

Populations ‘v’ Patients

Pick the Right Tool for your Problem:

The current emphasis on “World Class Commissioning” and the associated increased importance of simulation modelling has caused some discussion in the Healthcare community. At the highest level the issue seems to be whether to address problems using Continuous Simulation (of which Systems Dynamics is a subset) or whether to use Discrete Event Simulation. There are fundamental differences between these two types of simulation and the two types address different problems. This paper identifies these differences and suggests the Strengths and Weaknesses of each for a range of Health related problems.

Disclaimer: Focused_On Ltd always strives to give best value to its clients. Focused_On Ltd are able to provide solutions based on any of the technologies described in this report and will provide options in their Replies to Tenders to enable the Client to choose their approach. Focused_On will, in their Tenders, present their own opinions and recommendations. The opinions in this paper are based on Focused_On’s accumulated knowledge and on the published opinions of some Academics.

Focused_On have attempted to present impartial advice and guidance. Whilst they have taken every care in the preparation of this report, they cannot, however, be held responsible for any damages or losses incurred howsoever through the use of any tools or techniques whether or not these tools and techniques are referred to herein.

Optimized Resources: Greater Patient Care

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1 Management Summary

This paper outlines the differences between Continuous Simulations (e.g. System Dynamics) and Discrete Event Simulations (e.g. Extend and Patient Flow Planning).

As a Company, Focused_On Ltd (Focused) is comfortable to work with either technology, but they do have some fairly strong views on the most suitable methodology and toolset for different kinds of problem in Healthcare.

In their Replies to Tenders, Focused might well offer both options and allow the Client the choice. Where this choice exists, this paper might help the Client make the best decision.

Before you read any further, you might consider whether you really need to use simulation to address your problems. If you are considering making low risk, low cost and easily reversed decisions, then probably your best approach is to Just Do It (PDSA). If your issues relate to complex and expensive decisions which are not easily reversed, then you might consider simulation.

If your issues involve competition for and rationing of resources, then you certainly should consider simulation (and probably Discrete Event).

2 Simulation techniques

The simulation tool supplier ImagineThatInc (www.ImagineThatInc.com) supplies the ExtendSim product which allows both Continuous and Discrete Event simulations to be produced and are ideally placed to present an unbiased appraisal of each.

A system is the object of study or interest. When you simulate, you model the performance of a system over time. Models of systems are classified as either discrete event or continuous, although in the real world there is no such distinction and it is possible to model some real-world systems either discretely or continuously.

Before you build a model, you need to decide whether to model the system as discrete event or continuous. It is important to note that there is no such thing as **the** model of a system: a system can be modelled in any number of different ways, depending on what it is you want to accomplish. In general, how you model the system depends on the purpose of the model and the type, level, and accuracy of information you want to gather.

Continuous modelling (sometimes known as process modelling) is used to describe a smooth flow of homogenous values (i.e Cohorts or Populations); discrete event modelling tracks individual and unique entities, known as items (i.e. Patients). In both types of simulations, what is of concern is changes in the state of the model.

The differences between discrete event and continuous are detailed in sections 2.2 and 2.3 below. The following table highlights the main differences.

2.1.1

Table of continuous and discrete event differences

Although not definitive, the following table will help you determine how to model your system:

Factor	Continuous Modelling	Discrete Event Modelling
What is modelled	Flows of "stuff" – indistinguishable people in Cohorts of Populations	Processing of discrete "items" – Patients being Treated
Characteristics	Flows are generally defined via "Averages". They must be repeated for each query or junction at fixed time intervals.	Uses statistically assigned attributes to define unique Patient characteristics. These can then be tracked throughout the model and each Patient's attributes can show the variation encountered in real life
Time steps	Interval between time steps is constant. Model recalculations are sequential and time dependent.	Interval between events is dependent on when events occur. Model only needs to recalculate when events occur.
Ordering	Flows are in FIFO order and sequential linkages in model layout are critical.	Patients can flow in FIFO, LIFO, Priority, or any other Customized order.
Routing	Flows need to be explicitly routed by being turned off at one branch and turned on at the other.	Patients are automatically routed to the first available branch. 'Cloning' / 'Merging' can model parallel events.
Statistical Detail	Only general statistics about the system: amount, transit time. Any waiting time statistics tend to be somewhat 'contrived'.	In addition to general statistics, each Patient can be individually tracked: counts, utilization, cycle times, max Q length, Wait times, activity based costs
Resources	Resources and resource contentions can only be handled by increasing model complexity. A fairly simple model can become extremely complex when handling multiple resource types with specialised skills.	Accepts that competition for time, capacity, or skill capability resources will be inherent in a process and is targeted on handling this problem simply.
Suitable Uses in Healthcare	Economics, Systems dynamics, Epidemiology and Flow related Health Strategy Applications.	Patient-focused Health Services where resource Capacity (e.g. Beds) & Capability (e.g. Doctors, Nurses, Therapists) are important

