

Optimizing the Resources of a Healthcare Department using a Genetic Algorithm

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Abstract: Musculoskeletal disorders affect over 100 million people in Europe and with our population ageing this number is expected to rise which will put increased pressure on orthopaedic departments. The orthopaedic Integrated Clinical Assessment and Treatment Service (ICATS) was implemented in the United Kingdom by the Department of Health (DOH) to reduce the bottleneck within the department. However, due to unanticipated arrivals the DOH are aware that queues have started to build up again. In previous work we implemented a resource allocation methodology, based on Classic Queueing Theory, to find the minimum number of resources required for the system to reach steady state. In this paper we have extended our approach to develop a methodology which finds the best way to distribute a fixed number of resources through the healthcare department to minimize the overall waiting time. Using an Exhaustive Search Algorithm to find an optimal solution would take a lot of computational power and time therefore, to achieve our desired result we will use a Genetic algorithm. A Genetic algorithm is a heuristic search based on the process of natural evolution. The results show that although the Genetic Algorithm does not find the global optimum solution it finds a very close approximation and would be beneficial to use when there are a large number of resources to be distributed between many stages of a department as is commonly the case.

Keywords: Stochastic modeling, Orthopaedic ICATS, Genetic Algorithm, Queueing Theory

1 Introduction

It is estimated that musculoskeletal disorders affect more than 100 million people in Europe and 60% of patients on long term sickness in the United Kingdom (UK) state musculoskeletal problems as their reasons (Arthritis Foundation, 2009; Department of Health, 2006). Our population is ageing therefore these figures are expected to rise which will have a severe impact on the efficiency of orthopaedic departments.

The orthopaedic Integrated Clinical Assessment and Treatment Service (ICATS) was implemented in England, Scotland and Wales in 2005 to reduce the bottleneck that was created by patients waiting for an appointment with an orthopaedic surgeon. This ICATS system was implemented in Northern Ireland in

2007 and as it is the region of the UK with the highest waiting lists we will use data from the Southern Health and Social Care Board in this paper (Department of Health, 2006). The ICATS system has now been employed for over 5 years in Great Britain and over 3 years in Northern Ireland and in this time it has evolved. The orthopaedic process now begins with a patient referral being assessed by a healthcare professional (Physiotherapist, Podiatrist or General Practitioner with a special interest in Orthopaedics) in Paper Triage where they decide on the most appropriate treatment pathway (Southern Health and Social Care Trust, 2010). The pathways include going for a Face to Face (F2F) assessment with an ICATS health professional (55%), having diagnostic tests (7%), being sent to another department for treatment (10%), being referred back to their General Practitioner with management advice (3%) or having surgery (19%). It is also known that 6% of orthopaedic referrals do not attend their appointment. If a patient is sent to F2F assessment then 60% of those patients will be sent to Treatment and Review (T&R) appointments. On average patients receive three T&R sessions before being discharged, 20% of patients referred to F2F assessment will be sent to their GP with management advice and 20% will be sent to an orthopaedic consultant to have surgery 1 (Southern Health and Social Care Trust, 2010). A visual representation of the process along with the corresponding percentages can be seen in Figure. This new process tries to ensure that the patients' waiting time is reduced, that they see the correct healthcare professional first time and that the consultant's time is better spent in surgery with patients who require their expertise then in outpatient appointments (Rymaszewski et al. 2005).

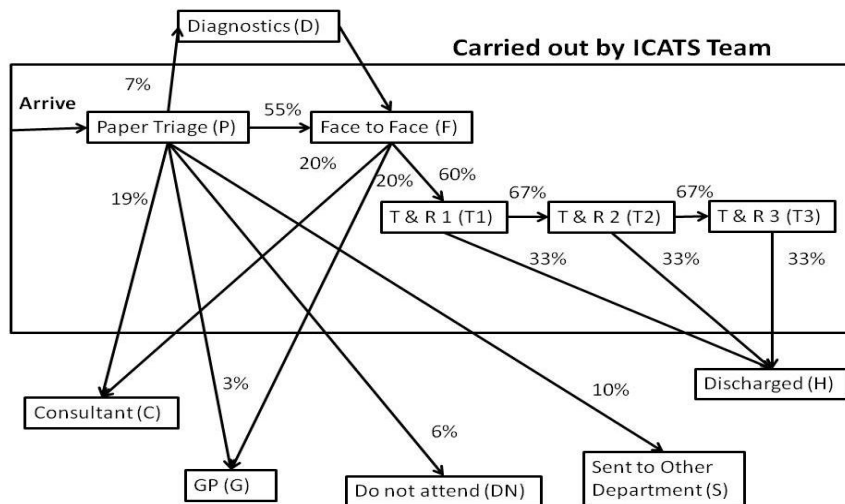


Figure 1. Orthopaedic ICATS Process

In 2010 the Southern Health and Social Care Board produced a document (Southern Health and Social Care, 2010) which stated that due to the number of

unanticipated arrivals to Orthopaedic ICATS the queues within the system are building up and the resources are unable to cope with the demand. In previous work (Gillespie, et al. 2011) we have developed a resource allocation methodology which finds the minimum number of resources required within the department for the system to reach steady state. In this paper we will extend this work to develop a methodology which finds the best way to distribute a fixed number of resources through a healthcare department to minimize the overall waiting time. To achieve this we use a genetic algorithm (GA) which is a search heuristic which mimics the process of natural evolution.

