GENERAL ARTICLE

Estimating the Impact of Lifestyle Changes on Treatment Outcomes for People with Knee Osteoarthritis through System Dynamics Simulation Modelling

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ABSTRACT
With the increasing number of patients suffering from knee osteoarthritis, the UK National Health Service is considering introducing a new treatment option that would focus on lifestyle changes. This study aims to develop a novel model that could serve as a tool to estimate the impact of such an intervention on treatment outcomes. In collaboration with the Forth Valley Royal Hospital, Larbert, United Kingdom, the model was formulated as a system dynamics simulation model and was built using Insight Maker, a web-based modelling tool. To the best of our knowledge, this paper is the first to employ system dynamics to tackle this problem. The simulations were run for several configurations to better understand the potential impact of advanced lifestyle treatment under various scenarios. The results for the most expected scenario suggest that introducing advanced lifestyle treatment would increase the average number of recovered patients by 4%, and reduce the average numbers of temporarily disabled, permanently disabled and deceased patients by 21%, 9% and 4%, respectively. The results also reveal that even with low advanced lifestyle treatment acceptance rates, the treatment outcomes could improve without any changes to current resources.

KEYWORDS
Knee osteoarthritis; Lifestyle changes; Patient education; System dynamics simulation; Quality improvement.

1. Introduction

According to Arthritis Research UK (2013), almost 20% of people aged 45 and over in the UK - close to 5 million people - have required treatment for knee Osteoarthritis (OA). Taking into account the increase in the main knee OA risk factors (age and obesity), it has been estimated that the number of people with knee OA will increase to 8.3 million by 2035. This projection suggests that policies related to the management of knee OA need to be reviewed to ensure the availability of high-quality treatment and suitable resources. As the symptoms of knee OA worsen, people initially seek treatment in a primary care system. Care providers may prescribe medications to

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reduce pain. Patients may also be referred to orthopaedic specialists. More than 2000 people are being referred to orthopaedic consultants at the knee clinic at the National Health Service (NHS) Forth Valley Royal Hospital every year. These patients can receive non-surgical treatment (mainly anti-inflammatory drugs), surgical treatment, or a combination of both. Depending on the treatment stage and the outcome of the treatment, each patient belongs to one of the following categories:

- **Temporarily disabled** - patients receiving treatment.
- **Recovered** - patients who regained a normal health condition after treatment.
- **Permanently disabled** - patients with permanent disability after complications of treatment.
- **Deceased** - patients who died after treatment.

The current average waiting time for an orthopaedic consultant appointment is greater than the target of 12 weeks. Given current resource availability, it is very difficult to reduce these waiting times. Therefore, the hospital management would like to consider an option of introducing a new intervention, called advanced lifestyle treatment (ALT), which would take place during the time a referred patient waits for his/her appointment. This intervention would involve classes delivered by a musculoskeletal specialist with the emphasis on changes in lifestyle, such as pain management, joint protection, readiness to change and weight management. After participating in these classes, there is a small but significant chance of sufficient functional recovery that the patient would not require any further treatment. This study aims to investigate whether the introduction of the ALT for patients with knee OA in the NHS Forth Valley region would result in significantly improved treatment outcomes (i.e. more recovered and less temporarily/permanently disabled patients).

The system studied in this paper is too complex to evaluate what effects different policies would have on it. These effects could be tested by implementing the policies in the real world and then evaluating the impact. However, the feedback process of such real-world experiments is usually very slow and it may involve high associated costs. Therefore, given the dynamic complexity of the system, simulation seems a more practical and less costly method to estimate the impact of new policies.

Although several studies in the OA research literature have used different simulation modelling techniques to model the care system for patients with knee OA (Bassette et al., 2009; Chancellor, Hunsche, Cruz, & Sarasin, 2011; Kamath et al., 2003; Latimer et al., 2011; Maetzel, Krahn, & Naglie, 2003; Vanderby, Carter, Noseworthy, & Marshall, 2015), they have not focused on assessing the impact of patient education programs. On the other hand, the studies that focused on estimating the benefits of such programs relied mainly on randomized clinical trials rather than on simulation-based methods. Coleman et al. (2012) assessed the benefits of a 6-week self-management program for patients with knee OA. The results of this randomized clinical trial demonstrated significant benefits with regard to quality of life and pain. Hopman-Rock & Westhoff (2000) evaluated the effectiveness of a self-management program for people with hip or knee osteoarthritis. This program comprised six two-hour sessions that included health education classes delivered by a peer as well as physical exercises delivered by a physical therapist. The authors concluded that the self-management program had moderate positive effects on quality of life, self-efficacy and physically active lifestyle. In a study developed by Mazzuca et al. (1997), the authors assessed the self-care education program delivered by an arthritis nurse specialist as an additional primary care intervention for patients with knee osteoarthritis. These classes focused on teaching patients the principles of joint protection and management of joint pain. They concluded that patients, who completed this self-care education program, were less likely to suffer from disability and resting knee pain one year after participation. However, the results of the study also showed that the program had no significant effect on general health status and walking knee pain. Another randomized clinical trial was conducted by Maurer, Stern, Kinossian, Cook, & Schumacher (1999). In this study, the authors compared the effectiveness of isokinetic quadriceps exercise and educational interventions. The patient education program consisted of four sessions of lectures. The authors concluded that exercise had a more significant impact on reducing knee pain than the patient education program. However, considering the fact that patient education programs were much less costly, the small benefits they provided were clinically significant. These studies have provided a methodological approach on simulation techniques in the OA care context as well as evidence of significant benefits of patient education programs. A distinguishing feature of this paper is the application of System Dynamics (SD) to the management of knee OA aiming to estimate the benefits of patient education programs.

