demonstrated that for type 2 diabetes patients who are not considered 'high risk' and who have not yet developed retinopathy, the screening interval could be extended from one to two years without any increase to the number of patients who lose their vision. Such a change could bring about a 25% saving in screening costs.



Outputs showing no clinical detrement (left) but 25% cost saving (right)</td></tr>
<tr><td>Outcomes:</td><td colspan="3">Presented findings to Royal Devon and Exeter NHS Foundation Trust, who are looking into taking the case to commissioners to argue for local policy change, or instigation of pilot</td></tr>
</table>

	study. Publication in Diabetes Care, which argues for national change to NICE guidelines and supports findings of previous studies (but proposes a more *palatable* change).

Case Study 4.

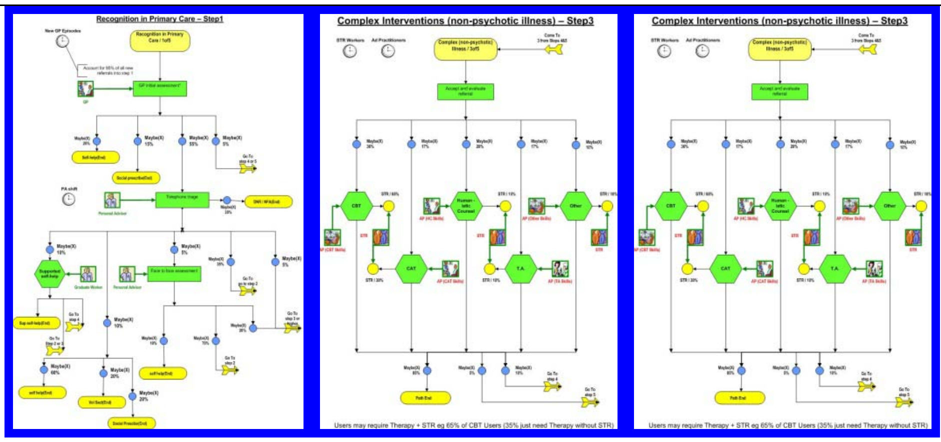
Title:	**Coronary Heart Disease Model (CHD)**		
Initiator/s:	Keith Cooper, Ruth Davies; Southampton University.	**Date:**	1999-2002
Funding:	Project commissioned by The National Centre for Outcomes Development and Department of Health R&D	**Reference/s:**	[49, 50]
Purpose:	To inform the Department of Health about the benefits and risks of different screening and treatment options for CHD and to help determine resources needed. The model was to include hospital resources and hence queues		
Method:	Discrete Event Simulation developed in POST system programmed in *Borland Delphi.*		
Details:	An existing (prevalent) population of CHD patients between the ages of 35 and 84 are classified as follows: have angina but no history of previous myocardial infarction (MI), angina and previous MI, and MI but no angina. New (incident) patients with no previous CHD arrive in the simulation at any time with angina, unstable angina or an MI. Patients receive hospital treatment if they have unstable angina or myocardial infarction. Referrals to re-vascularisation are made for severe patients which will improve their symptoms and may improve their life expectancy. The main risk factors for the transitions between the disease states are age, and for MIs, the number of previous MIs. These transition rates can be modified by coronary heart disease interventions, such as re-vascularisation and secondary prevention medications.  Flowchart of the pathways in the CHD model - *from Cooper et al (2002)[50]* The model is user friendly such that the user can change the input data easily via various menus. The results will calculate costs and costs benefits and can output to a spreadsheet. It is designed to model the patients in a population of about a million i.e. the catchment of a tertiary centre. It could model a smaller population		

	but would slow down for a larger one – also the queuing information would not be meaningful if not related to a hospital.
Outcomes:	The model did inform reports and decisions from DH but there was no funding to maintain it. The data and the assumptions to some extent are becoming out of date. There was huge potential in the link with the Prevention model but this was never exploited. There were some interesting problems with the model itself. One is that, without any feedback loops, the queues are very unstable. Another is that, as we relaxed the resources, we had to make decisions about whom to admit as we were unlikely to find more patients in the same category i.e. the patients would be older, sicker etc. Overall, the model development was successful, user friendly, refereed by experts, and had the potential to influence policy but the model was not maintained beyond the end of the project.

