A simulation-based decision support tool for informing the management of patients in retinal services

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Abstract

Retinal vascular diseases are a leading cause of blindness in the Western world. Advancement in the clinical management of these diseases has been fast-paced, with new treatments becoming available. Eye care services account for nearly one in ten hospital outpatient appointments in England. This paper discusses the development of a decision support toolkit (DST) that facilitates the improvement of retinal services by identifying cost savings and efficiencies within the pathway of care. The paper describes the development of the DST with the help of NHS and commercial experts in the retinal pathway. The DST enables users to model their own services by working with the DST interface allowing them to specify local services. Users can input local estimates or data of service demands and capacities thus creating a baseline discrete event simulation model. Users can then compare the baseline with potential changes in the patient pathway in the safety of a virtual environment. The tool enables key decision makers to estimate the likely impact of changes, such as increased use of new treatment vs. existing treatment regime. By making such changes the impact on activity, cost, staffing levels, skill-mix and utilisation of resources can be easily understood. Such previously unobtainable quantitative information can be used to support business cases for change in retinal services.

Keywords: Discrete event simulation, decision support toolkit, ophthalmology, retinal services and patient flow modelling.

1. Introduction

Eye care services are provided in primary care and community settings such as high street optometrists, as well as acute hospitals. Eye services have a low profile, yet involve a high volume of work. They account for nearly one in ten hospital outpatient appointments (the second highest demand specialty with 5.95m ophthalmology attendances in 2009/10 in England) and 7-8% of all operations performed by the National Health Service (NHS), where demand has risen by 25% over seven years **(**UK Vision Strategy 2014).

Most hospital activity in retinal services is accounted for by four conditions, all of which are expected to increase in prevalence as the population ages. These conditions are diabetic macular oedema (DMO), retinal vascular occlusions (RVO) and age-related macular degeneration (AMD), which are all treated with retinal laser or injections. The fourth condition is associated with surgical operations.

DMO is a complication of diabetic retinopathy and a leading cause of blindness (Ford et al. 2013). The prevalence of DMO is likely to increase with more people suffering from diabetes (Holman et al. 2011). In 2010, the estimated healthcare costs for DMO in England were £92 million, with £65.6 million being spent on hospital treatment and related costs (Minassian, Owens and Reidy 2012). RVO is a blockage of the small veins that carry blood away from the retina, which is the second most common sight-threating retinal vascular disorder after DMO (Laouri et al. 2011). There are two types of retinal vein occlusion: branch retinal vein occlusion or central retinal vein occlusion. AMD is an eye condition that affects a tiny part of the retina at the back of your eye for those aged over 50. AMD causes problems with your central vision, but does not lead to total loss of sight. There are two types, wet AMD and dry AMD.

According to Owen *et al*. (2012) there are 513,500 prevalent cases of late AMD. Patients diagnosed with RVO, DMO and AMD are usually treated with an injection in to the eye with varying frequency. If patients are left untreated, many eye conditions deteriorate rapidly. Early intervention can save sight or prevent further loss and allow people, many of them elderly, to maintain their independence. Delayed intervention can cost them their sight. Preserving or saving a person's sight can reduce their risk of other adverse events, such as falling or becoming unemployed.

The treatment of patients is resource intensive, requiring a multi-disciplinary team including radiologists, optometrists, specialist nurses, eye consultants and pharmacists. Combining this with an increasingly aged population and increased life expectancy, it is clear that healthcare systems around the world will find the management of such patients more and more challenging. This will essentially create an increase in demand for this service, without consideration of the related increases across other areas of the healthcare system. 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, etc.).

In this context, there is growing evidence of financial pressures building in the NHS this year; 2015/16 has been cited as a possible financial 'cliff edge' as providers plan to cut emergency and other elective work as part of the opportunity cost of diverting a further £1.8 billion of NHS allocations to consolidate the £3.8 billion (The Kings Fund, 2014). There can be little doubt that the NHS faces an unprecedented resource challenge. Therefore, hospitals and commissioners of health services need to find effective and efficient ways of delivering services to achieve the best outcomes for ophthalmology patients who need care and support at all times. The key question is

where and how to make changes to ensure that care and support are delivered in an efficient and effective manner.