Although the discrete event simulation is a more popular approach to tackle healthcare problems (see e.g. Tako et al., 2014), an SD approach has also been heavily used in a considerable number of studies to model several components of healthcare systems and evaluate the effectiveness of public health policies (see e.g. Katsaliaki & Mustafee, 2011; Morilla et al., 2014). These papers have shown that SD is a useful technique to better understand and explain the effects of various changes in the studied healthcare processes. With regard to applications to public health policy evaluation, a few studies have employed SD models to estimate the impact of different treatment programs for HIV/AIDS to find the most cost-effective testing and treating options (see e.g. Anderson et al., 1998; Atum et al., 2007). Other studies based on SD simulation modelling have been developed to compare different public health strategies aimed at improving the long-term health impact of smoking (see e.g. Ahmad, 2005; Ahmad & Billimek, 2005; Tengs et al., 2004). Similarly to these studies, the model developed in this paper was built to estimate the long-term benefits of a new treatment method and to support decision making at a strategic level. SD modelling is a more suitable approach for this study because it allows us to determine the general trends of the system's performance after introducing a new treatment option. Other popular simulation techniques, like discrete event simulations, have been showed to be less suited and rarely used for such problems (Brailsford et al., 2004).

In this study, a novel simulation model was developed applying the SD modelling approach. The SD simulation model developed in this study would allow estimation of the expected benefits of introducing the ALT for knee OA patients in the NHS Forth Valley region.

2. Model development

2.1. Process diagram

The modelling process started with gaining an understanding of the OA care system after patients are referred to an orthopaedic consultant. A causal loop diagram (CLD) was developed to illustrate a conceptual model that shows the relationships between the variables involved in the system. The CLD capturing the main variable interrelations is shown in Figure 1.

Patients enter the system after being referred to the knee clinic for an appointment

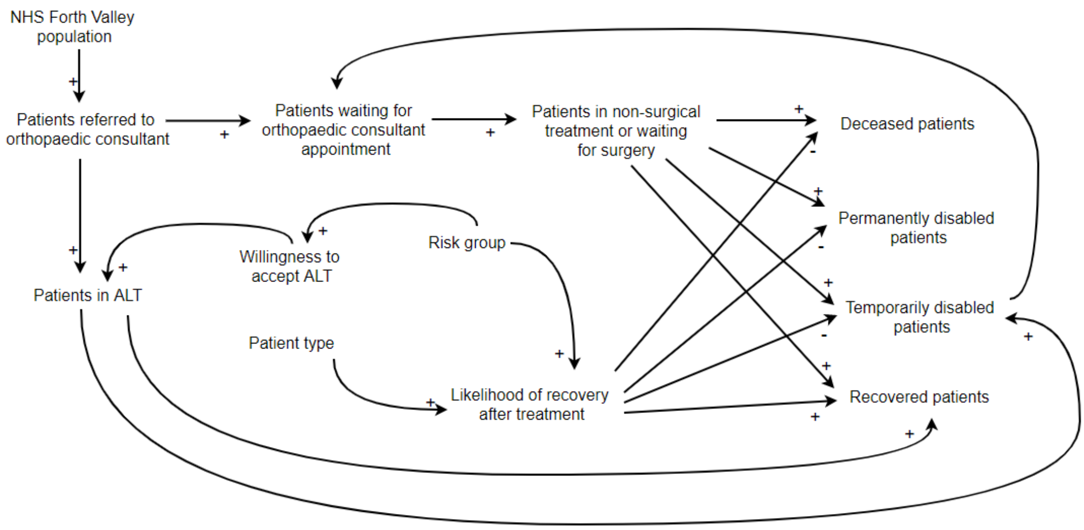

Figure 1. Causal loop diagram

with an orthopaedic consultant. All patients in the system are said to be temporarily disabled. Since ALT is not currently available, all referred patients wait for their knee clinic appointment. There are three main possible outcomes of the appointment: (1) a patient starts a non-surgical (NS) treatment; (2) a patient is put on a waiting list for surgery; or (3) a patient is discharged (DIS) home when no treatment is required. The possible treatment outcomes of both surgical and non-surgical interventions are temporary disability, permanent disability, recovery and death. If a patient is still temporarily disabled after treatment, s/he is sent back to the knee clinic and waits for another appointment with an orthopaedic consultant.

As shown in Figure 1, if ALT were available, a patient would be able to decide whether s/he wants to participate in the ALT classes after being referred to the knee clinic. If s/he accepts the ALT, s/he would join the waiting list for the classes. There are only two possible outcomes of the ALT - temporary disability and recovery. When ALT does not lead to recovery, a patient would wait for his/her knee clinic appointment and continue with the process as described above.