Case Study 5

Title:	**Improving Access to Psychological Therapies (IAPT)**		
Initiator/s:	South Tyneside PCT	**Date:**	2007 – 2008
Funding:	South of Tyne Commissioners of Adult Mental Health Services, modelling undertaken by *Focused-On Ltd*.	**Reference/s:**	[8]
Purpose:	To find new ways of designing processes that achieve better patient flow, deliver greater care, are supported by staff, and provide better value-for-money for the delivery of mental health services in South Tyneside.		
Method:	A discrete event simulation – FlowModel implement in *Extend* (*ImagineThat Inc*)..		
Details:	Staff moved from paper process maps to PC-based PatientFlow planning. Their drawings linked to source data, reference material plus shift profiles, duration (usually defined as a triangular distribution) of value-adding activities and courses of treatment, and identify which staff and facilities are needed. The focus was on the first 3 Steps: • Recognition in Primary Care • Brief Interventions • Complex Interventions (non-psychotic illnesses)		

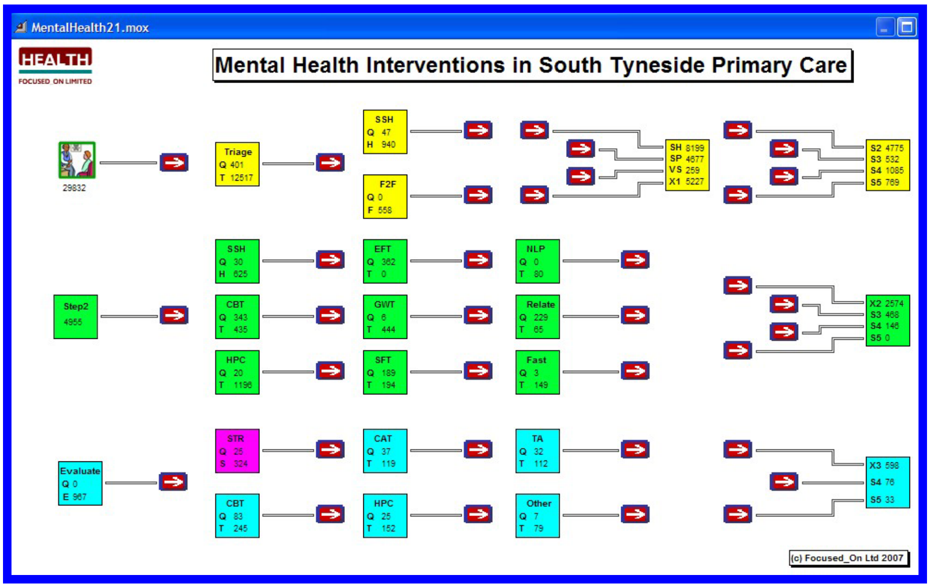
Appendix 2: Service Delivery Operational Research Methods Reference



PatientFlow plans - charting patient pathways in the model

This phase gave everyone a shared-understanding. Clinical staff were reassured by its "fairness" and it engendered both "integrity & respect". It also provided a good understanding of the therapy skills within the teams.

The resulting simulation FlowModel could then be used to identify and measure likely patient queues and test the impact of organisational changes and the appropriate engagement of services that might be better provided via service level agreements with voluntary sector and other external providers.



FlowModel used for the simulation.

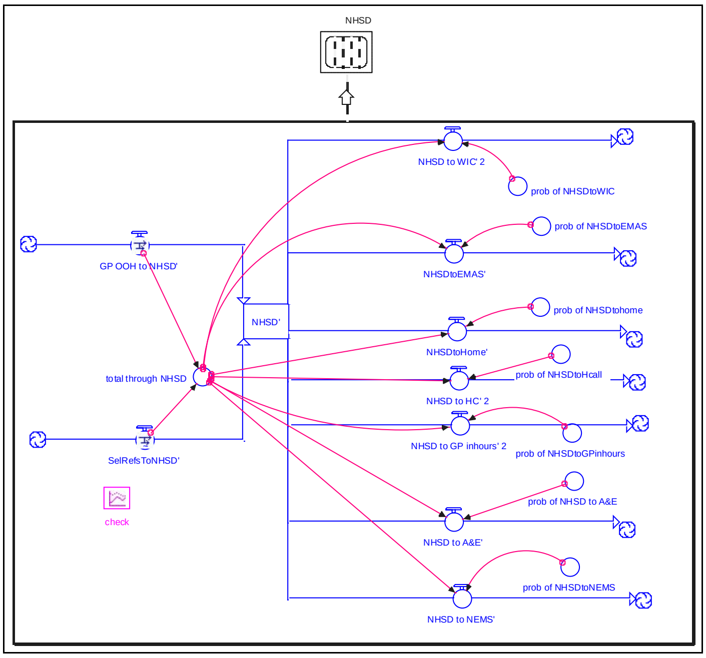
Outcomes:

The PatientFlow plans and the simulation FlowModel are being used very succesfully in collaboration by the local commissioner, the lead GP, and providers to build and deploy their 'dream team' of therapists in a way that can meet the 50% increase in referrals within approved headcount and budget.

