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A REUSABLE DISCRETE EVENT SIMULATION MODEL FOR IMPROVING ORTHOPEDIC WAITING LISTS

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ABSTRACT

Waiting lists for orthopedic treatment in Australia are lengthy and frequently breach time-based performance targets, due to high demand and limited resources. This paper presents a discrete event simulation model of an orthopedic treatment pathway in Australia from the point of referral to surgical intervention for knee pain patients. The simulation model was used to investigate strategies for reducing the backlog of patients and average waiting time for initial orthopedic review, showing that a reduction of 34% in average waiting time can be achieved by adding three additional appointments per week. The model demonstrates that introduction of community-based rehabilitation early in the patient journey can significantly reduce waiting lists and improve patient recovery, without the need for surgical intervention. This simulation model has been designed to be reusable for other types of orthopedic conditions, and for use in other health services.

1 INTRODUCTION

Public hospital orthopedic services are difficult to provide in a timely manner due to high demand and constraints on hospital resources. Consequently, patients can remain on waiting lists for extended periods of time. This problem has been exacerbated by frequent cancellation of elective surgeries due to re-prioritization of services during the COVID-19 pandemic. In Australia, the percentage of patients who waited longer than a year on an elective surgery waiting list increased from 2.8% in 2019-20 to 7.6% in 2020-21 (Australian Institute of Health and Welfare 2022). Between 2019-20 and 2020-21, the greatest increase was observed for 'Total knee replacement', with an increase from 11% to 32% in the proportion of patients who waited longer than a year and an increase from 223 to 308 in number days waited at the 50th percentile. This problem is ongoing - January 2022 saw further cancellation of elective procedures in Australia during a surge of COVID-19 cases. Delays in receiving treatment can be associated with adverse outcomes for patients, for example prolonged pain, lower mobility, and weight fluctuation due to an inability to exercise.

In this study, we investigate the process of orthopedic treatment in an Australian health service, from the point of referral to surgical intervention. In a number of cases, surgical intervention can be avoided through participation in community-based rehabilitation programmes. In the context of current exacerbated waiting times for knee replacement surgery, we parameterize the model with data relating to patients presenting with knee problems. The model is generalizable and can be easily re-parameterized with data concerning different orthopedic conditions within the service.

The aims of this research were to (i) develop a discrete event simulation model which is representative of the current orthopedic service delivery, (ii) examine the projected pressure on the service over a five-year period if no interventions are made, (iii) investigate the increase in capacity required to reduce waiting times and clear a backlog of waiting patients, and (iv) experiment with increasing access to community-based rehabilitation to improve outcomes and potentially negate the need for surgery.

This paper presents the following contributions:

- the literature on discrete event simulation of orthopedic services is reviewed and the potential for reusing an existing model is discussed;
- a new high-level discrete event simulation model of an Australian orthopedic service is presented and used to investigate ways of reducing waiting times;
- the model can be reused for other orthopedic services (e.g., hip replacements) and in other health services.

Section 2 includes a review of the literature on discrete event simulation models of orthopedic services. The possibility of using an existing model is explored and the barriers to adapting that model for reuse are discussed. Section 3 presents the conceptual simulation model design, model logic, data, and parameters. Section 4 shows the baseline model results and the results from scenario experimentation. Section 5 includes a discussion of the study and outlines future work.

2 LITERATURE REVIEW

2.1 Discrete Event Simulation Models of Orthopedic Services

At the outset of of this research project, the authors examined the existing literature, with the aim of determining whether a suitable model already existed that could be reused and adapted for our study. Orthopedic healthcare is a complex system with multiple components (typically referral, various appointments with medical and allied health staff, physiotherapy, and surgery). A review of the existing literature on discrete event simulation (DES) applied to improve patient flow through orthopedic services identified a variety of different model structures and objectives.