In many respects, the solution may lie in redesigning retinal services (eye care services). This requires commissioners to develop a change programme in partnership with providers, local area teams (who commission primary care eye services), local health and wellbeing boards and other stakeholders. 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. Thus there is a need for a decision support tool that captures the complexity in the system at a sufficient level and is user-friendly such that it can be easily understood and manipulated by end users. The tool should respond to the concerns of these 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. eye consultants, nurses) and 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 RVO patients are treated by a new treatment in the market (e.g. steroid), which may reduce the number of follow-up treatments and/or reviews. This could then enable the design of more pro-active and better-informed policies and help towards their integration into the commissioning process.

The current study has two objectives. Firstly, to explore the impact of a range of changes to the retinal services pathway using discrete event simulation (DES) and to explore the utility of this approach in this setting. Secondly, to develop a user friendly decision support toolkit (a further development on the DES model) with relevant simulation controls. The objective here is 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 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. We will experiment the impact of increasing the use of steroids in steps of 10% (and reduce conventional treatment accordingly) and evaluate the likely effect it has on activity, costing and staff utilisation (details in section 3).

Discrete Event Simulation

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. Moreover, DES provides the flexibility to incorporate capacity and resource constraints explicitly and to capture the "competition" between competing modelled entities for access to limited resources (a comprehensive overview of DES is given by Banks (Banks et al. 2005) and others or Fishman (Fishman 2001). For a review of DES modelling in healthcare see Gunal and Pidd (Gunal and Pidd 2010).

In the next section, we illustrate a qualitative map portraying the inner workings of the retinal services pathway, model building assumptions and the input parameters. All results with model outputs and scenarios are discussed in Section 3. Finally, in section 4 we discuss the limitations, usefulness and implications in practice.

2 Material and methods

2.1 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 (NICE) 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 Ophthalmology nurses across a number of clinics between March and August 2014. The interviews were conducted 'on line' using WebEx 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 Ophthalmology pathway in retinal services in order to establish what, in the experts' opinion, important areas for development were. 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 problems in the eye 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.

Figure 1 shows diagrammatically the inner workings of the Ophthalmology pathway. Patients are referred to retinal services via their General Practitioner (GP) or community optometrists, and on a small number of occasions via accident and emergency (A&E) or outpatient services. Typically, 70% of patients are referred to a retinal service via their GP, 20% internal hospital referral and 10% through A&E. Patients first go through a number of check-ups at the initial assessment (or 1st outpatient appointment), which may include use of LogMAR charts to measure visual acuity; a slit lamp to see areas at the front of the eye, including the eyelids, conjunctiva, iris, lens, sclera and cornea; Optical coherence tomography (OCT) to study the structure of the eye in three dimensional space, and angiography to evaluate the blood flow through the vessels in the back of the eye. All patients would be subject to a LogMAR chart, around 70% OCT, 40% slit lamp and 2% angiography.

After careful evaluation patients are diagnosed and categorised into AMD, DMO, RVO or no major diagnosis and placed into the observation category. The estimated prevalence and incidence of late stage AMD in the UK for a population greater or equal to 50 is 2.4% (Owen et al 2012). According to the Office of National Statistics

(ONS) mid-2013 population estimates 34% of UK population's age is 50 or more (ONS 2014). When users specify their clinical commissioning group (CCG) population the expected number of AMD patients could easily be calculated, and therefore the number of patients routed out to AMD is determined. CCGs are groups of General Practitioners and from April 2013 they will be responsible for designing local health services in England. As RVO is made up of two categories and the prevalence and incidence rates are different, 0.5–2.0% for branch RVO and 0.1–0.2% for central RVO (Laouri et al 2011). At each run of the simulation the model randomly selects a number 0.5-2.0% for branch RVO and 0.1-0.2% for central RVO and calculates the number of RVO patients accordingly (again using the specified CCG population). Before we could calculate the number of DMO patients, we first need to determine the prevalence of diabetes in England and according to Diabetes UK (Diabetes UK 2013) it's around 4.6% and the prevalence of DMO is estimated to be 7.12% (Minassian, Owens and Reidy 2012).

Patients are referred to relevant treatment depending on their diagnosis. The choice of treatment varies considerably between providers. As a result, users are asked to specify the percentage of patients receiving best supportive care, laser treatment, AntiVegF (Anti vascular endothelial growth factor), steroids and photodynamic therapy (PDT). Anti-VEGF treatments are given by an injection into the eye and work by reducing the growth of new blood vessels and the oedema (swelling) they may cause. AntiVEGF agents include ranibizumab (Lucentis), bevacizumab (Avastin) and aylibercept (Eylea). Steroids are also injected into the eye to treat inflammation caused by disease, such as kenolog (Triamcinolone), fluocinolone (Illuvien), and ozurdex (dexamethasone).