2.2. Stock and flow diagram

The next stage of the model development was to convert the final process diagram into a stock and flow map that could be used for an SD model. Firstly, all processes taking longer than one week on average as well as all delays were converted into stocks. Secondly, flows were determined based on the paths taken after decision points in the process diagram. The simplified version of the stock and flow diagram is shown in Figure 2.

Two main patient characteristics were identified when developing the diagram - type and risk group. The stratification of these characteristics and their descriptions are provided in Table 1. Patient type was included because it affects the average delay of waiting for the knee clinic appointment. The type of treatment a patient receives typically depends on whether any other health conditions or risk factors exist. The relevant co-morbidities for this study are physical impairment limiting activity, gastrointestinal bleeding, cardiovascular disease, diabetes, renal failure, hypertension,

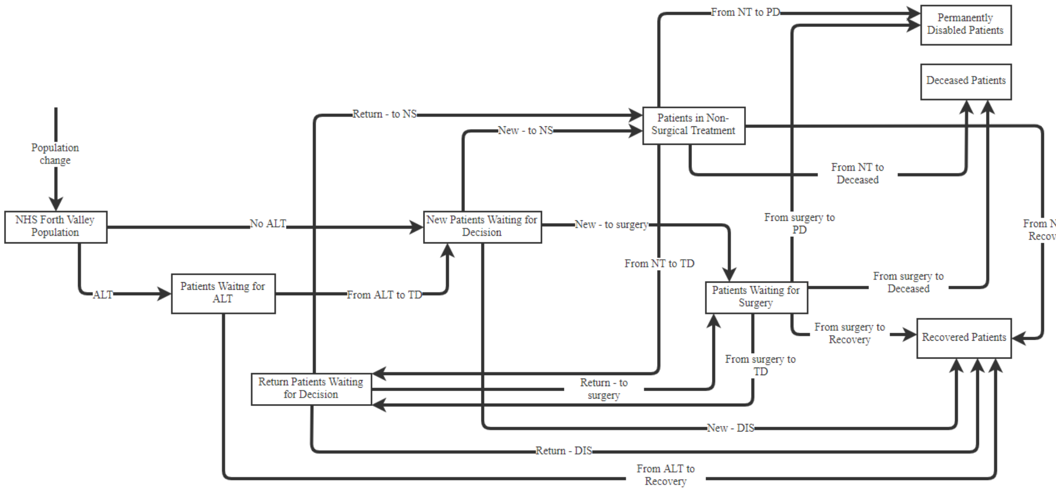

Figure 2. Simplified stock and flow diagram

and depression. Therefore, all patients were organised into four risk groups, as recommended by OARSI (Osteoarthritis Research Society International) (McAlindon et al., 2014). This stratification requires all stocks related to waiting for a decision or waiting for treatment stages, to be divided into smaller stocks containing patients with the same main characteristics.

2.2.1. Key variables

After developing the stock and flow diagram, factors affecting flows in the system were identified. To briefly describe the key variables, the inflows and outflows of the NHS Forth Valley population stock depend on the fractional population growth rate and the fractional referral rate (the percentage of the NHS Forth Valley population referred to the knee clinic) per time unit. Delays while waiting for a decision and waiting for treatment determine how fast patients flow through the system. Since treatment decisions and outcomes strongly depend on a patient's risk group (see Table 1), the proportions of referred patients in each group are very significant factors in this model. For the realistic SD model, it was crucial to know the distributions of treatment decisions and outcomes. Finally, to ensure that the model could be used to test the impact of the ALT, variables representing the fraction of patients in each risk group that would accept such intervention were introduced.

2.3. Model formulation

2.3.1. Assumptions

The following assumptions were made when building the simulation model:

- After a patient is referred to the knee clinic, neither s/he nor the clinic cancels any appointments or surgeries and all patients always show for their appointments or surgeries.
- Although the knee clinic provides care for both elective and trauma OA patients, trauma patients were excluded from this study, as they would not be offered

		Patient type	
		New	**Return**
Risk group	**Group 1 (G1)**	Patients with OA in one or both knees and with no other relevant health concerns waiting for their first knee clinic appointment	Patients with OA in one or both knees and with no other relevant health concerns returning to the knee clinic after a treatment chosen at the first appointment lead to temporary disability
	Group 2 (G2)	Patients with OA in one or both knees and with other relevant health concerns waiting for their first knee clinic appointment	Patients with OA in one or both knees and with other relevant health concerns returning to the knee clinic after a treatment chosen at the first appointment lead to temporary disability
	Group 3 (G3)	Patients with OA in knee(s) and other joints, and with no other relevant health concerns waiting for their first knee clinic appointment	Patients with OA in knee(s) and other joints, and with no other relevant health concerns returning to the knee clinic after a treatment chosen at the first appointment lead to temporary disability
	Group 4 (G4)	Patients with OA in knee(s) and other joints, and with other relevant health concerns waiting for their first knee clinic appointment	Patients with OA in knee(s) and other joints, and with other relevant health concerns returning to the knee clinic after a treatment chosen at the first appointment lead to temporary disability

Table 1. Main patient characteristics

the ALT. Therefore, it was assumed that the effects of the number of trauma patients and the treatment type they require are reflected in the randomness of input parameters.