Some systems, especially when a portion of the flow has a delay or wait time, can be modelled as either discrete event or continuous. In this case, you would generally choose how to model the system based on the level of detail required. Discrete event

models tend to provide much more detail about the workings of a system than continuous models.

2.2 Continuous Simulation (CS)

2.2.1 Description

Continuous simulations are analogous to a stream of fluid passing through a pipe; the volume may increase or decrease, but the flow is continuous. In continuous models, values change based directly on changes in time, and time changes in equal increments. In other words, values reflect the state of the modelled system at any particular time, and simulated time advances evenly from one time step to the next.

System Dynamics is a subset of Continuous Simulation. It is based in the work done by Prof. Jay Forrester at MIT in the early 1960s. It's first applications were for Industrial / Commercial applications, but it soon became an important methodology for studies of Urban Dynamics (Collins-Forrester- 1968) and subsequently Forrester examined the socio economic structure of the World in World Dynamics (1971).

Since that time, System Dynamics has been successfully used in studies involving large base populations where it is a good way of structuring the problem to be solved, formalising the relationships and interactions of the elements within the problem and testing the implications of alternative scenarios. Underlying System Dynamics is the concept of "Systems Thinking" where the users are forced to consider not just subsets of the problem, but the relationships between these subsets. The language of System Dynamics is, therefore, somewhat esoteric because problems are framed in terms of Stocks, Flows, Converters, Action Connectors etc.

Prof. Wostenholme of SymmeticsSD suggests that for a normal NHS application, a "Translator " is needed i.e. a SD professional who can listen to peoples problems and translate their desires into SD objects and language. He also suggests that SD best applies to problems that can be best considered from the 10,000 meters viewpoint. We would advise, therefore, that SD is not so well suited to Patient-focused problems but rather should be reserved for when Cohorts or Populations are being studied.

Since SD is based on Flows, any consideration of queues is very limited. The only queues which can be considered are First In, First Out and any consideration of waiting times is limited. Since Flows are homogeneous, SD will use Averages or Maxima in calculations. These Averages may be realistic when working with, for example, cohorts in a National Population, but they will probably be suspect when looking at the detailed problems such as Bed Occupancy in a high turnover Ward.

Without doubt, there is a role for SD in planning at a National level. It is also the obvious tool to use in Epidemiology Studies, it has applications in framing strategies for Health Care, particularly in the area of Community Health. If your concern is to understand the qualitative way in which a system operates and the types of interaction between components, then a quick System Dynamic study should be considered. If you need to make provision for multiple types of Patients with varying demands and you need some specific planning numbers, then DES should be considered.

2.3 Discrete Event Simulation (DES)

2.3.1 Description

In this kind of Health Service model an item is probably a Patient. In discrete event models, the Patients move through the process, from one activity or queue to the next activity or queue. The state of the model changes only when those movements occur; the mere passing of time has no direct effect. Instead, simulated time advances from one event to the next (e.g. Patient Arrives, Surgeon begins List, Surgical Procedure completed, Patient Discharged from Ward) and (like real life) it is unlikely that the time between events will be equal.

Simulations came to the fore with the very first computers. DES has been a commonly used technique in the UK since the early 1960s and there have been several languages written to support it's development. DES is profitably deployed where the items of concern are identifiable entities (e.g. your Patients). The very large advantage of DES is that all of the items are separate and can have their own characteristics (attributes). This means that your Patients can be queued and withdrawn from queues via any protocols (LIFO , FIFO, Priority, Reneging, Baulking, Matching Attributes etc). Because each Patient carries it's own attributes, we are able to be very much more specific (Minor Counselling and Self Help needed, One/Two Courses of CBT Needed, Severe Psychosis etc), so it is easier to reflect real life into your Patient mix and their Requirements.