If *x* percent of patients are referred to AntiVEGF treatment (typically around 64%), we then ask users to specify the percentage of patients on Lucentis (70%), Avastin (20%) and Eylea (10%). Similarly, if *y* percent of patients are treated with steroids (around 5%), what percentage of patients are on Triamcinolone (10%), Illuvien (5%) and Ozurdex (85%)? Note that these percentages are based on the responses from nurse interviews, hence are bound to vary between retinal services.

Once treatment commences patients have follow-up appointments to review their condition. Typically, patients would have as many follow-ups as treatment in the eye (injections). For instance, if a patient is on Avastin (an AntiVEGF treatment) then they are injected *z* times in the first year (with *z* follow-ups), *s* in the second year (with s follow-ups) and *t* in the third year (with *t* follow-ups). Similar information is entered for each treatment type to ensure that activities are modelled accurately within the simulation.

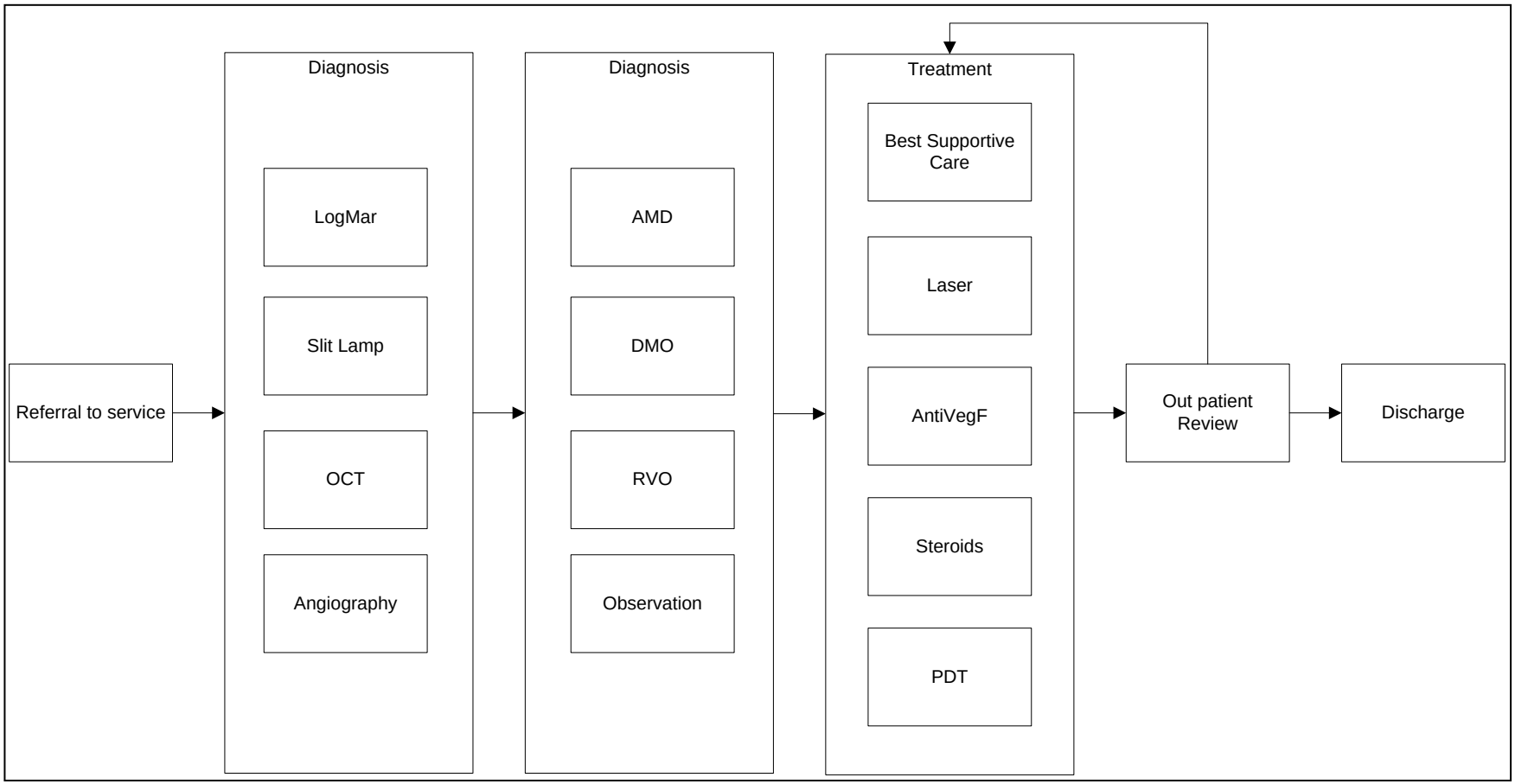

Figure 1 Conceptualised pathway for Ophthalmology patients. LogMar is logarithm of the minimum angle of resolution; OCT is optic coherence tomography; AMD is age-related macular degeneration; DMO is diabetic macular oedema; RVO is retinal vascular occlusions; AntiVegF is Anti vascular endothelial growth factor and PDT is photodynamic therapy.

2.2 Input parameters

Model inputs included staffing levels, staff salary, staff availability, treatment pathways, arrivals, discharges, percentage of patients falling into each treatment category, number of follow-ups, costing of each treatment, existing and new patient arrivals and treatment option visit parameters. The vast majority of input parameters are pre-determined through an in-depth review of the literature and expert opinions provided by the six specialist nurses. 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 Ophthalmology 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 patient numbers each year. The prevalence and the incidence rate in the general population is as specified above.

The *treatment* options for the service take into consideration the type of treatment provided to the patient, the length of treatment, the number of treatments (e.g. injections), the initial and follow up visits required dependent on patient type (AMD, RVO and DMO). 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 is 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 an Ophthalmology patient.