- Only new patients are offered the ALT.
- Any patient can be seen by any consultant or surgeon.
- The probability distribution of treatment outcomes does not depend on whether a patient is new or return.
- If a recovered patient seeks help from the orthopaedic department, s/he is treated as a new patient in the model.

2.3.2. Rate equations

After identifying the stocks and flows as well as the key variables, the rate equations that represent all the flows in the system were formulated. Formulating an SD model often requires the use of delays in rate equations. A delay can be described as the period of time by which the output is postponed. In this model, there are two main types of delays - waiting for decision delay and treatment delay. The waiting for decision delay determines how long it takes for a patient to flow through a relevant 'Waiting for Decision' stock, while a treatment delay describes how much time a patient spends in a relevant 'Waiting for Treatment'/'In the Treatment' stock.

The outflows, which depend on the delays described above, were formulated using a first-order material delay (Sterman, 2000). To formulate such rates, it was assumed that appointment waiting times vary among individual patients. Therefore, the system may sometimes experience larger or smaller patient outflows than usual. This assumption seems realistic as some patients wait longer for their appointments/treatment than others.

The rates of model outflows are proportional to the number of patients in a stock. The coefficient of proportionality is a fractional change rate, which can be represented using average delay time. For example, the outflows dependent on the first-order delays are expressed as

$$[\text{Outflow}] = \frac{[\text{Patients in Stock}]}{[\text{Average Delay Time}]}, \tag{1}$$

while other outflows are formulated using estimated fractional rates of change, i.e.

$$[\text{Outflow}] = [\text{Fractional Change Rate}] \times [\text{Patients in Stock}]. \tag{2}$$

Equation (2) was only used to describe the inflow and the outflows of the starting population stock ('NHS Forth Valley Population') because they depend on the fractional change rates that are measured as the percentage change in the size of the stock per time unit - the fractional population growth rate and the fractional referral rate. All the other flows were formulated using equation (1) since they depend on delays - waiting for decision delays and treatment delays.

2.3.3. Estimation of parameters and initial values

The final stage of model formulation was the estimation of parameters in the rate equations and initial values of stocks. There were two main sources of information - the data extracted from the hospital's appointment system, and the estimates, based on literature and extensive experience, provided by the orthopaedic consultants. The hospital provided a dataset with requests to confirm or to cancel knee clinic appointments, which was used to determine the referral rates, and a dataset consisting of individual knee clinic appointments, their outcomes, and the patient type.

Fractional Population Growth Rate. According to National Records of Scotland (2014), the projected percentage change in the NHS Forth Valley population from 2014 to 2039 is 7.14%. Assuming constant annual percentage growth rate, an estimate of the annual fractional population growth rate is δ =0.2762% (the weekly fractional growth rate is δ =0.0055%).

Fractional Referral Rate. Referral data covering the period from November 2012 to November 2013 was provided by the hospital. All individual entries were organised into three main categories: (1) approved appointment, (2) cancelled appointment, and (3) other. The number of entries within the approved appointment category were counted for each week to determine the number of referred patients per week.

The population of the NHS Forth Valley population 300,218 in 2013 (data obtained from publicly available publications by National Records of Scotland (2012)). Using this together with the weekly numbers of referred patients, fractional referral rates for 50 weeks were calculated. After investigating the histogram and testing how well different distributions fit the data, the normal distribution, with mean 0.00016195 and standard deviation 0.00003421, was selected as the best fit for this data. Distribution parameters were estimated using the method of moments and the goodness of fit was tested using the chi-square test.

Risk Distribution of Referred Patients. The average percentages of referred patients in each risk group was provided by an orthopaedic consultant working in the department as this data is not stored in the hospital's systems.

Delays. The hospital staff provided the estimates of the minimum, the maximum and the most likely length of delays. Since these estimates can be used as parameters of the triangular distribution, it was decided to use this distribution to subjectively describe the varying structure of delays.

It is important to note that the ALT would take place while a patient waits for their knee clinic appointment. In other words, new patients waiting for decision delay includes ALT delay. The estimate for new patients waiting for decision delay is based on the system without the ALT. Therefore, the length of waiting for decision delay for new patients, who accept this new treatment but do not recover after it, would be shorter than the length of waiting for decision without ALT delay.

Distribution of Treatment Decisions. Knee clinic appointment outcome data covering the period from September 2013 to September 2014 was provided by the hospital. All individual entries were organised into four main categories: (1) discharged to community, (2) non-surgical treatment, (3) surgical treatment, and (4) other. The number of entries within each category, except Other, were counted for each week to determine the weekly numbers of both new and return patients who were sent to the surgery waiting list, recommended a non-surgical treatment, or discharged to community. After testing how well different distributions fit the data, the following distributions were selected as the best fit for the data:

- **Weekly fractional rate of surgical treatment decision for new patients** - a beta distribution with shape (1) 3.7813 and shape (2) 15.6154.
- **Weekly fractional rate of surgical treatment decision for return patients** - a Weibull distribution with scale 0.164 and shape 2.62.
- **Weekly fractional rate of new patients DIS** - a normal distribution with mean 0.412 and standard deviation 0.0725.
- **Weekly fractional rate of return patients DIS** - a gamma distribution with shape 30.233 and rate 70.931.

