

Citation for published version:

Eren Demir, and David Southern, 'Enabling better management of patients: discrete event simulation combined with the STAR approach', *Journal of the Operational Research Society*, Vol. 68 (5): 577-590, December 2017.

DOI:

<https://doi.org/10.1057/s41274-016-0029-y>

Document Version:

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Enabling better management of patients: discrete event simulation combined with the STAR approach

Abstract

Squeezed budgets and funding cuts are expected to become a feature of the healthcare landscape in the future, forcing decision makers such as service managers, clinicians and commissioners to find effective ways of allocating scarce resources. This paper discusses the development of a decision support toolkit (DST) that facilitates the improvement of services by identifying cost savings and efficiencies within the pathway of care. With the help of National Health Service and commercial experts, we developed a discrete event simulation model for Deep Vein Thrombosis (DVT) patients and adapted the socio technical allocation of resources (STAR) approach to answer crucial questions like: what sort of interventions should we spend our money on? Where will we get the most value for our investment? How will we explain the choices we have made? The DST enables users to model their own services by working with the DST interface allowing users to specify local DVT services. They can input local estimates, or data of service demands and capacities, thus creating a baseline discrete event simulation model. The user can then compare the baseline with potential changes in the patient pathway in the safety of a virtual environment. By making such changes key decision makers can easily understand the impact on activity, cost, staffing levels, skill-mix, utilisation of resources and, more importantly, it allows them to find the interventions that have the highest benefit to patients and provide best value for money.

Keywords: Discrete event simulation, STAR, decision support toolkit, deep vein thrombosis, patient flow modelling.

1 Introduction

The treatments of chronic diseases are complex and resource intensive, requiring multi-disciplinary teams including radiologists, specialist nurses, consultants and pharmacists. Combining this with a continuously increasing population and increased life expectancy (ONS, 2013), it is clear that healthcare systems around the world will find the management of such patients more and more challenging. In England in particular, the National Health Service (NHS) is faced with additional pressures stemming from ever increasing resource and capacity constraints, e.g. reduction in budgets, fewer doctors and nurses, reduced number of hospital beds.

To help guide key decision makers easy to use tools are needed to find ways of increasing efficiency/productivity and improving quality of services. The tool should respond to the concerns of end users and enable them to achieve a better understanding of the system structure and operations, and how these influence key performance metrics, such as activity results (e.g. the number of patients treated per year), resource utilisation levels (e.g. radiologist, clinician, nurses and beds), clinical and cost outcomes. In this context, the tool should accommodate the playing-out of a range of policies and scenarios relevant to decision makers and allow testing of the possible impact of these scenarios on the care system performance indicators. For example, the tool could determine the likely resource utilisation impact of a new policy whereby more patients are treated in the community as opposed to hospital. This could then enable the design of more pro-active and better-informed policies and help towards their integration into the commissioning process.

The tool should also tackle some of the commissioning challenges. Often commissioners are confronted with the following questions: what sort of interventions should we spend our money on? Where will we get the most value for our investment? How will we explain the choices we have made? These choices are difficult and they matter. More importantly is there an objective way of answering these questions?

To tackle these issues (and more) we describe a DST that was developed with the aim of assisting those responsible with the management, commissioning and treatment of Deep Vein Thrombosis (DVT) in the UK. DVT is a condition in which a blood clot (thrombus) forms in a vein. In 2005, it was estimated that 25,000 people in the UK die from preventable hospital-acquired venous thromboembolism per annum (NICE, 2014a). Every year, one in a thousand people in the UK is affected by this disease (NICE, 2014a). The risk of developing DVT also depends on a series of secondary factors such as immobility, age, existing cancer symptoms, pregnancy, obesity and sex (NICE, 2014a). Other concomitant conditions may also have an impact on a patient developing a DVT. The diagnosis has profound implications for the individual and their family, as well as major cost implications for hospitals and community services.

Having created a baseline discrete event simulation model and established its face validity, the DST captures the complexity of DVT services at a sufficient level and operates within a user friendly environment, that is, an interface was built to allow users to specify their own local DVT service and input their own estimates or data of service demands and capacities. The main strength of this decision support tool is the adoption of a team approach to studying the system, involving DVT specialist nurses

across the country, ensuring that a variety of views and suggestions are taken, as well as systems modelling and simulations.

The DST further introduces the Socio-Technical Allocation of Resources (STAR) (Airoldi et al., 2014) which is an approach to assess the cost-effectiveness of all interventions considered for resource allocation by adding health economics concepts to the discrete event simulation model to integrate aspects such as scale, costs and benefits more clearly. In the case of DVT, the variety of treatment options (either in the community or hospital) can be seen as interventions. Service providers and commissioners are particularly interested in finding the interventions that has the highest benefit to patients and provide best value for money.

Most analyses underpinning recommendations as to which interventions should be provided are difficult to understand, for example, cost effective analysis (CEA) carried out by the National Institute for Health and Clinical Excellence (NICE) for each drug. CEA is not appropriate for local decisions on resource allocation over the mix of services that ought to be provided, which entail making trade-offs to allocate a fixed budget every year within national policies (Airoldi et al., 2014). We visually illustrate the relative cost-effectiveness of interventions and interpret the results in a simple and concise manner, so that it could easily be understood by a commissioner, service provider, clinician and nurses. This is crucial to ensure speedy and effective decision making for change.

The current study therefore has three objectives.

- 1) Explore the impact of a range of changes to the Deep Vein Thrombosis disease pathway using discrete event simulation (DES) and to explore the

utility of this approach in this setting. Simulating patient pathways brings together an individual patient's entire journey for their medical condition (i.e. longitudinal cycle of care), capturing variation as they flow through the care system and incorporating a large number of different patient attributes such as length of stay, age, gender and disease stage. It allows for the running of the model over extended time horizons. Patients move through the model and they can experience events at any point in time, such as a series of diagnosis, treatment (including pharmaceuticals), follow-ups, disease progression, etc.

- 2) DES studies usually just examine the trade-offs between resources (utilisations) and service as measured by the availability of care, often waiting times. We adapt the STAR approach within DES to help local decision makers decide which of the interventions for DVT patients are likely to generate the greatest health benefit, with the highest value for money. Therefore, this study aims to consider wider measures of quality of health care.
- 3) Develop a user friendly decision support toolkit (a further development on the DES model) to enable users to interact with the model by allowing them to make necessary changes to the input parameters, so that the model is service specific with a customized set of results, focusing on activity, costing, value for money and resource utilization. These indicators are known to be valuable for key decision makers in the process of commissioning and re-designing services. This toolkit would provide the user with the ability to compare and contrast results from one scenario with another scenario with the results dependent on the variables specified by the user.