The *costing* options within the simulation model comprise the costs of initial and follow up visits and the hourly rate of staff within an Ophthalmology clinic, which are

determined by the Unit Cost of Health and Social Care 2013 (PSSRU 2013). In addition, drug costs are also included using British National Formulary (BNF) (BNF 2014). All costing information can be overridden by the user. An initial visit costs around £106. The hourly rates of staff at an Ophthalmology clinic are shown in Table 1. The unit cost of Avastin, Lucentis, Eylea, Ozurdex, Triamcinolone and Iluvien is £242.66, £742.17, £816, £870.00, £1.49 and £5,500, respectively. Users can easily specify the number of available resources within their retinal services to analyse the effects of increasing/decreasing resources.

Table 1 Hourly rates of staff within an Ophthalmology clinic. GPwSI refers to General Practitioner with a Specialist Interest.

Consultant	£ 139.00
Staff Grade/GPwSI	£ 134.00
SpR	£ 71.00
Optomotrist	£ 67.00
Nurse	£ 100.00
Optician	£ 22.00
Technician	£ 22.00
Photographer	£ 22.00
Healthcare Assistant	£ 21.00

3 Illustrative Results

According to the responses from the nurses approximately 64% of patients receive AntiVegF for the treatment of AMD, RVO and DMO (10% best supportive care, 20 % laser, 5% steroids and 1% PDT). Of those on AntiVegF, 5%, 75% and 20% receive Avastin, Lucentis and Eylea, respectively, and of those on steroids, 85%, 10% and 5% receive Ozurdex, Kenolog and Illuvien, respectively. Given that there are various treatment options, we seek to explore the impact of increasing the use of steroids in steps of 10% (and reduce AntiVegF accordingly) and evaluate the likely effect it has on activity, costing and staff utilisation. Note that this is solely for illustrative

purposes and no assumption is made in relation to the efficacy of medication, e.g., AntiVegF may have fewer side effects compared to steroids (or vice or versa). However, we assumed that AntiVegF have the same beneficial effect as steroids.

We also asked nurses about the frequency of use of medication (i.e. the average number of injections per year per patient), to establish the activity associated with visiting outpatient clinics (see Table 2). Patients (particularly the elderly) are usually treated over a three year cycle; hence in a given year our model should separate new patients from existing patients, where the existing ones could either be in their second or third year of treatment. From the interviews, 70%, 20% and 10% of patients are new, second and year third year of treatment, respectively.