Parameters for a gamma distribution were estimated using the maximum likelihood method, while parameters for other remaining distributions were estimated using the method of moments. Weekly fractional rates of non-surgical treatment decisions were calculated by subtracting from one the weekly fractional rates of surgical treatment and DIS (discharged to community) decisions.

Orthopaedic consultants provided the probability estimates of patient's risk group given the treatment decisions. These probabilities can be assumed to be the same for both new and return patients. Using this data, it was not possible to calculate the required fractional rates of treatment decisions depending on the risk group by applying Bayes' theorem.

Distribution of Treatment Outcomes. The probability estimates of treatment outcomes based on literature (McAlindon et al., 2014) were provided by the orthopaedic consultants.

Initial Stock Values. The only initial stock value that had to be estimated was NHS Forth Valley population. The National Records of Scotland's population estimate of 303,529 for 2017 was used. The initial values of other stocks are zero.

2.4. Simulation setup

2.4.1. Insight Maker systems modelling software

Insight Maker (Forthmann-Roe, 2014) is a free web-based modelling and simulation software program. It was decided to choose this tool to build the SD model because of its accessibility to a wide audience of users. It allows developed models to be easily shared among users who can then, without any difficulty, change main parameters to test different scenarios.

2.4.2. Time step and initialization bias

The time step of the simulation was chosen to be one week because most of the parameters and data were based on weeks.

The simulation was initially empty, with no patients in all stocks except NHS Forth Valley population. However, this resulted in smaller numbers of patients waiting for decision or treatment than usual for the first few time steps of the simulation. To ensure that this initialization bias did not affect the results, a warm-up period of 50 weeks (1 year) was set up as after the graphical investigation of results when it was determined that after 50 weeks the system reaches a steady-state.

The simulation length, including the warm-up period, was set to 1000 weeks (20 years). This allowed for collection of the necessary output data for 950 weeks (19 years) by running a single long replication. These statistics were used to construct 95% confidence intervals by finding the average and the variance of all outcome measures.

2.5. Model validation

The first model output was aimed at producing the results that represent the real-world system. Two main validation tests were conducted - structural and behavioural. The structural validation was done to ensure that the structure of the model represents the realistic dynamics of the real-world system. This was achieved by holding a meeting with orthopaedic consultants who reviewed and assessed the model structure.

The next stage of the testing process was behavioural validation which focused on evaluating how patterns generated by the model match the observed historical figures. Due to the limited historical data, it was only possible to carry out this analysis on weekly fractional referral rates as well as weekly fractional rates of treatment decisions for new patients. The comparison between observed and simulated data is shown in Figure 3. It clearly illustrates that the distributions of the simulated values aligned with the distribution of historical data.

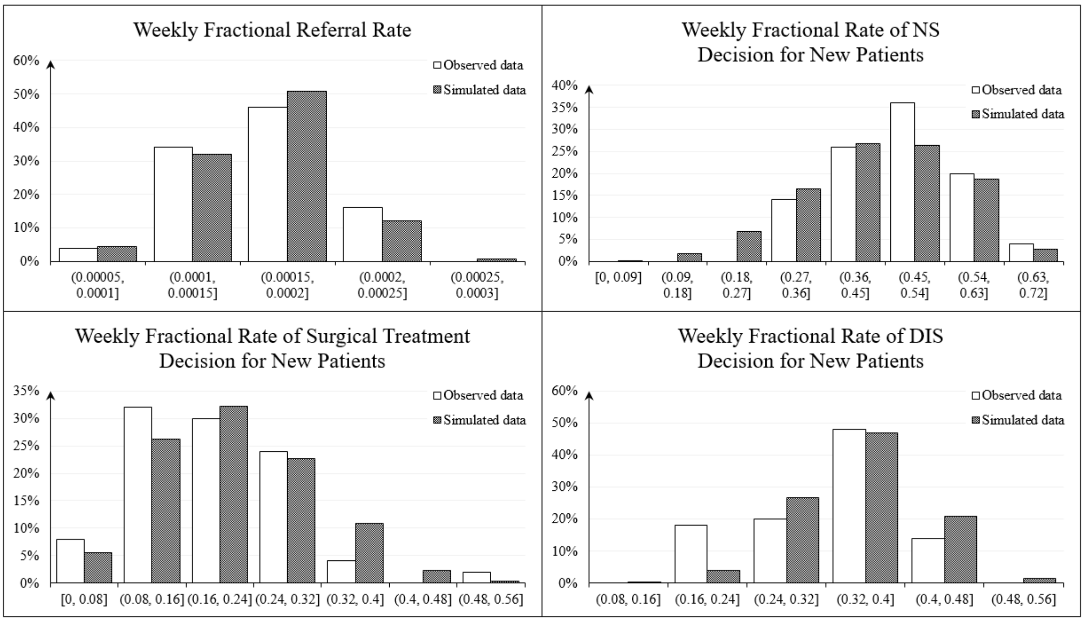

Figure 3. Model validation graphs

3. Results

Once the model was validated, it was possible to use it to evaluate the impact of the ALT. The following ALT acceptance rates for each risk group (the most expected scenario) were chosen: (1) Group 1 - 70%, (2) Group 2 - 90%, (3) Group 3 - 80%, and (4) Group 4 - 90% (see Table 1 for group definitions).