For illustration purposes we experiment to assess the possible impact of shifting more DVT patients from hospital care to community care services using the new treatment known as novel oral anticoagulant (NOAC) which is a new class of anticoagulant

drug, as opposed to standard of care (i.e. Warfarin). In addition to many outputs comparing the experiments based on key performance metrics, the STAR approach is implemented to examine which of the four possible interventions provide best value for money and benefit the patients most. The interventions are, 1) continue with the usual hospital treatment with Warfarin, 2) treat patients with NOAC in hospital, 3) treat with Warfarin in the community, and 4) treat with NOAC in the community. The policy rationale is that reducing the number of visits to hospital without affecting the quality of treatment (more importantly the outcome on patients), is strongly supported by the Department of Health in England, and therefore the DST should assist decision makers in changing the pathway for effective use of resources (i.e. the interventions that provide best value for money and benefits the patients most).

The next section provides an up-to-date review of the literature on healthcare simulation and application of DES for health economic modelling purposes. We then illustrate a qualitative map portraying the inner workings of the DVT pathway, model building assumptions, the input parameters, and describe the STAR approach in Section 3. All results with model outputs and scenarios are discussed in Section 4. Finally, in section 5 we discuss the limitations, usefulness and implications in practice.

2 Healthcare Simulation

One might ask a simple question “why is simulation needed?” Why can’t a simple calculation estimate the number of visits to hospital and/or costs associated with each intervention? There are marked differences between a simulation and cohort models (e.g. Excel based calculations). Cohort patient models estimate the outcome for a group of patients without explicitly considering the outcomes for each individual. They treat patients as sets of homogenous groups and view them in terms of “states” - healthy, ill or dead. They are difficult to adapt and hard to communicate, whereas a simulation captures all uncertainties (through distributional assumptions) such as variation in patient arrivals, diagnosis process, treatment and follow-ups, and thus the opportunity of capturing reality (to a certain extent). More importantly, the model enables us to incorporate individual event’s resource needs (e.g. consultant, nurse, consultation room, medication, etc.), enabling us to quantify the utilization of such resources.

Discrete Event Simulation (DES), System Dynamics (SD) and Agent Based Simulation (ABS) are the three popular simulation methodologies. DES has the ability to model individual patients and their unique trajectories as they flow through the care system and to incorporate a large number of different patient attributes such as age, gender and disease stage. It allows for the running of the model over extended time horizons. Patients move through the model and they can experience events at any discrete point in time.

SD divides populations into large homogenous groups, where each group of patients in the same clinical/care state is represented by the same variable state. The modelling of patients flows then aims to track the transition of these groups of patients between

the variable states and not the flow of each individual patient within the population (Brailsford, 2004).

ABS views the world differently to DES and SD. An Agent is an autonomous entity which has the ability to make decisions and therefore the focus in ABS, is to model how a decision is made. Individual behaviour of an agent is modelled and then multiple entities are sent to the environment in order for them to interact with each other and with the environment (Macal and North, 2010).

Out of the three simulation approaches (DES, SD and ABS), we have chosen to develop our model using DES as it allows for the running of the model over extended time horizons and enables tracking of individual patients footsteps in service and has the ability to incorporate capacity and resource constraints, hence capturing reality within a software environment (Simul8). Furthermore, it is an approach well understood and accepted by the NHS community, including clinicians, nurses, service managers and senior executives.

2.1 DES for health economic modelling purposes

Many DES models have been developed to support the planning of healthcare services including the operation of accident and emergency departments (Codrington-Virtue et al. 2005), English cervical cancer screening programme (Pilgrim and Chilcott, 2008), improvement measures in outpatient orthopaedics clinic (Rohleder et al. 2011), management of patients with Parkinson's disease (Demir et al. 2015), and many more. The literature in DES applied to healthcare services is vast. See Gunal and Pidd (Gunal and Pidd, 2010) for a comprehensive review of the literature on DES for performance modelling in hospitals. Katsaliaki and Mustafee (Katsaliaki and Mustafee, 2011) also present simulation applications in healthcare.

Within the last few years DES models have also been applied to fields such as cost-effectiveness analysis (or health economic modelling). Brennan et al (2006) suggests a taxonomy of model structures for economic evaluation of health technologies and, in doing so, identifies the role and importance of DES in health economics.

Pilgrim et al. (2009) used DES to develop the complete colorectal cancer patient pathway to examine the potential cost-effectiveness of different options for change across the entire colorectal cancer pathway. The benefits of each option were measured in terms of incremental life years and quality-adjusted years (QALYs) gained. The former represents the additional expected number of years of life gained by an individual patient as a result of the new option, as compared against the current service. The latter outcome is a generic health utility measure, accounting for both duration and quality of life.

Similar to the study by Pilgrim et al. (2009), Hideki and Barendregt (2011) developed a DES model that followed Australian population with osteoarthritis over their lifetimes. Intervention effects (i.e. total replacement of hips and knees) were modelled by means of disability-adjusted life-years (DALYs) averted, and one of their key findings was that both hip and knee replacements are cost-effective interventions to improve the quality of life of people with osteoarthritis.

Stahl et al. (2004) examined the effect of radically redesigning the delivery of anaesthesia care and determined the cost effectiveness of changes to balance efficiency and surgical safety of patients undergoing laparoscopic cholecystectomy. The impact of continuing with the current practice where an anaesthesiologist remains at all times until surgery is complete (including recovery) was compared against

several other staffing strategies, for example, physicians and nurses for anaesthesia coverage (the proposed new practice). DES was used to compare these two strategies and according to the cost-effectiveness analysis, the proposed new practice is more effective and less costly.

NICE recently published a comprehensive report (NICE, 2014b) on cost effectiveness modelling using patient level simulation. The report exhaustively compares existing modelling techniques against DES. Typically, existing methods are decision trees and Markov Chain Monte Carlo simulation applied for cost effectiveness analysis purposes, e.g., QALYs and incremental cost effectiveness ratio (ICER). Given the exhaustive nature of the report it is clear that no matter what modelling methodology is utilised the health economic modelling is always the same (QALYs and ICER) combined with sensitivity analysis. Note that NICE plays a very important role in England in the use of health technologies within the NHS, such as the use of new and existing medicines, treatments and procedures.

Other DES models were also developed for similar purposes. Igarashi et al. (2016) compared the health and economic consequences in Japan of using pharmacotherapy to support smoking cessation with unassisted attempts and the current mix of strategies used. According to their findings, increased utilisation of smoking cessation pharmacotherapy to support quit attempts is predicted to provide improvements in health outcomes over a lifetime with no additional costs. A similar study was also conducted by Getsios et al. (2013) and Mayorga et al (2014) estimating the health and economic outcomes associated with smoking cessation interventions. Comas et al. (2014) assessed the cost-effectiveness of switching from one method of breast cancer screening to another (i.e. screen-film mammography to digital mammography). An interesting study was conducted by Verjan et al (2013), where the economic impact of

providing healthcare at home was compared against traditional hospitalisation using modelling with Petri nets and discrete event simulation. A key finding was that healthcare at home can be used to control and improve patients flow on hospitals.