Now, commissioners for adult mental health services across all South of Tyne are taking this work right through to crisis resolution & home treatment and in-patient psychiatric beds

Appendix 2: Service Delivery Operational Research Methods Reference

Case Study 6

<table>
<tr><td>Title:</td><td colspan="3">Emergency and On-demand Health Care Model (ECOD)</td></tr>
<tr><td>Initiator/s:</td><td>Sally Brailsford, University of Southampton</td><td>Date:</td><td>2001</td></tr>
<tr><td>Funding:</td><td>Commissioned by Nottingham Health Authority as part of a larger project.</td><td>Reference/s:</td><td>[8, 33]</td></tr>
<tr><td>Purpose:</td><td colspan="3">To provide a whole-system review of emergency and on-demand health care in Nottingham.</td></tr>
<tr><td>Method:</td><td colspan="3">System Dynamics model (implemented in STELLA software).</td></tr>
<tr><td>Details:</td><td colspan="3">A conceptual map showing patient pathways through the care system was developed based on individual interviews. This was used to construct a stock-flow SD model which was populated with current activity data. The model could then be used to simulate patient flows and identify bottle-necks.


The NHS Direct Sub-model of the STELLA model (taken from Brailsford et al) [33]</td></tr>
<tr><td>Outcomes:</td><td colspan="3">The model was used to investigate patient flows and bottlenecks and as a tool for provoking and facilitating discussion. The Nottingham steering group for ECOD used the model to test and evaluate different scenarios of care. However the primary use of the model was for promoting greater understanding of the dynamics of the system rather than in generating numerical outputs.

The essentially generic framework adopted and the models use of routinely collected data entails that this approach can readily be adapted elsewhere.</td></tr>
</table>

Case Study 7

<table>
<tr><td>Title:</td><td colspan="3">Modelling the Restructuring of Secondary Care Services in a South West England Health Economy</td></tr>
<tr><td>Initiator/s:</td><td>Dr Adam Pollard - Modelling Lead, Royal Cornwall Hospitals Trust; Adam S Pollard – Mathematical Services

Dr Michael Coupe, formerly Dir. of Planning, Royal Cornwall Hospitals Trust</td><td>Date:</td><td>2007</td></tr>
<tr><td>Funding:</td><td>Royal Cornwall NHS Trust (in-house development)</td><td>Reference/s:</td><td>[8]</td></tr>
<tr><td>Purpose:</td><td colspan="3">To model how much activity there needs to be to meet demand and targets

To model how much capacity there needs to be and in which locations

To aid site and service optimisation and achieve financial balance</td></tr>
<tr><td>Method:</td><td colspan="3">Deterministic mathematical model implemented in spreadsheet (Microsoft Excel).</td></tr>
<tr><td>Details:</td><td colspan="3">

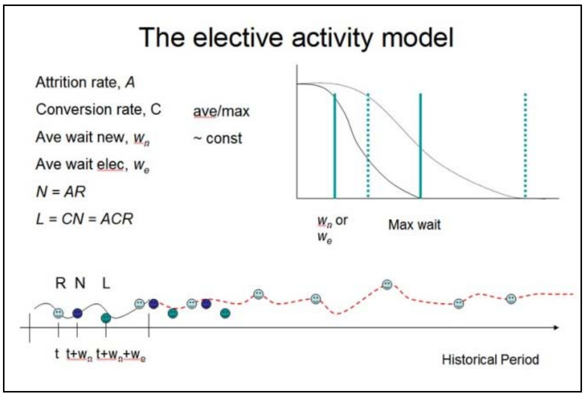
The principal task facing the modelling function of RCHT has been to model future demand for services and compare against capacity, which has been derived with the aid of Trust management against a backdrop of structural change.

Demand side variables include:

- Demography, Epidemiology, Primary and community care services activity impacting on referral levels, Centrally imposed access targets (eg. max. waiting times)
- PCT affordability envelopes, New providers entering the market for NHS funded healthcare
- Local cultural norms regarding the use of hospital services.

Supply side variables include:

- Productivity gains (ie. impact of service modernisation and redesign)
- Changes in clinical practice
- The appropriate level of clinical skill mix and financial resource
- Existing infrastructure



Graphed representation of Elective Activity in the model

</td></tr>
<tr><td>Outcomes:</td><td colspan="3">The model has been used extensively to generate predictive outcomes with</td></tr>
</table>

	confidence intervals for a range of alternative strategic scenarios. Application of the model has made an important contribution to the successful restructuring of the secondary care sector within a local NHS economy and in determining key aspects of the Local Development Plan for Cornwall. In particular, model outputs have been incorporated at policy level meetings between commissioners and providers and provided guidance in balancing constraints of demand, affordability and capacity in the context of centrally imposed targets.