	Weekly Average	95% confidence interval	
Temporarily disabled patients			
Total	**845.1**	**842.53**	**847.67**
Group 1	845.10	842.53	847.67
Group 2	240.16	239.44	240.88
Group 3	382.99	381.86	384.12
Group 4	74.77	74.53	75.01
Permanently disabled patients			
Total	**2.09**	**2.06**	**2.13**
Group 1	0.58	0.58	0.59
Group 2	1.19	1.17	1.21
Group 3	0.13	0.13	0.13
Group 4	0.19	0.19	0.20
Deceased patients			
Total	**0.065**	**0.065**	**0.066**
Group 1	0.017	0.017	0.017
Group 2	0.036	0.035	0.036
Group 3	0.002	0.002	0.002
Group 4	0.011	0.010	0.011
Recovered patients			
Total	**45.76**	**45.08**	**46.44**
Group 1	11.16	11.04	11.27
Group 2	17.91	17.65	18.18
Group 3	4.68	4.60	4.76
Group 4	12.01	11.76	12.26
Surgeries			
Total	**15.4**	**15.24**	**15.56**
Group 1	6.85	6.78	6.92
Group 2	7.15	7.08	7.23
Group 3	0.80	0.79	0.81
Group 4	0.60	0.59	0.60
Patients waiting for decision			
Total	**531.71**	**528.99**	**534.43**
New patients waiting for decision			
Total	**384.39**	**382.04**	**386.73**
Group 1	103.23	102.64	103.81
Group 2	155.23	154.26	156.2
Group 3	37.81	37.58	38.04
Group 4	88.12	87.55	88.69
Return patients waiting for decision			
Total	**147.32**	**145.93**	**148.71**
Group 1	29.74	29.43	30.05
Group 2	79.28	78.54	80.02
Group 3	14.59	14.46	14.72
Group 4	23.70	23.48	23.93
Knee clinic appointments for new patients			
Total	**40.29**	**39.64**	**40.94**
Group 1	10.82	10.65	10.99
Group 2	16.27	16.01	16.54
Group 3	3.96	3.90	4.03
Group 4	9.24	9.09	9.39
Knee clinic appointments for return patients			
Total	**22.99**	**22.63**	**23.36**
Group 1	4.64	4.57	4.72
Group 2	12.37	12.18	12.57
Group 3	2.28	2.24	9.39
Group 4	3.70	3.64	3.76
Patients in NS treatment			
Total	**71.63**	**70.20**	**73.07**
Group 1	13.96	13.66	14.26
Group 2	38.39	37.64	39.14
Group 3	7.18	7.04	7.33
Group 4	12.10	11.84	12.35
Patients waiting for surgery			
Total	**181.07**	**180.13**	**182.00**
Group 1	80.58	80.20	80.96
Group 2	84.08	83.62	84.53
Group 3	9.40	9.34	9.46
Group 4	7.16	7.11	7.22

Table 2. Results for the most expected scenario

One additional model modification was required to be made to the probability of choosing surgery for new patients (the weekly fractional rate of surgical decision for new patients). ALT is expected to help non-surgical patients achieve self-management and it is not expected to have any impact on surgery patients. Therefore, it was estimated that patients who would accept the ALT, but would not recover, would be 1.6 times more likely to undergo surgery than the ones who did not accept the ALT. Simulation output based on the most expected scenario is provided in Table 2. To compare the mean difference between the system with no ALT and the system with it, a paired t-test was used. The results of a paired t-test are summarized in Table 3. Based on these results, the impact of the ALT on system performance is as follows:

- **Average number of temporarily disabled patients.** The average number of temporarily disabled patients would decrease by 21% (221 patients at any given time). The smallest decrease (16%) would be experienced by Group 1 patients while the largest reduction (29%) would be experienced by Group 4 patients.
- **Average number of permanently disabled patients**. The average number of permanently disabled patients would decrease by 9% (10 patients per year). The group which would face the largest effect is Group 4 (reduction of 20%).
- **Average number of recovered patients.** There would be 4% more recovered patients (85 patients per year) after introducing the ALT. Group 4 patients would face the largest effect (increase of 6%), which is expected as this group has the highest estimated recovery rate after the ALT.
- **Average number of deceased patients.** The death rate after the OA treatment is not very high (on average 4 patients per year). Therefore, introducing the ALT would not result in significant improvements in this area.
- **Average number of new and return patients waiting for decision.** Introducing the ALT would create a new cohort of patients waiting for the ALT, which would contain patients that would normally be waiting for decision. Therefore, the average number of patients waiting for decision would be smaller. It was estimated that this figure would decrease by 36% (217 patients per year) and 23% (43 patients per year) respectively for new and return patients.
- **Average number of surgeries.** As shown in Table 3, the average difference in the number of surgeries is not statistically significant at the 95% confidence level. This is expected because the orthopaedic consultants had previously suggested that only patients who were never going to have a surgery were likely to recover after the ALT. Therefore, the number of patients having surgery is not different in the systems with or without the ALT.
- **Average number of patients waiting for surgery.** As the number of people having surgery would not change significantly because of the ALT, the average number of patients waiting for surgery would decrease by only 1% (2 patients at any given time). As shown in Table 3, the difference is not significant for Group 1 and Group 3 at the 95% confidence level.
- **Average number of patients in non-surgical treatment.** As those patients, who recover after the ALT would most likely have had a non-surgical treatment, the average number of patients having the non-surgical treatment would decrease. It was estimated that we would face a reduction of 21% (19 patients at any given time).
- **Average number of knee clinic appointments for new and return patients.** These figures are directly linked with the patients waiting for decision, therefore they were also expected to decrease. It was estimated that the average