Our approach of combining DES with the STAR approach is unique in its response to the concerns and needs of key decision makers, where the adaptation of the STAR approach could easily help commissioners/clinicians determine the interventions that have the greatest health benefit and that provide best value for money. In all of the above instances, either QALYs and/or ICER were utilised for cost effectiveness analysis. It is clear from the literature review and authors' domain knowledge, to date no model has been developed and implemented tackling all the above specified challenges within a single DST framework.

3 Material and methods

3.1 Additional setting description

The first stage of the pathway mapping was to research the current practices within the industry, which occur for the particular disease being evaluated. This included utilising publications from the industry, such as the National Institute of Clinical Excellence and other sources of information, which are recognised within the industry. This allowed a baseline plan of the treatment events and a range of 'what-if' scenarios for a particular patient within the patient pathway.

The second phase of the pathway mapping consisted of structured interviews with DVT nurses across a number of clinics between March and July 2013. The interviews were conducted 'on line' using technology to allow the interviewer to share a working diagrammatic representation of the pathway. The interviewer discussed each stage of the pathway with the interviewee taking account of the interviewee's opinion and

adjusting the pathway in ‘real time’ as comments were made. Once the interviewee was satisfied with the structure of the pathway, the interview was closed. The interviews were recorded so that the interviewer could review comments after the event to ensure that all salient points had been captured. In total six experts were interviewed iteratively. The objective was to explore the DVT pathway in order to establish what, in the experts’ opinion, important areas were for development. They viewed the number of options, which need to be static or variable for the simulation model to represent the possible scenarios which could be run by a clinic around the country.

According to the interviews the typical care system in place in England, and elsewhere for diagnosing, treating and looking after patients with DVT, comprises a complex set of services offered in and out of hospital. Examples of care services offered in hospital include emergency care, outpatient appointments with specialists such as specialist nurses, access to advanced diagnostic procedures such as ultrasound and blood tests. In addition, each individual patient’s treatment option through the three main options of DVT influences to a large extent the type, location and intensity of care services in each individual’s care package.

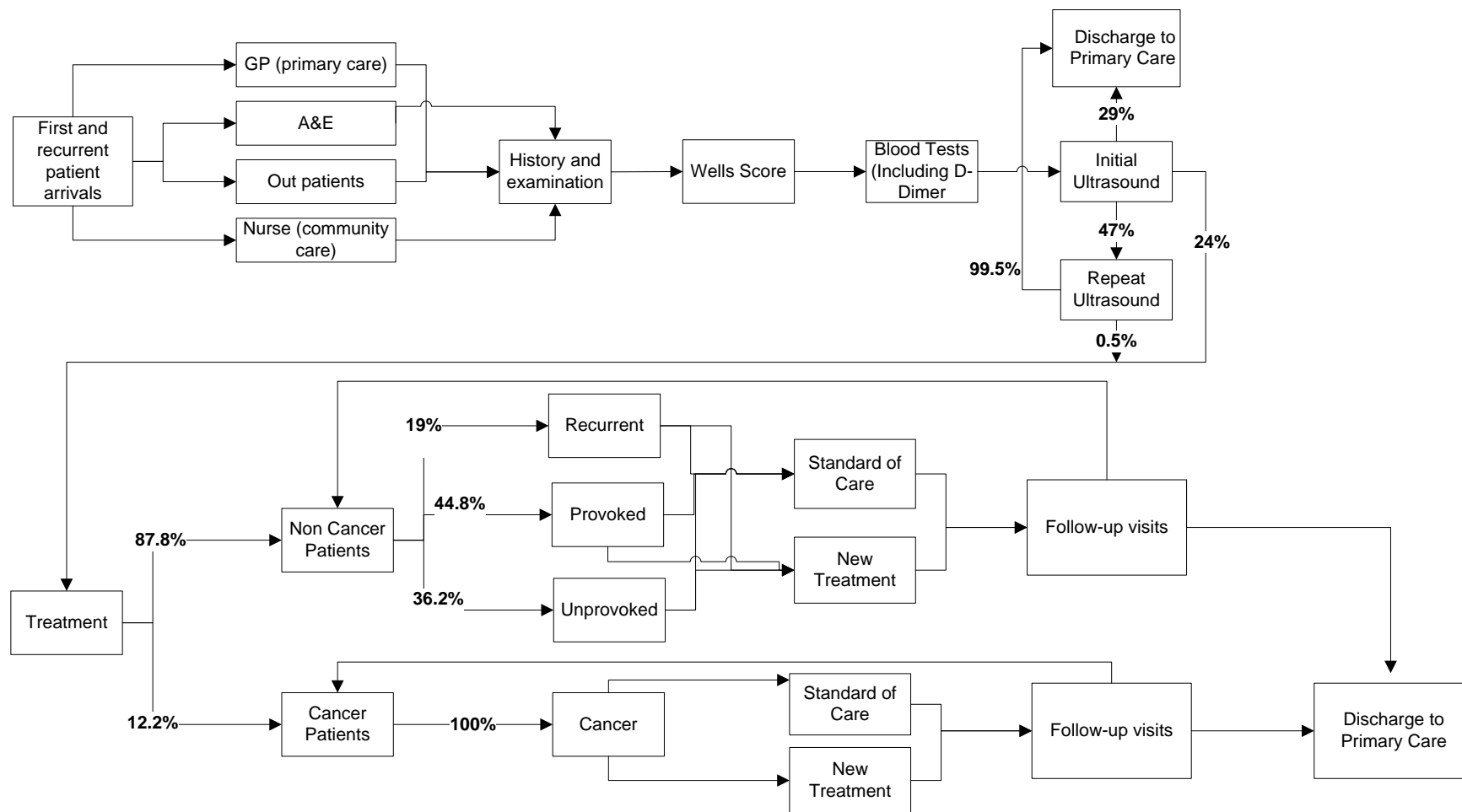


Figure 1 Conceptualised pathway for DVT patients.

Figure 1 shows diagrammatically the inner workings of the DVT pathway. Arrivals are split into two: new patients and recurrent (those experiencing a recurrence of the disease) where 19% of arrivals are recurrent (Martinez, Rietbrock , Bamber , & Cohen, 2011). The annual incidence rate of DVT is 104.6 patients per 100,000 population, which is a parameter used as part of demand for DVT services (Martinez, Rietbrock , Bamber , & Cohen, 2011). A patient can be presented to the service via their general practitioner (which is the majority of cases), accident and emergency, outpatient services or a community nurse. The diagnosis is made up of four stages: history and examination, Wells score, D-dimer test and an ultra sound. Wells score is a clinical prediction rule used to estimate the pre-test probability. This suggests whether a patient is at low, moderate or high risk of having suffered a DVT, which may guide subsequent investigation and management. Depending on who is delivering the service, the Wells score test can be carried out either by a GP or a clinician at an anticoagulation service.