Table 2 Average number of visits to the outpatient clinic for injections in the eye per year per patient according to treatment type

Drug	**Frequency of use in the first year (i.e. the average number of injections)**	**Frequency of use in the second year (i.e. the average number of injections)**
Avastin	5	3
Lucentis	7	4
Eylea	7	4
Ozurdex	2	1
Kenolog	2	1
Illuvien	1	0

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. Based on this population and the prevalence and incidence statistics specified above for RVO, DMO and AMD, the estimated number of patients treated within retinal services is 4,359.

The simulation was run for three years to capture the individual trajectories in the cohort over this period and to estimate the likely impact of changes in performance indicators. 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).

The model was run for a simulation period of 3 years with a warm up period of 1 year determined using the Welch method (Law and Kelton 2000) to make sure that the results were not collected until all patients in the cohort had gone through the care system. The weekly simulation period was Monday to Friday from 9am to 5pm reflecting the current operating arrangements in retinal services.

3.1 Model Validation

The model validation process was carried out by comparing the expected number of activity results over a 3-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 4,491 by the end of year 3 (1% increase each year). The total number of visits over a 3-year period was calculated taking into account the total cohort size, the number of DMO, RVO and AMD patients, the average number of injections (for each drug type) and follow-up visits per year for each patient type, and the simulation duration of 3 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 retinal care services 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 nurses throughout the study significantly increased confidence in the validity of the model.

3.2 Experimentation

The aim of the experiment is to explore the impact of increasing the use of steroids in steps of 10% (and reduce AntiVegF accordingly), keeping the number of treatments and the percentage of patients on Avastin, Lucentis, Eylea (AntiVegF) and Ozurdex, Kenolog, Illuvien (steroids) the same and evaluate the likely effect it has on activity and costing (see Table 3 for the list of experiments). 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.

Table 3: Scenario analysis based on decreasing use of AntiVegF in steps of 10%

Treatment type	**Baseline (% of patients receiving)**	**Experiment 1 (% of patients receiving)**	**Experiment 2 (% of patients receiving)**	**Experiment 3 (% of patients receiving)**	**Experiment 4 (% of patients receiving)**
Best Supportive Care	10	10	10	10	10
Laser	20	20	20	20	20
Anti VegF	**64**	**54**	**44**	**34**	**24**
Steroid	**5**	**15**	**25**	**35**	**45**
PDT	1	1	1	1	1
Total	**100**	**100**	**100**	**100**	**100**

Note that the experiments presented below do not consider the efficacy and side effects of AntiVegF and steroids, it is a purely an experimentation based on various "what if scenarios", to showcase some of the features of the decision support tool. According to Figures 2 and 3 reducing AntiVegF (and increasing steroids) by 10% has a significant impact on activity and costing. For instance, a comparison between the baseline model (64% on AntiVegF and 5% steroids) and experiment 3 (34% AntiVegF and 35% steroids) shows a dramatic reduction in the number of treatments, that is 17,134 and 9,118 injections in year 1, respectively (see Table 4). The decrease is due to the fact that the average number of injections administered in a year for steroids is less than AntiVegF (based on nurse interviews). Furthermore, we also notice a reduction in drug costs from £13,025,750 to £6,919,311 (in year 1) and the knock on effect on total costing of the entire pathway (including drug, staff and other costs) is a reduction from £13,349,762 to £8,844,221. An interesting insight is the reduction in outpatient visits, which are primarily made up of follow-ups, from 19,508 (baseline year 1) to 13,322 (experiment 3), again due to less follow-ups for those on steroids.

According to nurse interviews a typical retinal service may have five consultants (or specialist) which may vary considerably depending on geographical region of the clinic and specialisation. The experimented changes seem to have no effect on consultant's service hours. The total number of service hours to treat all patients (where a consultant is involved) is around 2,500 hours per year (see Figure 4), which is equivalent to 0.3 full time equivalent of a consultant time, that is, each of the five consultants would spend around 30% of their time treating patients.

There is a noticeable small variation in activity across the years and the reason for this is that we assumed the number of times a patient visits a clinic for treatment is fixed

(according to the interviews we had with the nurses, see Table 2), hence no distributional assumptions were made on these treatment types. This small variation is caused by the number of "new" arrivals each year during simulation run.

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 three years) with respect to arrivals; diagnosis process (LogMAR charts, slit lamp, OCT and angiography); treatment process (e.g. follow-ups, treatment type, number of injections, etc.); 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.