DES is more suitable where we have the detailed information on Patient differences and we have at least an idea of the sort of provision we'd like to make for different types of Patients.

Because DES works at a very much lower level than SD, Staff Availability, Skills and Shifts will most often be considered. This can have very great benefits. We have seen that a minor change in staffing schedules, moving two staff from Counselling to Telephone Triage for one half day per week, can change the entire operation of a system.

Step back before you start building a DES flow model and look at the bigger picture and decide what would be the most appropriate level of detail to work at for the problem and your questions for which you want to model answers. As you know, sometimes small detail changes can have quite large impact.

If your concerns are how many Beds of What type, how many staff and when should Staff be available, or What should your inter-Ward transfer policies be, then DES is probably most suitable.

3 Summary

When looking at the literature concerned with Systems Dynamics and other Simulation techniques one is struck by the polarisation of views. It seems as if a “System Dynamicist” has only interest in System Dynamics and not in any other area. This is akin to a Civil Engineer saying he only needs small hand tools and they will do everything that larger construction tools will do. It is not justifiable.

The proponents of Discrete Event are somewhat less evangelical. Perhaps it is because they are more pragmatic or confident of the many important projects where DES has delivered effective solutions and insights.

It is core to Focused_On’s beliefs that both techniques have their most suitable applications.

At the highest level, for a successful application of Simulation techniques, the following steps are necessary.

3.1 Define your Problem

It is very important that you are clear in terms of what you want to achieve. Objectives should be explicit and measurable. If you can’t measure it, then you’ll never know whether you’ve achieved it. Similarly objectives should be contained. If you have too many of them in a single study, you’ll lose focus.

Probably a reasonable maximum is for less than five measurable objectives. These should be generated with total Clinical agreement and commitment.

3.2 Choose the Tool

In the light of your objectives decide whether you need a high level study of the area or whether you need a more detailed study. Decide whether you can work with averages and rates of service or whether you need to investigate Waiting Times and Queue Lengths.

3.3 Involve your Staff

A model will not implement your chosen strategy. It will only point you towards a good strategy. Implementation is done by people and therefore the people must have confidence in what they are doing. This means they must be involved in the modelling stages of the project and they must be confident their opinions have been taken into account. It is particularly important that Clinicians are engaged throughout the process.

3.4 Evolve your Strategy

As long as the stakeholders’ interests have been properly incorporated, the model should, at the minimum, appear as reasonable. If possible, it needs calibration

against reality to ensure its technical integrity (if you model something that has never been done before, carefully test your outcomes with controlled inputs).

Similarly, as you make further changes to your model (e.g. increase staffing), results should be subject to sanity checks to make sure your initial assumptions remain relevant in the new scenario.

As the changes are made, the results scrutinised and further adjustments made, you will progress towards your final strategy with consensus and confidence,

3.5 Make sure it is a Commissioning Tool

A Commissioner needs to agree the amount of service to be provided and the costs of this service. Therefore the model needs to include adequate financial statistics and the level of Patient treatments.

It is also essential that the quality of the service is specified. The output from the modelling phase should therefore include precise definitions of not only how many Patients will be treated, but also of how they will be treated. Focused_On's Patient Flow Drawings are ideally suited to provide this specification.

4 Appendices

4.1 Client Benefits

Be aware that in a properly conducted study more than half the benefit will probably arise from the Planning and your Discussions with colleagues. With proper planning tools and a skilled facilitator, not only will understandings be enhanced but team work and commitment will be greatly increased. It is not uncommon for solutions to become obvious from going through the structured process mapping before any of it is committed for simulation. With the right simulation model, you can solve the paradox: "*Tried & Tested Solutions that have Never Been Done Before!*"

4.2 Simulation c.f. Spreadsheets

Be very careful about using Spreadsheets. They will generally rely on averages which are certainly not a valid basis for planning when the Patients you are dealing with show large variations. For further detail on this point, please see <http://www.focused-on.com/SpreadsheetsSimulation.pdf> .

Where demand varies in an unpredictable fashion, as in this example, certainly some of the pitfalls of spreadsheets will also apply to a System Dynamics model.

4.3 System Dynamics c.f. Discrete Event – Two Examples

It is not intended to present one problem modelled in both fashions. Several Academic studies have done this, but it is misleading and a mistake. Each problem has its own problem domain and Client Expectations. Depending on these the chosen technique might be SD or DES. To force SD onto a natural DES problem

makes the technique look cumbersome and the model look artificial. The converse is equally true.