The Wells score on its own is not enough to confirm DVT, hence a D-dimer test is carried out (blood test), which detects pieces of blood clot that have been broken down and are loose in the bloodstream. The larger the number of fragments found, the more likely that the patient has a blood clot. However, the D-dimer test is not always reliable and therefore an additional test, an ultrasound scan, needs to be performed to confirm DVT. The D-dimer test and ultrasound scan results can be categorized as positive or negative, whereas the Wells score is ranged from 0 to 9. A patient scoring greater than 2 is at a high risk of having suffered a DVT. Wells et al. (2003) found that 46% of patients have a 'Wells Score' of greater than 2, whereas 30% of D-dimer (Wells, et al., 2003), 24% of ultrasound and 1% of repeat ultrasound tests are found to be positive, respectively (Goodacre, et al., 2006).

For a patient to be deemed to have a DVT, physicians rely on the combination of test results. Individual diagnostic outcomes expressed in probabilities (see Table 1) are multiplied to calculate the final outcome of diagnosis, that is, whether the patient is diagnosed for DVT (hence treatment) or not diagnosed (no treatment). For instance, if a patient has a positive Wells score (i.e. greater than 2), a negative D-dimer test result and a positive ultrasound result then treatment commences (7.728% of all cases - see Outcome 2 from Table 2). Note that there are many combinations and the percentages are calculated using the values shown in Table 2. For example, Outcome 1 is estimated to be 0.03312 ($0.46 \times 0.30 \times 0.24$).

Diagnostic tests	Probability of a positive diagnostic outcome (+)	Probability of a negative diagnostic outcome (-)
Wells Score	0.46	0.54
D Dimer	0.30	0.70
Ultrasound	0.24	0.76
Repeat Ultrasound	0.01	0.99

Table 1: Individual diagnostic outcomes expressed in probabilities.

	Wells Score	D-dimer test	Ultrasound	Probability	Final Outcome
Outcome 1	+ (0.46)	+ (0.30)	+ (0.24)	0.03312	Treatment
Outcome 2	+ (0.46)	- (0.70)	+ (0.24)	0.07728	Treatment
Outcome 3	- (0.54)	- (0.70)	+ (0.24)	0.09072	Treatment
Outcome 4	- (0.54)	+ (0.30)	+ (0.24)	0.03888	Treatment
Outcome 5	+ (0.46)	+ (0.30)	- (0.76)	0.10488	Repeat ultrasound
Outcome 6	- (0.54)	- (0.70)	- (0.76)	0.28728	No treatment
Outcome 7	+ (0.46)	- (0.70)	- (0.76)	0.24472	Repeat ultrasound
Outcome 8	- (0.54)	+ (0.30)	- (0.76)	0.12312	Repeat ultrasound
Total	NA	NA	NA	1	NA

Table 2: Combination of diagnostic tests and outcomes. + and – refers to positive and negative diagnostic outcome, respectively.

As the outcome of each diagnostic test is independent from each other, we assumed independence and thus multiplied to calculate the probability of the final outcome of diagnosis.

According to the above calculations, around 29% of patients are discharged back to primary care (Outcome 6), i.e., no trace of DVT; 24% are diagnosed of DVT after an initial ultrasound test ($P(\text{Outcome 1}) + P(\text{Outcome 2}) + P(\text{Outcome 3}) + P(\text{Outcome 4}) = 0.24$). The remaining 47% (Outcome 5+Outcome 7+ Outcome 11) have a repeat ultrasound. After similar calculations as above, we found that approximately 0.5% of repeated ultrasound patients are diagnosed with DVT and the remaining 99.5% are discharged back to primary care (no DVT).

So far we have described the diagnosis aspect of the DVT care pathway. When a patient is diagnosed treatment commences within 1-4 weeks of diagnosis. The treatment arm distinguishes cancer from non-cancer patients. Approximately 87.8% of DVT patients are non-cancer (Martinez, Rietbrock , Bamber , & Cohen, 2011). These patients are further categorised into groups: recurrent (recurrence of DVT, i.e. 19% of all admissions are recurrent), 44.8% are provoked and 36.2% are unprovoked (Martinez, Rietbrock , Bamber , & Cohen, 2011). Provoked and unprovoked DVT types are not distinguished for cancer patients. Provoked DVTs can be linked to a discernible event such as surgery or plane travel, whereas unprovoked DVTs have no obvious causes. Patients could either be on standard of care or new treatment (NOAC). In standard of care all patients are initially treated with Low Weight Molecular Heparin (LMWH) in the first eight days followed by Warfarin in subsequent weeks and months.

Typically, 22%, 63% and 15% of provoked patients on Warfarin visit anticoagulation clinics (also known as INR clinics) on an average of 9, 14 and 24 times over 3, 6 and 12 months, respectively (Winter, Keeling, Sharpen, Cohen, & Vallance, 2005) (Rose, James, Chapman, & Marshall, 2011). In the case of Unprovoked patients on Warfarin, 6%, 63% and 31% visit INR clinics on average of 9, 14 and 24 times over 3, 6 and 12 months, respectively. Similarly for recurrent patients, 3%, 42% and 55% visit 9, 14 and 24 times over 3, 6 and 12 months, respectively.

INR clinics have long been considered resource intensive due to the strict monitoring of the side effects of Warfarin, which in extreme cases can be life threatening.

Conversely the under treatment of patients can lead to side effects. Newer treatments have far less severe side effects, thus enabling the rationalisation of the patient pathway. In the new treatment pathway (NOAC), patients have an initial visit (first attendance with the consultant) and a follow-up visit for routine review (in total 2 outpatient attendances). Patients on standard of care are required to attend a clinic (under the control of a nurse) for treatment (9, 14 or 24 times over 3, 6 and 12 months, respectively). Significant savings in time and other resources can be expected from the new treatment as a result of dramatic reductions in the number of visits to INR clinics.

3.2 Model building including assumptions

As is the case in modelling studies, some aspects of the real life service were not included in the model (if they were not relevant to the objectives of the study) and others were modified for simplification purposes. These were discussed and agreed with the nurses and specialists who were consulted during the model building process. The model building (or conceptualisation) was mostly related to the telephone interviews held with six DVT specialist nurses. Other staff specialties (e.g.

administrative clerks, other specialists that were not included) and infrastructure elements (e.g. consultation rooms, mode of transportation used for community visits) that could be seen as capacity constraints, were not included in the model as these were not seen as critical by the stakeholders. There are no cancellations (either patient or service initiated) of outpatient consultations or community based visits. The presence of co-morbidities and other factors, such as socio-economic status or living arrangements, that may complicate the provision of care for a particular patient, were not included in the model. However, cancer patients diagnosed for DVT are regarded as a major complication, and thus the care pathway explicitly distinguishes these two groups, i.e., cancer and non-cancer patients have a unique flow within the model. Other complications such as presence of co-morbidities and other factors were not included, as recommended by nurses and specialists.

3.3 Input parameters

Model inputs included staffing levels, staff salary, staff availability, treatment pathways (hospital and the community), arrivals, discharges, percentage of patients falling into each category, costing of each service, existing and new patient arrivals and treatment option visit parameters (see the Table in Appendix for details). The vast majority of input parameters are pre-determined through in-depth review of the literature and, on a small number of occasions, nurses provided their expert opinion. Note that all input parameters are pre-populated and can be changed by the service provider (or purchaser) if the users deem this to be necessary to fit their geographical area.