number of knee clinic appointments would reduce by 13% (6 patients per week) and 22% (7 patients per week) respectively for new and return patients.
- **Average number of patients waiting and completing the ALT.** Simulation results showed that, on average, there would be 61 patients waiting for the ALT and 44 patients completing this treatment per week.

Given the results above and assuming that a new patient appointment takes 20 minutes and a return patient appointment takes 10 minutes on average, it was estimated that, if the class were run by an orthopaedic consultant, approximately 14 patients would need to be seen by an orthopaedic consultant in an ALT class each hour to ensure that the total consultant time is the same for the system with or without the ALT.

4. Discussion

4.1. Key findings

The model developed in this paper using data from multiple sources, simulates the flow of knee osteoarthritis patients within the orthopaedic department in the NHS Forth Valley Hospital. It provides insightful information about how patients are distributed across the system. Although this paper presented the results of the most expected scenario after introducing ALT, the simulation model developed in this study can serve as a tool for understanding how the system performs under various 'what-if' scenarios by changing some of the estimated parameters.

In this paper, the focus was on evaluating the potential impact of offering ALT classes on the overall treatment outcomes for knee OA patients. The results, based on the most expected scenario, indicate that in the presence of the ALT, the treatment outcomes would improve as follows:

- There would be 4% more recovered patients each year on average.
- The average number of temporarily disabled patients would decrease by 21%.
- The average number of permanently disabled patients per year would drop by 9%.
- The treatment would result in death for 4% less patients each year on average.

The largest improvements would be achieved for patients with co-morbidities (Group 2 and Group 4). The number of permanently disabled patients in these groups would decrease by 12% compared to a reduction of 3% for the patients with no co-morbidities (Group 1 and Group 3). Better recovery rates would also have a significant impact on the individuals with the relevant health conditions increasing the number of recovered patients by 5%. These results not only highlight the importance of offering the ALT classes for these patients, but they can also be used to show which patients groups should be targeted first to achieve the largest possible positive impact on the treatment outcomes.

This study also showed some positive impact on the overall system. A significant decrease in the knee clinic appointments would increase the availability of orthopaedic surgeons which could help to reduce surgery waiting times. Furthermore, the results demonstrate that the average resource utilisation would not change, if 14 patients were seen by an orthopaedic consultant in the ALT classes each hour. These improvements would be achieved by organising three hours of classes on lifestyle changes each week.

	Without ALT	With ALT	Difference	95% confidence interval		Statistically significant?
Temporarily disabled patients						
Total	**1066**	**845**	**-221**	**-225**	**-217**	**Yes**
Group 1	285	240	-45	-46	-44	Yes
Group 2	477	383	-94	-96	-92	Yes
Group 3	97	75	-23	-23	-22	Yes
Group 4	207	147	-59	-60	-59	Yes
Permanently disabled patients						
Total	**2.3**	**2.1**	**-0.208**	**-0.282**	**-0.134**	**Yes**
Group 1	0.6	0.6	-0.016	-0.026	-0.005	Yes
Group 2	1.3	1.2	-0.134	-0.179	-0.089	Yes
Group 3	0.1	0.1	-0.010	-0.014	-0.005	Yes
Group 4	0.2	0.2	-0.048	-0.063	-0.034	Yes
Deceased patients						
Total	**0.069**	**0.065**	**-0.003**	**-0.0042**	**-0.0019**	**Yes**
Group 1	0.017	0.017	0.0001	-0.0001	0.0004	No
Group 2	0.037	0.036	-0.0008	-0.0013	-0.0002	Yes
Group 3	0.002	0.002	0.0000	0.0000	0.0001	No
Group 4	0.013	0.011	-0.0024	-0.0032	-0.0017	Yes
Recovered patients						
Total	**44**	**46**	**1.7**	**0.84**	**2.56**	**Yes**
Group 1	11.0	11.2	0.18	0.02	0.33	Yes
Group 2	17.2	17.9	0.71	0.36	1.06	Yes
Group 3	4.5	4.7	0.17	0.07	0.27	Yes
Group 4	11.4	12.0	0.64	0.35	0.93	Yes
Surgeries						
Total	**15.5**	**15.4**	**-0.10**	**-0.32**	**0.12**	**No**
Group 1	6.8	6.9	0.05	-0.04	0.15	No
Group 2	7.3	7.2	-0.15	-0.26	-0.05	Yes
Group 3	0.8	0.8	0.01	0.00	0.02	No
Group 4	0.6	0.6	-0.01	-0.02	0.00	Yes
New patients waiting for decision						
Total	**601**	**384**	**-217**	**-220**	**-214**	**Yes**
Group 1	150	103	-47	-48	-46	Yes
Group 2	240	155	-85	-87	-84	Yes
Group 3	60	38	-22	-23	-22	Yes
Group 4	150	88	-62	-63	-61	Yes
Return patients waiting for decision						
Total	**191**	**147**	**-43**	**-46**	**-41**	**Yes**
Group 1	37	30	-7.7	-8.1	-7.2	Yes
Group 2	102	79	-22.6	-23.7	-21.4	Yes
Group 3	19	15	-4.1	-4.4	-3.9	Yes
Group 4	33	24	-9.1	-9.4	-8.7	Yes
Knee clinic appointments for new patients						
Total	**46**	**40**	**-6**	**-7**	**-5**	**Yes**
Group 1	12	11	-0.8	-1.0	-0.6	Yes
Group 2	19	16	-2.3	-2.7	-2.0	Yes
Group 3	5	4	-0.7	-0.8	-0.6	Yes
Group 4	12	9	-2.4	-2.6	-2.2	Yes
Knee clinic appointments for return patients						
Total	**30**	**23**	**-7**	**-7**	**-6**	**Yes**
Group 1	6	5	-1.2	-1.3	-1.0	Yes
Group 2	16	12	-3.4	-3.7	-3.1	Yes
Group 3	3	2	-0.6	-0.7	-0.6	Yes
Group 4	5	4	-1.4	-1.5	-1.3	Yes
Patients in NS treatment						
Total	**91**	**72**	**-19**	**-22**	**-17**	**Yes**
Group 1	17	14	-3.3	-3.7	-2.8	Yes
Group 2	48	38	-9.9	-11.2	-8.7	Yes
Group 3	9	7	-1.9	-2.2	-1.7	Yes
Group 4	16	12	-4.3	-4.7	-3.9	Yes
Patients waiting for surgery						
Total	**183**	**181**	**-2**	**-3**	**-1**	**Yes**
Group 1	80	81	0.1	-0.4	0.6	No
Group 2	86	84	-2.3	-2.9	-1.7	Yes
Group 3	9	9	0.1	0.0	0.1	No
Group 4	7	7	-0.2	-0.3	-0.1	Yes