Table 4: The impact of decreasing the use of AntiVegF on activity and costing

		AntiVegF		**Steroids**		**Total number of outpatient visits**	**Total Cost of pathway**
		Activity	**Costing**	**Activity**	**Costing**		
Baseline	Year 1	17,134	£13,025,750	372	£324,012	19,508	£13,349,762
	Year 2	17,317	£13,134,719	376	£327,496	19,720	£13,462,215
	Year 3	17,080	£12,936,778	376	£327,496	19,463	£13,264,274
Experiment 1	Year 1	14,593	£11,059,365	1,010	£879,710	17,518	£11,939,075
	Year 2	14,698	£11,164,928	908	£790,868	17,676	£11,955,796
	Year 3	14,730	£11,189,297	995	£866,645	17,758	£12,055,942
Experiment 2	Year 1	11,669	£8,852,070	1,600	£1,393,600	15,260	£10,245,670
	Year 2	11,895	£9,027,767	1,639	£1,427,569	15,506	£10,455,336
	Year 3	12,139	£9,214,648	1,613	£1,404,923	15,770	£10,619,571
Experiment 3	Year 1	9,118	£6,919,311	2,210	£1,924,910	13,322	£8,844,221
	Year 2	9,175	£6,970,528	2,253	£1,962,363	13,378	£8,932,891
	Year 3	9,451	£7,149,988	2,288	£1,992,848	13,807	£9,142,836
Experiment 4	Year 1	6,534	£4,995,210	2,871	£2,500,641	11,383	£7,495,851
	Year 2	6,412	£4,866,675	2,936	£2,557,256	11,369	£7,423,931
	Year 3	6,735	£5,093,139	2,824	£2,459,704	11,591	£7,552,843

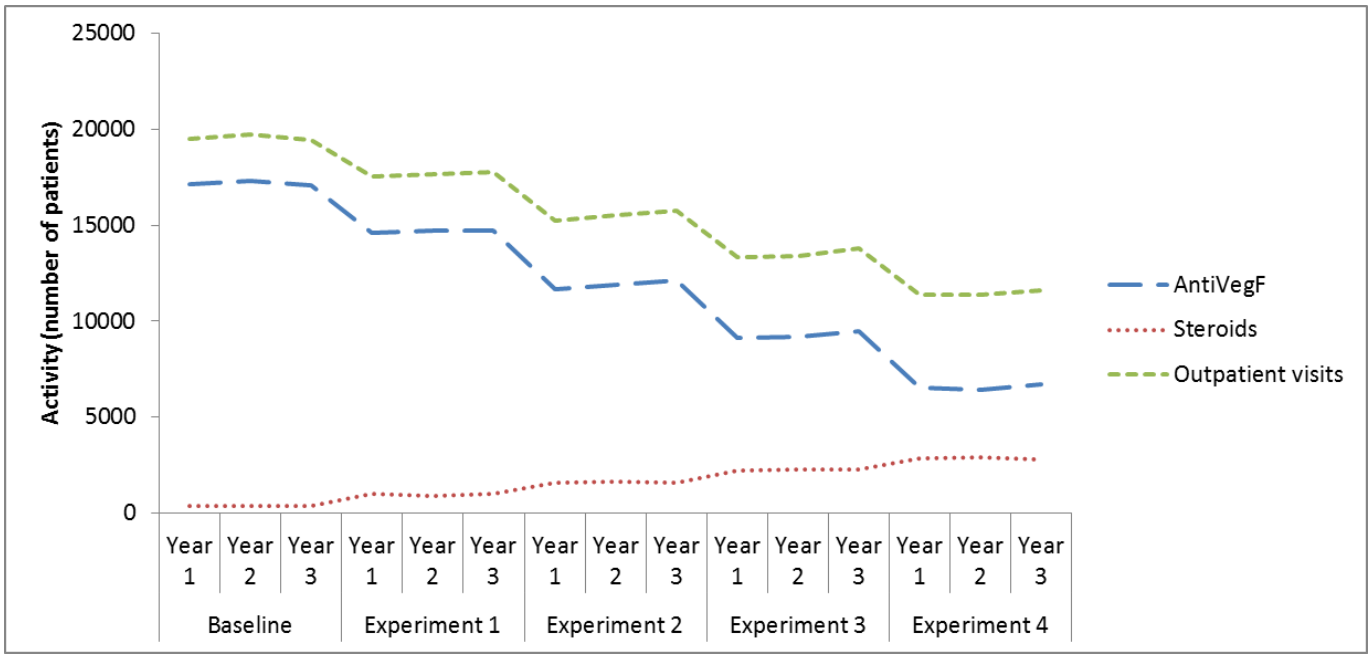

Figure 2: The impact of decreasing AntiVegF and increasing Steroids in steps of 10% on activity (the number of treated patients and outpatient visits)