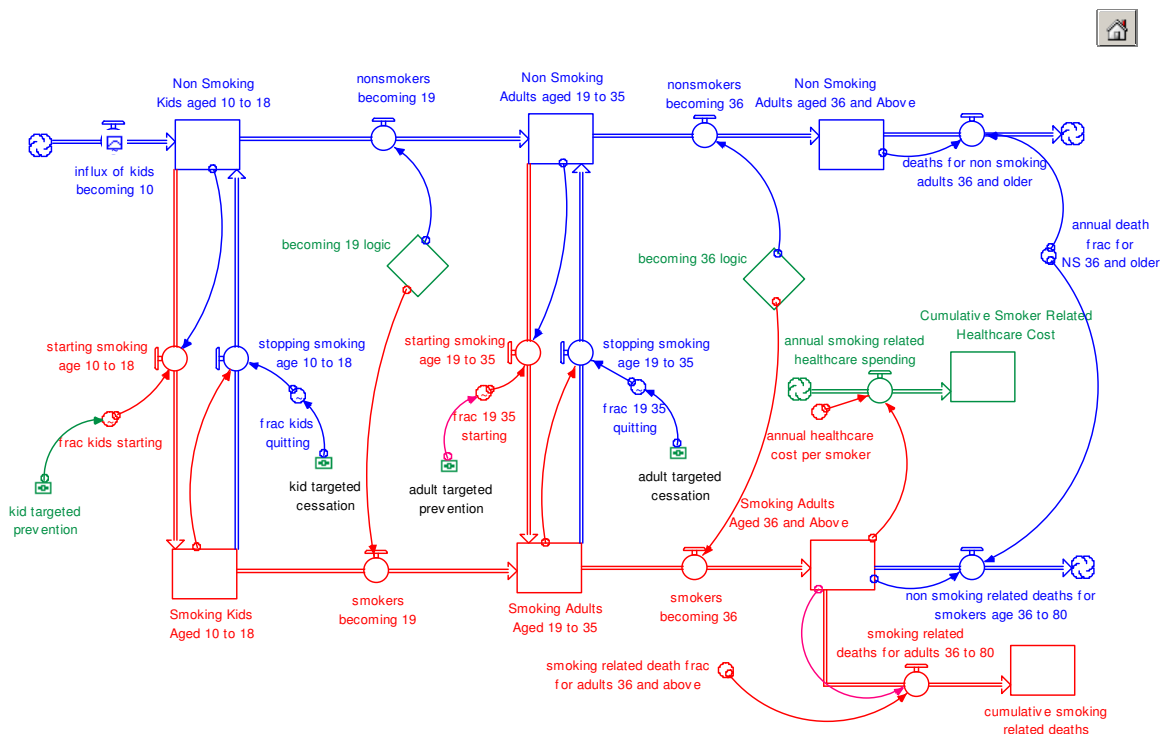
4.3.1 Smoking Cessation using System Dynamics

This example is taken from the website of iseesystems (www.iseesystems.com) as an example of how the iThink software might be used at a policy level. It investigates the investments which might be made under four headings (Adult / Young Person & Prevention / Cessation).

It is a good example of effective use of System Dynamics. It deals with the general population and with rudimentary demographics (ageing between 10 -18, 19 - 35, 35+ groups).

It has clearly defined controls (the effort put into Prevention/Cessation for each age group), and it has a good optimization metric (the Cumulative Smoker Related Healthcare Cost).

The problem has no need of detailed statistics involving queue times and waiting times. This is then an excellent application for System Dynamics.