Table 3. Difference between the systems with and without the ALT

Although the results of this study suggest similar positive effects of advanced lifestyle treatment of knee osteoarthritis as previously presented in other studies based on randomized clinical trials (Coleman et al., 2012; Hopman-Rock & Westhoff, 2000; Maurer et al., 1999; Mazzuca et al., 1997), the use of SD can provide additional value when predicting intervention outcomes by giving insight into possible improvements before implementing any new interventions. Rather than focusing solely on how patient education programs can reduce knee pain and improve quality of life for knee OA patients, the results of this paper provide additional information on possible benefits in the overall system, such as a reduction in the number of knee clinic appointments and a decrease in the number people for a decision or treatment. This demonstrates an additional advantage of SD when modelling such dynamically complex systems to inform policy decisions. The simulation model developed in this study can be adapted to solve other relevant problems that aim to understand the behaviour of complex healthcare systems and test new possible ways of improving the efficiency of such systems.

4.2. Implementation

After the study showed the potential for improving patient flow for people with knee OA, the clinical team have been faced with the challenge of implementing the ALT to realise the benefits. Interventions for isolated parts of the treatment pathway in other health systems have yielded disappointing results (Dziedzic et al., 2018; Kennedy et al., 2013; Wang et al., 2016). However, the clinical team's aim is a more complex intervention to improve and accelerate implementation of non-surgical treatment for knee OA, with the intention of freeing orthopaedic surgeon time to provide surgery more quickly to those in need.

The project has been discussed with local primary care practitioners, exercise therapists, physiotherapists, public health specialists, improvement practitioners and service managers. Shared appointments have already been held with the content modified according to patient guidance and health literacy standards. The project team has observed a tangible reduction in referral rates to the orthopaedic department, in line with those predicted in the simulation, through utilising the principles of ALT in a primary care setting. Extremely positive improvements in pain and quality of life outcome measures have also been seen. Even the patients who require other treatment are better prepared and know what to expect from a referral to the orthopaedic department after the ALT appointments.

4.3. Limitations and Further Work

The limitations of this study include the reliance on experts' opinion to estimate important model parameters. Observing the system and collecting relevant data would increase the accuracy of the model results. Another limitation of our model is the small amount of historic data that were used to estimate the model parameters. The reliability of the model may be increased, if the same data were available for a longer period.

An additional limitation of the model is that delays do not depend on resource supply. As a result, this model cannot be used to evaluate the effect of resource availability. The reliability of this model could be increased by incorporating availability of orthopaedic consultants, orthopaedic surgeons, operating theatres and other resources, into the model and analysing their impact on the average length of various delays.

Another limitation is that the effect that shorter delays may have on the referral rates was not considered. Analysing this effect may improve the accuracy of the results. Another possible improvement to the simulation model is the incorporation of other risk factors (e.g. age) affecting treatment decisions and outcomes.

Adding these new patient characteristics and factors to the model would allow testing of a wider range of scenarios. This would enable policy-makers to further understand the extent to which various factors contribute to the long-term system performance.

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