The input parameters cover a range of areas for the DVT simulation model comprising *demand*, *diagnosis*, *treatment*, *costing*, and *salary* attributes. The *demand* for the service takes in to consideration the population and the annual increase in the

patient numbers each year. The population is 104.6 patients per 100,000 in the general population (Martinez et al, 2011) and is collaborated by the Office of National Statistics (ONS).

The *treatment* options for the service take into consideration the type of treatment provided to the patient, the length of treatment, the initial and follow up visits required dependent on patient type (e.g. provoked, unprovoked or recurrent). Further attributes include how much time is taken for the visits to occur, as well as the responsibility for each type of staff connected with such a visit. Each of these attributes are variable and can be determined by the user. The attributes are obtained through extensive research of the pathway and thorough detailed analysis of the treatment options which can be provided to a DVT patient.

The *costing* option within the simulation model comprises the costs of initial and follow up visits within a haematology clinic, which are determined by the National Payment by Result Tariff (2013/2014). However, they can be overridden by the user (Payment by Result, 2013). An initial visit costs around £247.00 and a follow-up visit is £113.00. The cost for the community treatment options are variable and can be determined locally, as this is an area where there can be variation dependent on the geographical region. The drug costs are determined by the Monthly Index of Medical Specialities (MIMS). Other costs which contribute to this area of the simulation model are the salaries of the staff involved, namely, haematologists, specialist nurses and radiologists (PSSRU, 2013). Users can easily specify the number of available resources within their DVT services to analyse the effects of increasing/decreasing resources (see the Table in Appendix for an exhaustive list of the input parameters).

3.4 Socio Technical Allocation of Resources (STAR)

The current healthcare landscape demands that those who plan or commission services at local, regional or national level provide high quality health and social services that offer good value for money. There is also a requirement to involve patients and the public in decisions about service planning. STAR helps those who plan or commission services to work with their stakeholders to allocate resources to benefit patients in their community. In our context, the objective is to allocate scarce resources for the treatment of DVT. The STAR methodology (Airoldi et al. 2014) is slightly modified to fit our purpose and is made up of the following components:

- Costs(c_j): the total cost of the entire pathway for patients in intervention j including individual patient's footsteps in each service (e.g. diagnosis, treatment, drug acquisition costs and follow-ups), use of equipment and staff costing (hourly rates).
- Population health benefit ($N_j \times B_j$): the product of the number of patients who benefit from the intervention (N_j) and the potential benefit (B_j) in quality (and length) of life, assuming successful implementation, to the typical beneficiary, compared with current care. Health benefits are generally measured in quality-adjusted life-years (QALYs). Due to time constraints and exploratory nature of this approach, Airoldi and colleagues (Airoldi et al. 2014) used direct rating with a visual analog scale technique on the basis of the evidence brought by clinical experts. During the nurse interviews DVT specialist nurses identified the intervention providing the greatest individual benefit, which was assigned a score of 100. They then scored the remaining three interventions relative to this benchmark score of 100. The interventions are, 1) continue with the usual hospital treatment with Warfarin, 2) use more NOAC in hospital, 3) treat

patients with Warfarin in the community, and 4) treat with NOAC in the community.

- Feasibility (p_j): Probability of success of achieving the assessed benefits.
- Expected benefit $E(v_j)$: The model underpinning the evaluation is to Max $\sum_j E(v_j)$, which is the expected benefit from intervention j calculated as $E(v_j) = p_j(N_j \times B_j)$.
- Value for money (VfM): $VfM_j = \left(\frac{E(v_j)}{c_j} \right) \times 1000$

The cost (c_j) and the expected benefit $E(v_j)$ are presented using a right angle triangle known as value for money triangle. The horizontal side of the triangle represents the cost (c_j) associated with the intervention and the vertical side represents the expected benefit score $E(v_j)$. The slope of the hypotenuse of the triangle represents cost-effectiveness. The steeper the slope, the greater the ratio of health benefits to costs. The triangles are used to generate a priority list (graphically illustrated for ease of understanding) in which interventions are ranked according to value for money.

4 Illustrative Results

4.1 Simulation Parameters

For illustration purposes of the model and the tool, we chose to evaluate the likely effect and size of some changes that seek to increase the use of new treatment (NOAC), in line with current policy guidance for DVT patients. The model was populated with a population of 250,000 (a typical size of a clinical commissioning group in England) at the beginning of year 1. The simulation was run for five years to capture the individual trajectories in the cohort over this period and to estimate the

likely impact of changes in performance indicators related to activity, costs, and utilisation of resources (e.g. nurses, consultants and haematologists).

The number of patients requiring treatment, which determines the level of demand on care services, is not constant over time but has an upward trend. The model captures this aspect through the year-to-year percentage increase in the number of patients in the service. The data for the yearly increase in arrivals is user specified and as such is determined by the values the user has entered (in this context a 1% increase is projected).

In the interviews we had with the six DVT specialist nurses we asked questions seeking their expert opinion (where no data or references were available). These included questions like: how patients enter the system, treatment time, the percentage of time each type of staff is responsible, and the number of resources. According to their responses, typically 60% of patients first present via general practitioner referrals, 10% through community care, 20% outpatients and 10% A&E. The average staff time it takes to conduct a first and follow-up visit to the DVT clinic is 75 and 60 minutes, respectively. On average Haematologists are responsible for 10% of all treatments, 80% DVT nurses and 10% radiographers. All remaining input parameters are entered according to the estimates provided in the appendix.

The model was run for a simulation period of 5 years with a warm up period of 1 year (determined using the Welch method) to make sure that the results were not collected until all patients in the cohort had gone through the DVT care system and had an initial contact with a nurse, radiographer or a haematologist. The weekly simulation period was Monday to Friday from 9am to 5pm reflecting the current operating arrangements in DVT care services.

4.2 Model Validation

The model validation process was carried out by comparing the expected number of activity results over a 5-year period using the known data in the actual care system, with the simulation results. As described in the previous section, the total patient population size is expected to reach 275 by the end of year 5. The total number of visits over a 5-year period was calculated taking into account the total cohort size, the fraction of the DVT category (i.e. provoked, unprovoked and recurrent), the number of visits per year for each category, and the simulation duration of 5 years. The difference between the real life calculations and the simulation model has been within the confidence interval range of 95%, giving a result from the model, which is within 5% either side of the expected result. This deems the model suitable to allow further experimentation with other scenarios.

To achieve face validity, the model was shown to each nurse individually and then in a workshop including all six nurses. The model structure was confirmed to be highly representative of the real world DVT care system by all six nurses in the individual meetings and during the workshop where the whole group was present. In general, the continuous engagement of the DVT nurses throughout the study significantly increased confidence in the validity of the model.