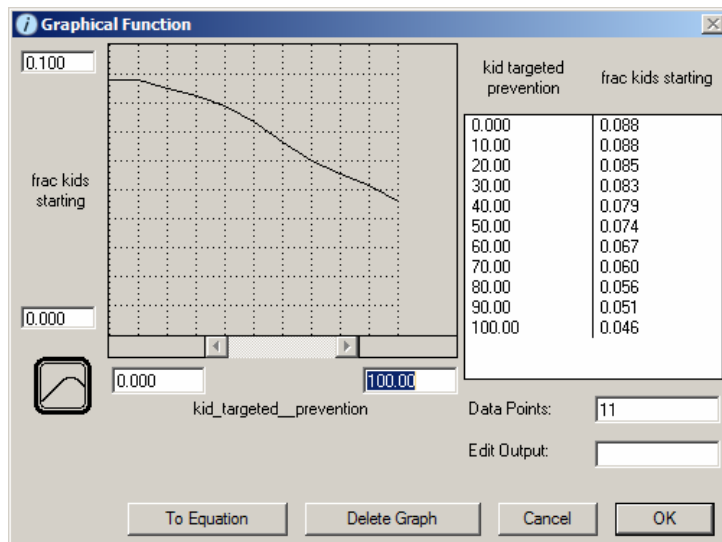


Given we have access to the annual death fraction for non-smokers 36 and over and the smoking related death fraction for smokers 36 and over (both of which are outside the model's influence), and we also have an estimate of the annual smoking related healthcare spend per smoker, then we only need to adjust investment in the four controls of Prevention/Cessation for (10-18) and (19-35).

These are specified via graph as below.

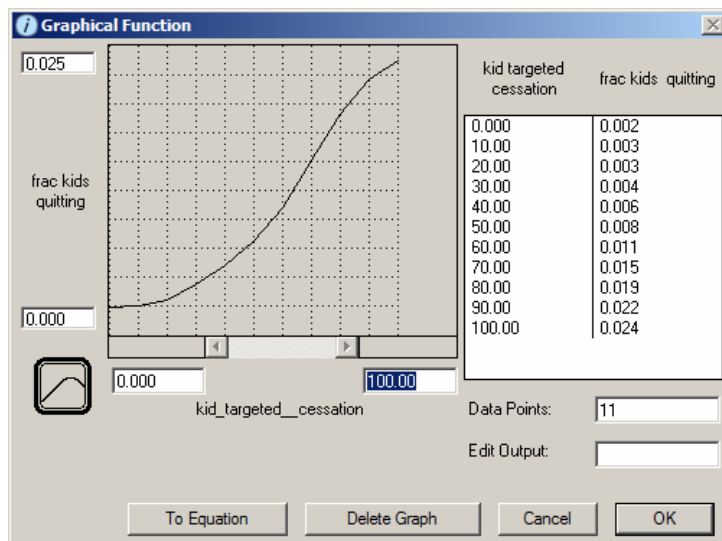
Prevention

Depending on the investment in Prevention, as the investment runs up the scale from 1 to 100 points, we expect the fraction of young people who start smoking to fall as below.



Cessation

Similarly as we increase the investment on Cessation, we expect the fraction of young people who cease smoking to increase as below.



Hence we have reduced the problem of generating a Smoking Cessation policy to the issues of estimating the Prevention and Cessation graphs for the (10-18)'s and the (19-35)'s. If these graphs are estimated, this System Dynamics model provides a tool which enables the optimal distribution of investment into each of the four Cessation categories to be found.