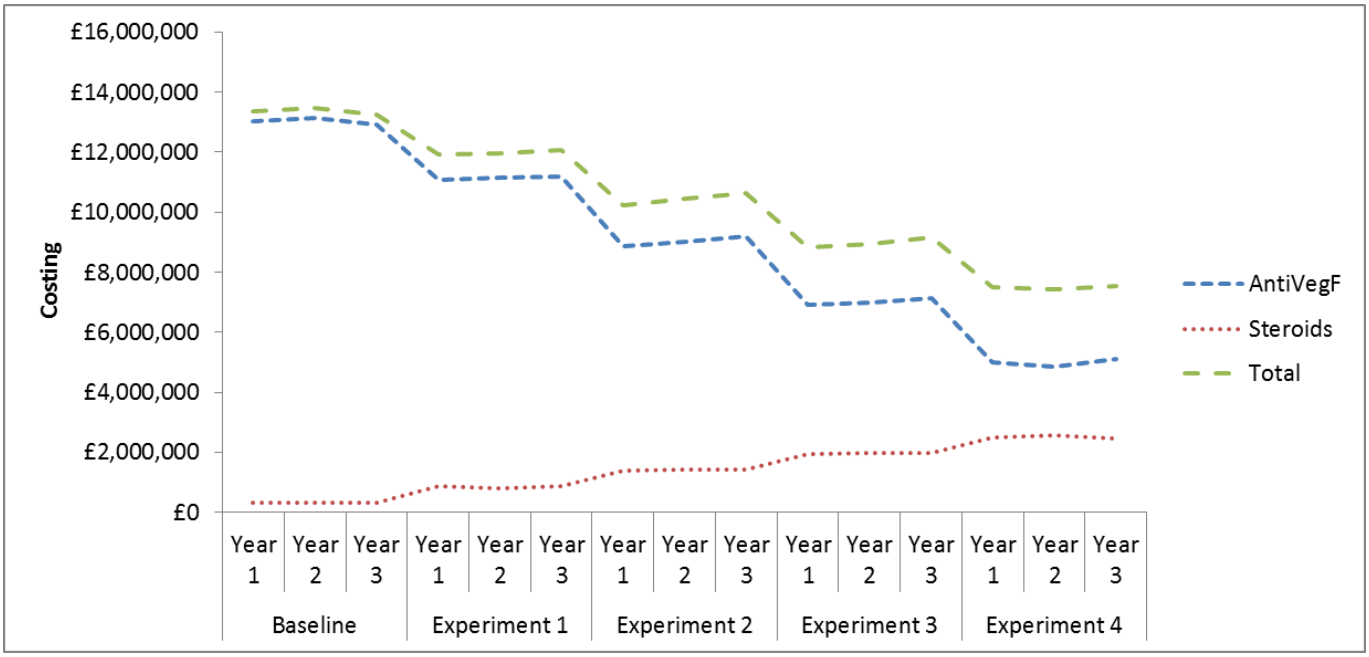

Figure 3: The impact of decreasing AntiVegF and increasing Steroids in steps of 10% on costing (total costing includes the cost of diagnosis, treatment, staff and medication).