2 Optimizing Health Care Departments using a GA

In many situations it can be difficult to find an exact solution to a problem. There could be many reasons for this including the complexity of the objective function and the computational power required. In these cases it may be sufficient to use a technique, such as the Genetic Algorithm, to find a local optimum or to be at least close to a local or global optimum.

The Genetic Algorithm (GA) belongs to a larger class of evolutionary algorithms and can be used as a search heuristic which mimics the process of natural evolution. The algorithms can be used to generate useful solutions to optimisation and search problems within many sectors. The GA differs from other conventional methods as it does not search from a single point but operates on a whole population of points. This improves the chance of the algorithm reaching the global optimum and reduces the risk of becoming trapped in a local optimum. As the normal genetic algorithm does not use any auxiliary information about the objective function values, such as the derivatives, it can be applied to any kind of continuous or discrete optimization problem. This means that the GA is versatile and can be used within many different application areas to optimize a function by finding the best solutions (Holland, 1975).

Given a specific problem to solve a user is required to provide the GA with a set of potential solutions which can be quantitatively evaluated within a metric called the objective function. This can be done for a set of solutions which the user already knows work but in most cases these are done at random. The GA evaluates each solution according to a fitness function but in many cases, when the candidates are randomly selected from a pool, this will not work and infeasible solutions will be deleted. In some cases the solution is promising and these are kept and allowed to reproduce, therefore producing multiple 'offspring' (new solutions). However, these solutions may not be optimum and the GA allows random changes to be introduced in the copying process. These 'offspring' are then the potential solutions for the next generation. This process is repeated with the expectation that the average fitness of the function will increase with each generation until the optimal solution is found. There are many different selection methods which could be used to select the individuals to be copied over to the next generation, these include the Elitist method, Roulette wheel selection, Scaling selection and Rank selection (Marczyk, 2004).

In this paper we have developed a methodology for finding the best way to distribute a fixed number of resources to a healthcare facility by applying a genetic algorithm. Let us consider a healthcare department with i distinct consecutive stages, where $i=1, \dots, n$. Let the arrival rate and service rate, λ_i and μ_i respectively, follow an exponential distribution, c_i be the number of resources available to each stage and let there be an infinite waiting room/list for each stage. This can be seen as a network of infinite queues M/M/ c_i and can be analysed using queueing theory. If we have a fixed number of resources, C , available to the department we can use the GA to find the best way to distribute the resources in order to minimize the waiting time at each stage. The overall waiting time for such a network of infinite queues can be found using Little's formula from classic queueing theory (Koizumi, et al. 2005).

The objective for the GA is to minimize:

$$\min f(\mathbf{c}) = \sum_{i=1}^n \frac{\left[\sum_{n_i=0}^{c_i-1} \frac{\omega_i^{n_i}}{n_i!} + \frac{\omega_i^{c_i}}{(1-\rho_i)c_i!} \right]^{-1} \frac{\rho_i \omega_i^{c_i}}{(1-\rho_i)^2 c_i!}}{\lambda_i} \quad (1)$$

where $\mathbf{c}=(c_1, \dots, c_n)$, $n_i (< c_i)$ is the number of occupied resources up the maximum number of resources c_i , $\omega_i=\lambda_i/\mu_i$ and $\rho_i=\omega_i/c_i < 1$ in a steady state system. For more information on this equation see Koizumi, et al. (2005).

The optimization problem is then solved subject to the constraints:

$$\mathbf{A}\mathbf{c} \leq \mathbf{b}, \quad \sum_{i=1}^n c_i = C, \quad \text{and } c_i > 0 \text{ for } i=1, \dots, n$$

where \mathbf{A} is an $(n \times n)$ diagonal matrix consisting of the maximum utilization value, α , for each diagonal element. The utilization value states how busy the system is allowed to be. Typically this is around 85% otherwise the queues become inefficient. \mathbf{b} is a $1 \times n$ vector containing the constraint values. In the following section we will describe how this methodology can be applied to the orthopaedic ICATS process to minimise the overall waiting time.

3 Orthopaedic ICATS Process

The ICATS process that is described in Section 1 includes all the different elements of the system. However, in this paper we will focus on the five stages where the ICATS team are working. These stages are Paper Triage (1), F2F (2) assessment and the three T&R sessions (3, 4 and 5). In 2009/2010 the number of patients referred to orthopaedic ICATS department was 8522 and this is used to find the external arrival rate to Paper Triage (Southern Health and Social Care Trust, 2010). The internal arrival rates within the department are found using the general traffic equation (Equation 2) (Koizumi, et al. 2005), as follows

$$\lambda_j = \lambda_i + \sum_{i=1}^5 r_{ij} \lambda_i \quad (2)$$

where $j=1,\dots,5$, λ_i is the arrival rate to stage i , λ_j is the arrival rate to stage j and r_{ij} is the proportion of patients who move from stage i to stage j .