4.3 Experimentation

The aim of the experiment is to assess the possible impact of shifting more DVT patients from hospital care to community care services using the new treatment. There is evidence that this should have a positive impact on the operational and financial performance of the DVT care system (NICE, 2014a), it is important to support this by stronger evidence including quantification of any benefit of such policy. In addition, STAR will help key decision makers better understand the interventions that are likely

to benefit the patients the most with the greatest savings (efficiency and productivity), and thus effective decision making benefiting patients, tax payers, the NHS and beyond.

The tool enables users to input parameters for two sets of scenarios, the first for the baseline model (existing service) and the second for experimentation. Therefore, all input parameters can be customised for both scenarios. In the first scenario it is assumed that 100% of patients are treated in hospital (hence 0% in the community) and 0% on new treatment. The second scenario tests the impact of increasing community services for the treatment of DVT, e.g. 80% in hospital and 20% in the community (see Table 3 for a list of scenarios). In addition, we increase the use of new treatment in steps of 20% (and reduce standard of care) and investigate key performance metrics as in Table 3 (column 1).

Key performance measure	Baseline - 100% in hospital and 0% on new treatment	80% in hospital and 20% on new treatment	60% in hospital and 40% on new treatment
Total number of INR visits (first and follow-ups), including cancer patients	61,494 [57,804, 65,184]	42,295 [39,292, 45,298]	34,884 [32,930, 36,907]
Total cost of standard of care (including drug costs), i.e., LMWH and Warfarin (including cancer)	£3,039,843 [£2,863,532, £3,216,154]	£2,146,730 [£2,015,779, £2,277,681]	£1,330,469 [£1,251,971, £1,408,967]
Total cost of new treatment (including drug costs and cancer patients)	£0.00	£201,357 [£189,074, £213,841]	£374,225 [£352,520, £395,930]
Total cost (standard of care + new treatment) including cancer	£3,039,843 [£2,863,532, £3,216,154]	£2,348,087 [£2,214,246, £2,481,928]	£1,704,694 [£1,609,231, £1,800,157]
Total nurse service hours	11,195 [10,523, 11,867]	9,578 [8,888, 10,277]	7,125 [6,633, 7,617]
Total haematologist service hours	4,407 [4098, 4729]	3,568 [3,372, 3,786]	1,549 [1,443, 1,659]

Table 3 Key performance metrics and the generated high level outputs from the DVT model (numbers in brackets is the 95% confidence interval).

The model was run 100 times using a different seed for each run for a period of five years. The results indicate that increasing use of community services (under the new treatment regime) will have a positive impact on the number of INR visits and its associated costs. The number of INR visits has reduced from 61,494 (on average) to 42,295 under the 20% increase on new treatment (in community care). This is quite a significant reduction taking into account the fact that nurses in the DVT treatment services are highly utilised and under huge workload pressure (11,195 nurse hours have reduced down to 9,578). The other positive impact of the increased use of new treatment and its resulting decrease in the activity and nurse service hours is the cost savings. The total costs have reduced from £3,039,843 to £2,348,087 (£691,756 savings). These reductions are significant in the DVT care services and the general health care services, where squeezed budgets and funding cuts are expected to become a feature of the healthcare landscape in the future (Figure 2 illustrates the comparison between the scenarios). Undoubtedly increased use of new treatment (NOAC) in the community generates huge savings, but is it value for money and more importantly, would patients actually benefit from this service transformation?

According to Table 4 treating patients in the community with NOAC generates the highest value for money with an expected health benefit of 24,300, which is much greater than patients treated in the community and hospital with warfarin. Figure 3 shows the same information as Table 4 but in graphic form. Graphical illustration attracted considerable attention amongst the decision makers which had stimulated the discussion and generated important learning, e.g., treating patients in hospital with Warfarin consumed the largest amount of costing, with very little health benefit, whereas NOAC in the community produced a steep hypotenuse representing greater ratio of health benefits to costs.

Intervention	Number of patients (N)	Health improvement as indicated by nurses (B_j)	Probability of success (p_j)	Expected Health Benefit $E(v_j)$	Value for Money (VfM _j)	Total Cost (c_j)
NOAC Community	243	100	1	24,300	859.96	£28,257
NOAC Hospital	321	100	1	32,100	261.08	£122,953
Warfarin Community	322	30	1	9,660	38.10	£253,543.40
Warfarin Hospital	465	30	1	13,950	13.73	£1,015,999.10

Table 4 Results based on 60% of patients been treated in hospital with Warfarin and 40% in the community with NOAC over the 5 year simulation period (ranked by value for money). Probability of success ($p_j = 1$) means that the intervention (Warfarin or NOAC) can be successfully implemented in practice with a probability of 1.

Note that the model is not limited to these outputs, it's developed to generate a series of key performance metrics, reporting scenario 1 and scenario 2 (for each of the five years) with respect to arrivals; diagnosis process (wells score test, d-dimer test, ultrasound and repeat ultrasound); treatment process (standard of care, new treatment, DVT categories, cancer patients, initial treatment, follow-ups); financial reporting of all activities in the diagnosis and treatment phase; and staff utilisation in terms of service hours and full time equivalent needed to ensure services are provided efficiently and effectively.

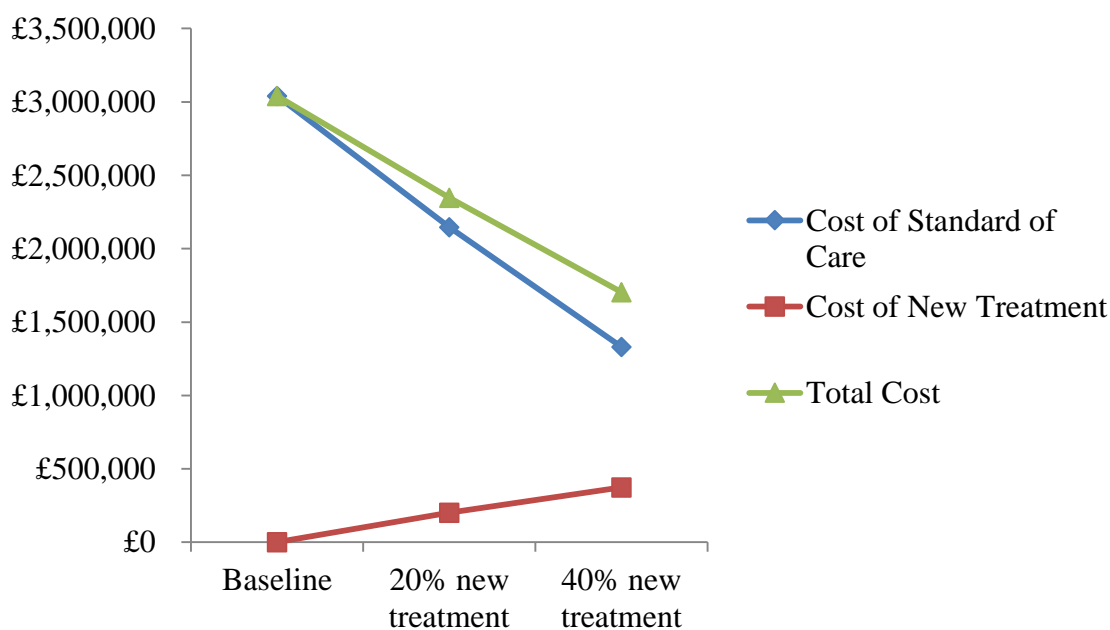


Figure 2 Costing implications of new treatment (NOAC) in community care (vs. standard of care in hospital, i.e., Warfarin)