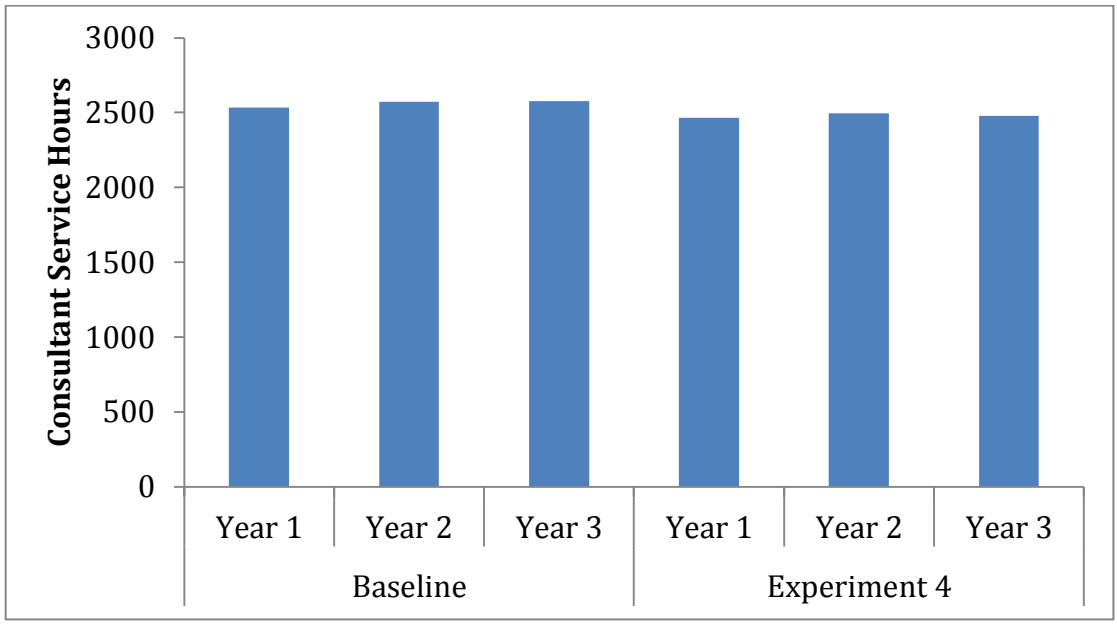

Figure 4: Consultant service hours (baseline vs. experiment 4)

4 Discussion

The authors are aware of the many difficulties that are faced in the planning and approving of new healthcare services. Changes can be introduced without proper consideration of the impact on the service. Frequently 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 was developed, in conjunction with specialists in the retinal pathway, specifically to address these issues. It is designed to allow 'non-experts' to test change on the pathway within the validated simulation. The simulation will present the impact of changes in a way that can be easily understood by both the executives and the pathway specialists. The intention is that this will facilitate service planning and decision making and speed up the pace of change in the ophthalmology pathway.

This simulation is currently being used nationally by a major pharmaceutical company, who also supply some of the drugs in the pathway, to facilitate service

change in the UK. The pharmaceutical company's healthcare development team are working with providers to improve services and health outcomes for retinal patients.

The choice of using simulation methods as opposed to analytical methods was partly dictated by the complexity of the pathway and the ease of use for end-users. In this respect, the need to track individual patient journeys (or trajectories) through the care system, the ability to capture the complex web of interactions of patients going through the diagnosis stage to various forms of treatment (including follow-ups) and the need to model notions of limited availability of resources (such as staff) have motivated us to select DES. Furthermore, DES enables user to take their pathway beyond flow-diagram drawings (i.e. the conceptualised pathway with experts) by using the animation features offered by SIMUL8, which allows you to see your patient pathway actually running. We developed a view of the operations from various angles and levels of magnification. This allowed users to detect design flaws that appear credible when seen just on paper in a 2-D drawing.

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 can 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 problems in the eye.

There is an increasing need to improve efficiency and effectiveness in health care delivery. However complexities in the delivery of services present commissioners with significant challenges. The development of a simulation based DSS enables a wide variety of scenarios to be tested and the impact on performance indicators to be

easily evaluated, offering commissioner's huge potential to experiment with change in the safety of a virtual environment.

The simulation results suggest that an increased use of steroids will have a positive impact on the workload (i.e. number of injections and outpatient visits) and costing. The policy rationale follows that reducing the number of unnecessary visits to hospital without affecting the quality of treatment (more importantly the outcome on patients), is strongly supported by the simulation results. As such, the simulation based DSS 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. Although the changes have implied a decrease in activity and costing (hence the opportunity to allocate resources to other areas of need), there are no changes to consultant service hours.

A limitation of the study is that we did not take account of co-morbidities and interactions with other diseases (e.g. diabetes) 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. Furthermore, some of the input parameters (e.g. percentage of patients on AntiVegF and steroids, and frequency of treatment) were determined by asking nurses during the interviews. However, a data driven approach would have made our model and findings more robust and accurate by identifying the distribution for each treatment type (i.e. frequency of use of treatment) as opposed to using a fixed value.

The main strength of this decision support tool is the adoption of a team approach to studying the system, involving six 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.

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