4.3.2 Intensive Care Unit using Discrete Event Simulation

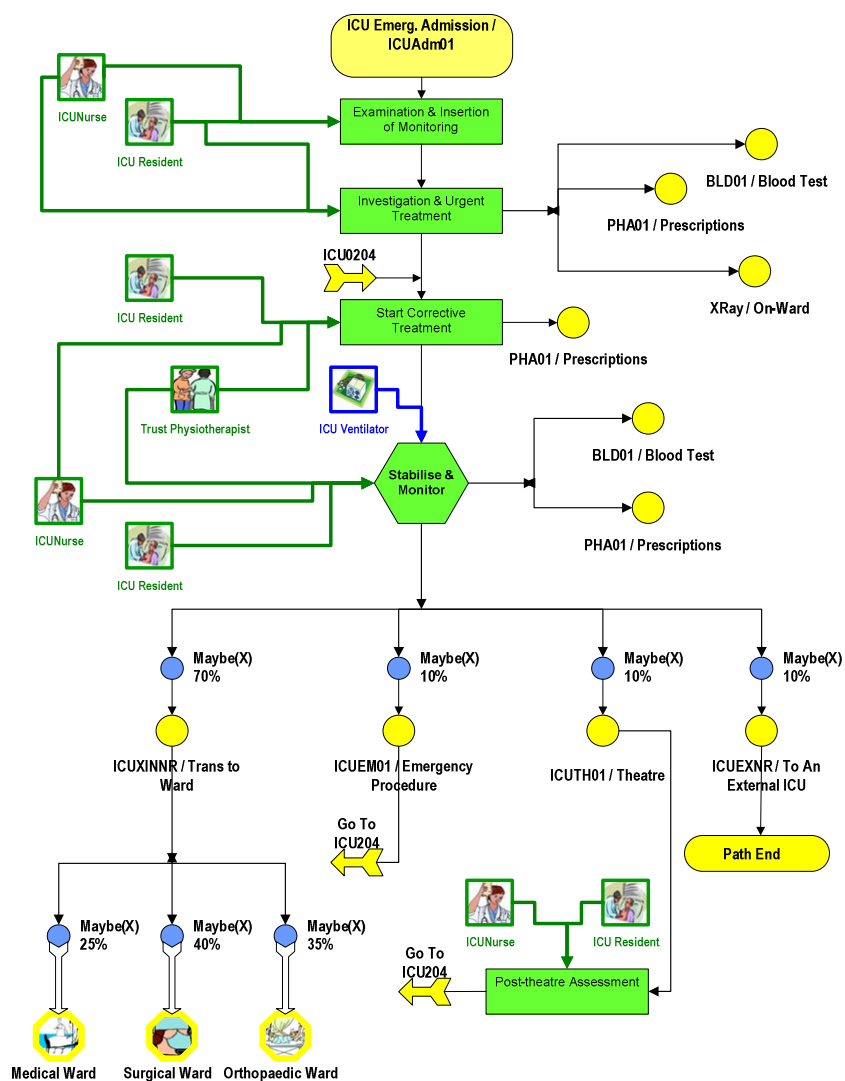
This model looks at the resources inside an Intensive Care Unit. The categories of Admissions to the Unit are Emergency (30%), Post Elective Surgery (60%) and Transfers in from remote ICU's (10%). There are about 800 Admissions per year, whose arrivals can be defined by an Exponential distribution with Mean 11 hours.

The duration of the treatment for each category is estimated as Triangular with Electives having Minimum 16 Hrs, Maximum 48 Hrs and Most Likely 24 Hrs. The corresponding numbers for both Emergencies and Transfers are (48 / 168 / 96).

Emergencies require 1:1 Nursing, the other categories 1:2 (i.e. One Nurse, Two Patients).

The current resources for this unit (6 Beds and 4 Full Times Nurses) are causing Admission difficulties (Emergencies and Transfers refused, Operations Cancelled) and the problem is to decide the optimum resource levels.

The study begins with mapping the problem in Patient terms. This is done using Focused_On's Patient Flow Planning software. An Emergency Admission is below.



This is created using “Drag and Drop” and is not just a drawing. Behind every object on this drawing is a dialog. The solid green objects in the drawing specify what is to be done, the green bordered objects say who will do it and the green connectors specify this person’s involvement and when it will be done.

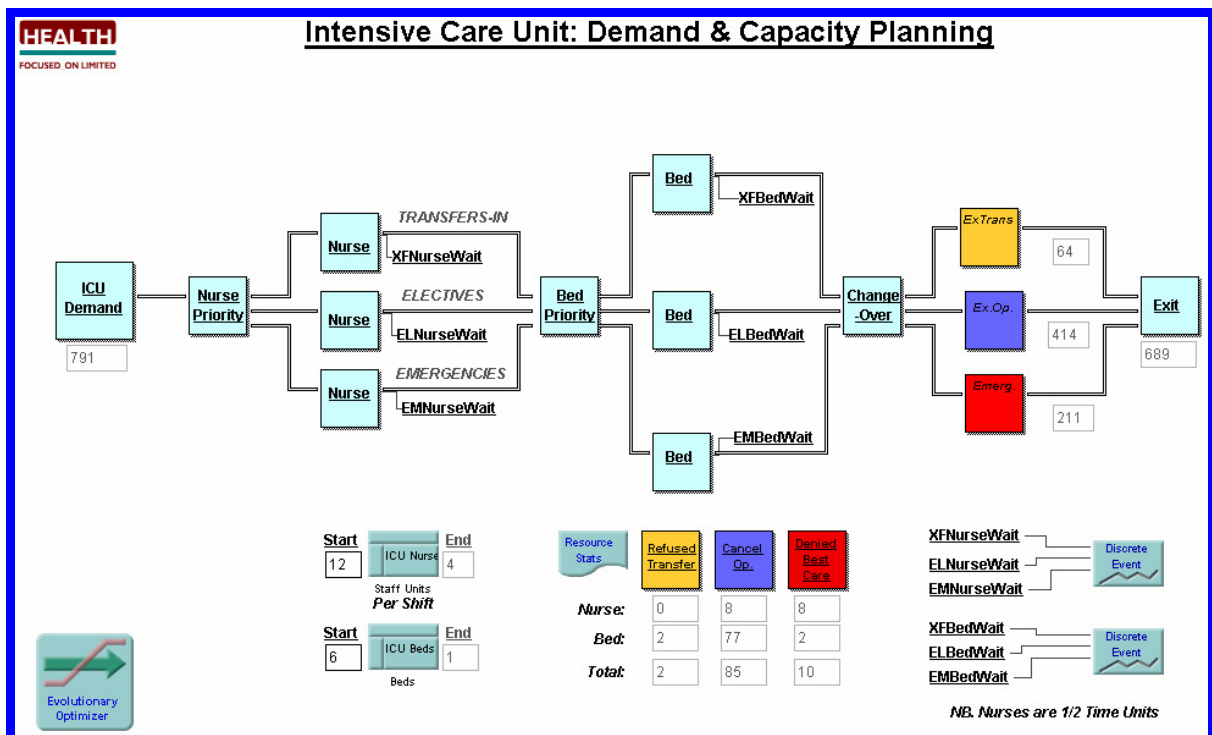
For example, if a double click is made onto the X-Ray icon (Yellow circle) we see:

The dialog box is titled 'PPFV6 from Focused_On'. It contains the following fields and options:

- Invoke a Process or Task:** The name of the process or task to be invoked is 'XRay'.
- Description:** 'On-Ward'.
- Invoked via:** 'Support Process'.
- When using, set variable:** Two empty text boxes.
- Dependent/Independent:** 'Independent'.
- Limit on time to Queue:** '15' Mins.
- Failure process:** 'ICUFailXRay'.
- Effect on duration of invoking activity:** 'No Effect'.
- Usages will be scheduled:**
 - Within duration of Task/Activity
 - Periodically during Period
 - Up to '1' usages during task duration
 - each with %age prob. '33'
- Notes:** A text area containing: 'About 1 in 3 will need X-Rays. When the Resident has called for an Xray, ring Ext 2158 and be sure you get a time. Enter this time onto the Patient notes. For InWard Xray protocol see file: %PPF/XraysInWard.doc'.
- Buttons:** OK, Cancel, Print, Position Text, Edit Notes, Search Notes, Notes Help.

This dialog is specific to the invocation of a Process. Most of the data in the dialog exists to inform the simulation, but very importantly the Notes at the bottom are a very valuable feature which allows documentation of the activity and allows the specification of standards and protocols to be followed as this activity is performed. This is very valuable to enable Commissioners to specify their needs and can help the provider in the induction of new recruits.

When the problem has been analysed and the drawings have been produced and populated with data and notes, then we can begin the simulation. This is now easy because all of the analysis and discussions have taken place up front.



On this screen it can be seen we can specify the number of Beds and Number of Nursing Units available. The simulation will run and report on each of Refused Transfers, Cancelled Operations or Refused Emergencies, classifying each refusal as to its reason (Lack of Bed/Lack of Nurse).

When we ascribe a cost to each Resource (Bed, Nursing Unit), A Benefit for each treatment and a cost for each refusal, we can run an Optimizer which, subject to this objective function, will search until it has found an optimum solution to the problem. This unit, with these admissions, was optimised to 9 beds with 7 Nurses available.

Some very important points can be drawn from this model.

- Good data was available
- Although waiting times were not of relevance, Renege Times were (A Renege Time is the time a Patient can wait in a queue before doing something else). In an ICU these times are likely to be short.
- The Queues used (Reneging Queues and Priority Queues) would have made this model very difficult using a different technique.
- The sharing of Bed and Nurse Resources with varying demand levels and different priorities would most likely have guaranteed an incomprehensible System Dynamics model.

Hence, just as the Smoking Cessation was a natural and profitable SD Application, so this one is a natural and profitable DES Application.

5 Proposal

When you are dealing with Populations, consider first SD, if your problem has logically complex parts or you need detailed statistics, you might consider DES.

When you are dealing with Patients, consider first DES, if your needs are for broad brush guidance, you might consider SD.