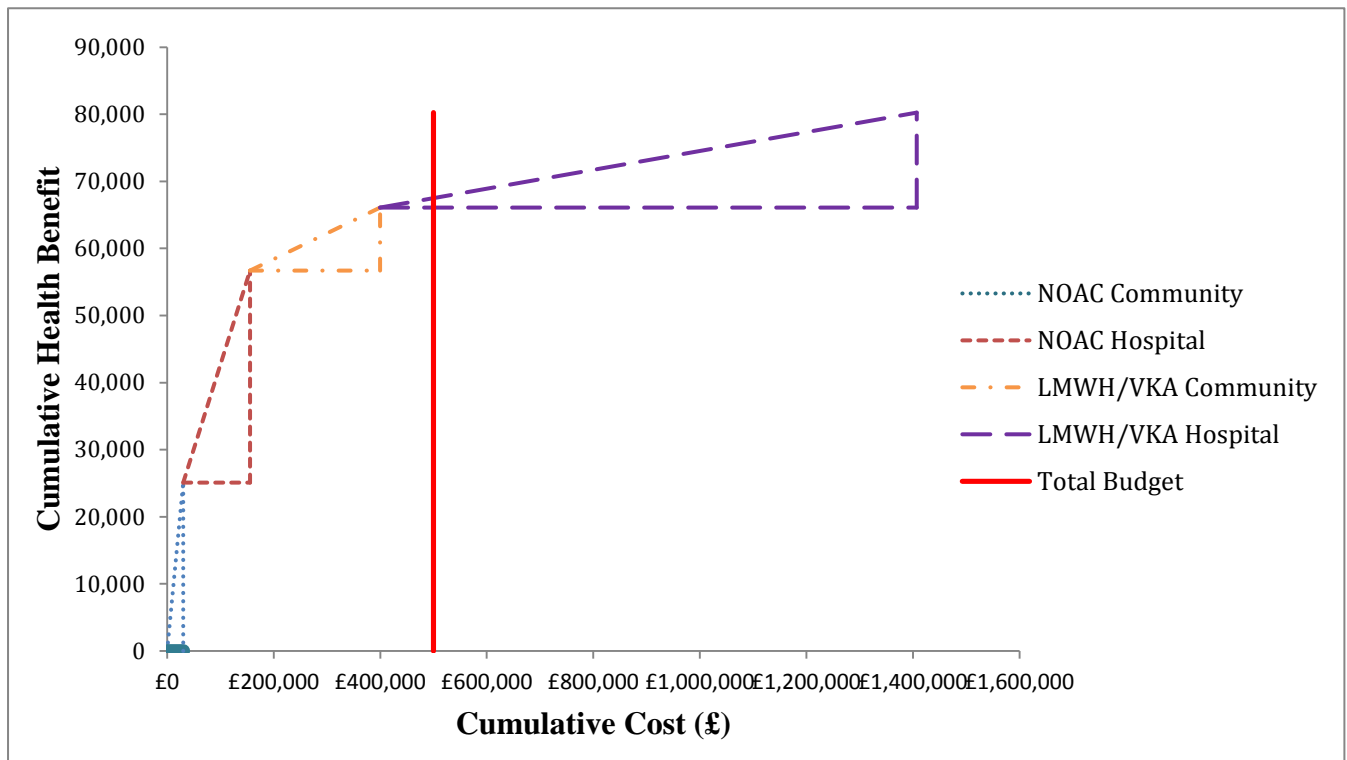


Figure 3 Interventions ranked according to value for money

5 Discussion

As described earlier in the paper the tool was designed with specialists in the DVT patient pathway. The authors have first-hand experience of the frustration that can sometimes accompany planning and approving new services in healthcare systems. Often changes are introduced without proper consideration of the impact on the service. It is also often the case that those people working in the healthcare system know how they would like to improve the service they deliver, but lack the expertise to frame those improvements in a manner that will be acceptable to executives and holders of finance budgets. This tool therefore has been designed to allow ‘non-experts’ to test change on the pathway in a validated simulation. The simulation will present the impact of changes in a pathway in a way that can be easily understood by both the executive and pathway specialists. It is the authors’ intention that this will

facilitate service planning and decision making and speed up the pace of change in the DVT pathway. Furthermore, the use of simulation as a decision making tool is still in its infancy in the UK. We would therefore recommend that a longer term study on the impact of the DVT simulation would be helpful. We would suggest following the progress of service development projects that use simulation, in comparison with those that do not. The simulation could also be improved by incorporating primary care data which would add considerably to the robustness of the assumptions that are used to support the simulation.

This DVT simulation is currently being used by a major pharmaceutical company to facilitate service change in the UK. The simulation is being used nationwide by the pharmaceutical company's healthcare development team with the objective of developing DVT services for the benefit of patients, the healthcare provider and the company, who also supply some of the drugs used in the pathway.

The tool allows decision makers to better understand the operation of the system in relation to key performance metrics associated with activity, cost implications and resource utilisation. The ease of use of the tool with relevant sets of exported results means that senior decision makers could be more proactive with evidence based approach in re-designing their care pathway in finding the most efficient and effective delivery of care to patients with DVT.

The illustrative scenarios which were tested on the simulation based DST developed in this research, give a clear indication of the importance of the tool to guide decision making in the health management sector. If we take into account the significant number of possible scenarios which can be simulated and the wide range of performance indicators incorporated in the model, the huge potential of the tool

becomes obvious. This can only be welcomed in the area of healthcare management given how important it is for the wellbeing of individuals and society, the complexity of the health care delivery system, and the growing challenges to improve effectiveness and efficiency in health care delivery.

The simulation results suggest that an increased use of new treatment (or NOAC) in community services will have a positive impact on the workload (i.e. INR visits) and utilisation of DVT nurses. The policy rationale follows that making more use of new treatment to treat and monitor the evolution of the DVT patients health state, and thereby alleviate the workload pressures on nurses, is strongly supported by the simulation results. STAR further supports this in relation to health benefits to costs. The visual aids have proved essential to make the cost effectiveness analysis framework accessible to those key decision makers who lack quantitative ability. In addition, the triangles helped clinicians, nurses and commissioners to share their knowledge and articulate their opinions on the impact of service re-design.