When we have a fixed number of resources, C , which can be distributed throughout the ICATS department we can find the best distribution of resources which minimises the overall waiting time to each stage using the GA described above. Therefore, for our system we want to:

$\min f(c_1, \dots, c_5)$ such that

$$\sum_1^5 c_i = C,$$

$$\alpha c_1 \geq \omega_1$$

\vdots

$$\alpha c_5 \geq \omega_5$$

$$c_1 \dots c_5 \geq 0$$

where α is the maximum utilization value for each queue which determines how busy the system is allowed to be.

4 Results

We applied the Genetic Algorithm described in Section 2 to two different utilization values of the ICATS department and compared it with a set of solutions that we have found using an Exhaustive Search Algorithm (ESA) programmed in Matlab. An ESA examines every possible solution before selecting the most optimal (Coban and Mersereau, 1998) and the approach is renowned for its long execution times, especially for large datasets (Hui and Yonghui, 2010). Matlab is a numerical computing environment which integrates computation, visualization and programming within a user-friendly interface and presents the solution in a familiar mathematical format. The Maximum Utilization (UMax) values for each stage of the department which we have used are 1 and 0.85 respectively.

Table 1 shows that most of the time the ESA finds a better combination of resources to minimize the overall waiting time. However, the GA finds a very close approximation to the global optimum. We also note that when there are 7 resources and a utilization maximum value of 1 the GA finds a better solution to our problem. We can also see that the ESA takes much longer to run in Matlab compared to the GA as expected.

Table 1. The combinations found using ESA and GA for the ICATS department

| No. of Re-sources C | UMax | Method | c_1 | c_2 | c_3 | c_4 | c_5 | The overall waiting time | Time to perform method (Secs) |
|-----------------------|------|--------|-------|-------|-------|-------|-------|--------------------------|-------------------------------|
| 6.5 | 1 | ESA | 1 | 2 | 1.4 | 1.1 | 1 | 1.3932 | 21.4296 |
| | | GA | 1.07 | 1.97 | 1.28 | 1.09 | 1.09 | 1.6346 | 2.1469 |
| | 0.85 | ESA | 1 | 2.2 | 1.3 | 1.0 | 1 | 1.5514 | 21.2766 |
| | | GA | 1.01 | 2.13 | 1.35 | 1.01 | 1 | 1.4602 | 2.0954 |
| 7 | 1 | ESA | 1 | 2.2 | 1.5 | 1.2 | 1.1 | 0.9502 | 34.0848 |
| | | GA | 1.01 | 1.92 | 1.29 | 1.23 | 1.56 | 1.5426 | 2.2079 |
| | 0.85 | ESA | 1 | 2.2 | 1.5 | 1.2 | 1.1 | 0.9502 | 32.5935 |
| | | GA | 1.00 | 2.11 | 1.27 | 1.62 | 1 | 1.2773 | 2.1376 |
| 7.5 | 1 | ESA | 1 | 2.3 | 1.7 | 1.3 | 1.2 | 0.7182 | 52.9350 |
| | | GA | 1.04 | 2.26 | 1.63 | 1.33 | 1.24 | 0.7125 | 2.1644 |
| | 0.85 | ESA | 1 | 2.3 | 1.7 | 1.3 | 1.2 | 0.7182 | 49.0474 |
| | | GA | 1.06 | 2.17 | 1.60 | 1.41 | 1.27 | 0.7236 | 2.0809 |

Orthopaedic ICATS has only 5 stages and at present we only require 6 or 7 resources for the system to reach steady state and produce an acceptable waiting time. However, in a more complex department, such as Accident and Emergency which has to treat a broad spectrum of injuries and diseased, there could be many more stages and hundreds of staff which would leave ESA too costly and time consuming to undertake. Therefore, the GA described above could be used within these circumstances as it is accurate, quicker and does not require nearly as much computational power.

5 Conclusions and Further Work

The orthopaedic Integrated Clinical Assessment and Treatment Service was implemented in the United Kingdom by the Department of Health (DOH) to reduce the bottleneck within the department. However, due to unanticipated arrivals the DOH are aware that queues have started to build up within the new department. In this paper we have used a Genetic Algorithm to distribute a fixed number of resources throughout an orthopaedic ICATS department so that we reduce the queues and minimise the overall waiting time at each stage. We found that although the GA does not always find the global maximum it does find a very close approximation and it less costly and time consuming to run compared with an enumeration method build in Matlab. This methodology is a generic model which could be implemented within any department and would be very beneficial when there are a correspondly large number of stages and a large number of resources to be distributed.

In further work we would like to implement the GA in different ICATS scenarios to investigate the impact of changing the constraints. This will help to determine how robust our GA is and whether it would be possible to adapt the methodology to implement within a more complex environment. We also plan to

implement the results of our GA within a simulation model to determine the impact of variation and whether we can make the ICATS process more realistic.

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