As such, the simulation based DST developed here is a very good example of the “evidence based decision making” tools, which have gained in popularity in the last few years, especially within the healthcare management sector. It is also a good example of how a DST can be developed and used in the context of integrating health (i.e. in the hospital) and social care (i.e. in the community) systems. Although the discrete event simulation and the STAR approach were developed for DVT patients, similar approach can be adapted for other disease areas. Given the uniqueness of our approach (i.e. combining DES with STAR within a single decision support tool), this paper makes a significant contribution towards empowering key decision makers to enable better management of patients.

A limitation of the study is that we did not take account of co-morbidities and interactions with other diseases which may impact on the speed of disease progression and the associated level of care. The model was built using information from a single context, which can “corrupt” the results and reduce confidence in the validity of the results and the ensuing policy decisions.

The main strength of this decision support tool is the adoption of a team approach to studying the system, involving six DVT specialist nurses across the country, ensuring that a variety of views and suggestions were taken as well as systems modelling and simulation. This led to a model with high face validity and credibility among its users. Future work could explore additional ways in which the current model could incorporate individual patient characteristics (e.g. disease severity, age group, gender, etc.), which may alter patients pathway and explore the impact on activity results and costing. Furthermore, the evaluation of performance would be more realistic if it included performance indicators related to the quality of care and its impact on the quality of life of patients, and investigated how these aspects may affect readmission and mortality and the movement of patients between the different care services within the pathway.

Acknowledgements

We would like to thank the following DVT Nurses for their valuable input towards establishing the DVT pathway: Jo Eggleston, University Hospitals NHS Trust; Emma Kinnaird, Bristol Royal Infirmary; Sarah Stockhall, Royal Liverpool University Hospital; Zara Lester, Royal Eye Infirmary; Carole Oughton, Broomfield Hospital, and Marilyn Rees, Lansdowne Hospital.

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Appendix

	Estimate	Distribution	Reference
Demand			
Please specify prevalence rate of DVT within your population	104.6 per 100,0000 population	Poisson	Martinez et al. (2011)
Please specify the proportion of patients with Cancer	12.20%	Multinomial	Martinez et al. (2011)
Please specify the % of the diagnosed population with RECURRENT DVT	19%	Multinomial	Martinez et al. (2011)
Please specify the annual increase for each year (1-5) of patient arrivals	User specified	Bernoulli	N/A
Diagnosis			
What is the percentage of DVT patients arriving from the following sources?			
Percentage arriving from the GP Direct	User specified/Expert opinion	Multinomial	N/A
Percentage arriving from Community Care	User specified/Expert opinion	Multinomial	N/A
Percentage arriving from outpatients	User specified/Expert opinion	Multinomial	N/A
Percentage arriving from Accident and Emergency (A&E)	User specified/Expert opinion	Multinomial	N/A
What percentage of DVT patients will...			
have a 'Wells Score' of greater than 2	46%	Bernoulli	Wells et al. (2003)
have a 'Wells Score' of less than or equal to 2	54%	Bernoulli	Wells et al. (2003)
What percentage of DVT patients will have a...			
positive 'D-Dimer' test result	30%	Bernoulli	Wells et al. (2003)
negative 'D-Dimer' test result	70%	Bernoulli	Wells et al. (2003)
What % of people will have a			
Positive first ultrasound	24%	Bernoulli	Goodacre et al. (2006)
Positive repeat ultrasound	1%	Bernoulli	Goodacre et al. (2006)
What percentage of DVT patients will have			
Unprovoked	44.80%	Multinomial	Martinez et al. (2011)
Provoked	36.20%	Multinomial	Martinez et al. (2011)

Recurrent	19.0%	Multinomial	Martinez et al. (2011)
Treatment			
What percentage of patients will receive the following options?			
Standard of Care (LMWH + Warfarin)	User specified/Expert opinion	Bernoulli	N/A
New treatment	User specified/Expert opinion	Bernoulli	N/A
Please define the % of patients and length of treatment			
	Recurrent		Bauersachs et al. (2010)
3 months	3%	Multinomial	
6 months	42%	Multinomial	
12 months	55%	Multinomial	
	Provoked		
3 months	22%	Multinomial	
6 months	63%	Multinomial	
12 months	15%	Multinomial	
	Unprovoked		
3 months	6%	Multinomial	
6 months	63%	Multinomial	
12 months	31%	Multinomial	
Please indicate the length of treatment for cancer patients			
6 months	100%	Fixed	Noble et al. (2008)
Please indicate the number of follow up visits required	Warfarin		
3 months	9	Poisson	Winter et al. (2005), Rose et al. (2011), Keeling et al. (2011)
6 months	14	Poisson	
12 months	24	Poisson	
	LMWH		
8 days	8	Fixed	(Scottish Intercollegiate Guidelines Network, 2010)
	New treatment		
3 months	2	Poisson	New treatment Prescribing Information (PI)
6 months	2	Poisson	
12 months	2	Poisson	
On average how much staff time does it take to conduct a FIRST visit to the DVT clinic	User specified/Expert opinion	Average	N/A
Please indicate the % of time each type of staff is responsible			
Haematologist	User specified/Expert opinion	Multinomial	N/A
Nurse	User specified/Expert opinion	Multinomial	N/A

Radiologist	User specified/Expert opinion	Multinomial	Expert Opinion
On average how much staff time does it take to conduct a FOLLOW-UP visit to the DVT Clinic	User specified/Expert opinion	Average	Expert Opinion
Please indicate the percentage of time each type of staff is responsible			
Haematologist	User specified/Expert opinion	Multinomial	Expert Opinion
Nurse	User specified/Expert opinion	Multinomial	Expert Opinion
Radiologist	User specified/Expert opinion	Multinomial	Expert Opinion
Costing			
Cost of FIRST Visit to Haematology/DVT clinic	£247	Fixed	Payment by Result (2013)
Cost of FOLLOW-UP Visit to Haematology/DVT clinic	£113	Fixed	Payment by Result (2013)
Cost of FIRST visit community DVT clinic	User specified/Expert opinion	Fixed	N/A
Cost of FOLLOW-UP visit community DVT clinic	User specified/Expert opinion	Fixed	N/A
New treatment price per tablet	£2.10	Fixed	(MIMS)
LMWH (NON CANCER) cost per day	£9.77	Fixed	(MIMS), assuming an average patient weight of 80kg
LMWH (CANCER) cost per day month 1	£8.47	Fixed	(MIMS) assuming an average weight of a patient 69-82Kg
LMWH (CANCER) cost per day after month 1		Fixed	
Warfarin cost per day	£0.07	Fixed	(MIMS)
Salary - Hourly Cost			
Haematologist	£139	Fixed	PSSRU (2013)
Nurse	£123	Fixed	PSSRU (2013)
Radiologist	£139	Fixed	PSSRU (2013)
Number of resources			
Haematologist	User specified/Expert opinion	Fixed	N/A
Nurse	User specified/Expert opinion	Fixed	N/A
Radiologist	User specified/Expert opinion	Fixed	N/A

Table: The input parameters associated with the DVT model.