The majority of studies focused on a single component of orthopedic services. Individual hospital clinics were the most frequently modelled component of orthopedic services, with many papers producing detailed models of specific hospital clinics. Rohleder et al. (2011) created a DES model of an orthopedic clinic in the USA, demonstrating that improvements to patient throughput time could be made by optimizing staff levels and improving appointment scheduling (without the need for additional resources). Baril et al. (2014) focused on optimizing the performance of an orthopedic clinic using a detailed DES model with design of experiments. The authors focused on appointment scheduling to improve clinic performance from the perspective of both patients and staff. Ltaif et al. (2022) combined DES with goal-programming optimization to find a queuing configuration which would maximize patient satisfaction within a Tunisian hospital orthopedic clinic.

Some studies have focused on creating a detailed simulation that is applicable to more than one orthopedic clinic. Weerawat et al. (2014) presented a ‘generic’ DES model, applied to five wards in the same hospital orthopedic clinic in Thailand by modifying input parameters. In this study the model was designed to quantify the impact of proposed initiatives on key performance indicators, such as patient waiting times. The model is highly detailed and would require adaptation for use in a different hospital or healthcare system. Suhaimi et al. (2018) identified that many existing simulation models share common features but are rarely reused. The authors remark that this is due to model logic and parameterization which is tied to a specific hospital or healthcare system, and would require substantial time and effort to transport to a new setting. A new ‘flexible’ DES model for orthopedic clinics was presented and demonstrated with application to two clinics in the USA. The model is designed to analyse length of stay-based performance measures under various staff scheduling configurations.

In contrast, some of the published literature has focused on creating high-level models of orthopedic services, which are modelled in a lower level of detail or as part of a wider system. Demir et al. (2017) created a DES decision support tool to forecast patient demand within a UK hospital trust over a five year period. The forecasted demand on outpatient orthopedic resources was captured in the simulation, where orthopedics services were not modelled in any detail. Bowers et al. (2015) presented a DES model of a musculoskeletal physiotherapy service with 9 clinic locations in the UK. The model objective was to understand the impact of patient decision-making (choice of clinic) and various management options on the flow of patients through the system.

The aims of this research paper (outlined in Section 1) involve modeling multiple interacting components of an orthopedic service pathway. To the best of our knowledge, there is only one model on orthopedic services which is sufficiently similar for comparison, which is discussed in the next section.

2.2 Reuse of Orthopedic Discrete Event Simulation Models

The literature on discrete event simulation applied to model health services is vast. One contributing factor to the large volume of literature is a lack of model reuse - the majority of published simulation studies have developed a new bespoke model for a specific unit (e.g., emergency department) and facility (e.g., hospital) which cannot be easily transported to a different setting (Günal and Pidd 2010). Interest in simulation model reuse dates back at least twenty years. Robinson et al. (2004) proposed that this lies along a spectrum, for example reuse of code, reuse of conceptual models, or reuse of complete models. The authors suggested that reuse should intuitively save time and cost in model development.

'Generic' or 'generalizable' models have been suggested as a means for improving model reuse. Fletcher and Worthington (2009) proposed that " 'generic hospital models suggest a potential for understanding general problems faced by hospitals and the potential general solutions to improve service delivery". Complementary to these are 'generalizable' models, defined by Boyle et al. (2022) as 'those that can represent multiple units and, through customization using real data, be used to investigate site-specific problems'. In this study we initially aimed to reuse an existing simulation model by adapting it to suit our problem setting. Some of the models discussed in Section 2.1 are labeled as generic and aim towards model reusability (Weerawat et al. 2014; Suhaimi et al. 2018), however these models are designed for detailed modeling of orthopedic clinics within hospitals and are therefore unsuited for our aim of modeling multiple components on an orthopedic service pathway.

The only model identified by the authors which concerned a sufficiently similar problem-setting to merit consideration for reuse was that developed by Comans et al. (2017). It modelled multiple components of a musculoskeletal (orthopedic) service in Australia, from patient referral to surgical intervention. The authors used a mixed-methods simulation, where discrete event simulation was used to capture the flow of patients through the conceptual flow diagram shown in Figure 1 and agent based simulation was used to model patient characteristics. The patient flow diagram shown in Figure 1 is similar to the conceptual model we present in Section 3 and therefore we planned to reuse it with some adaptations.

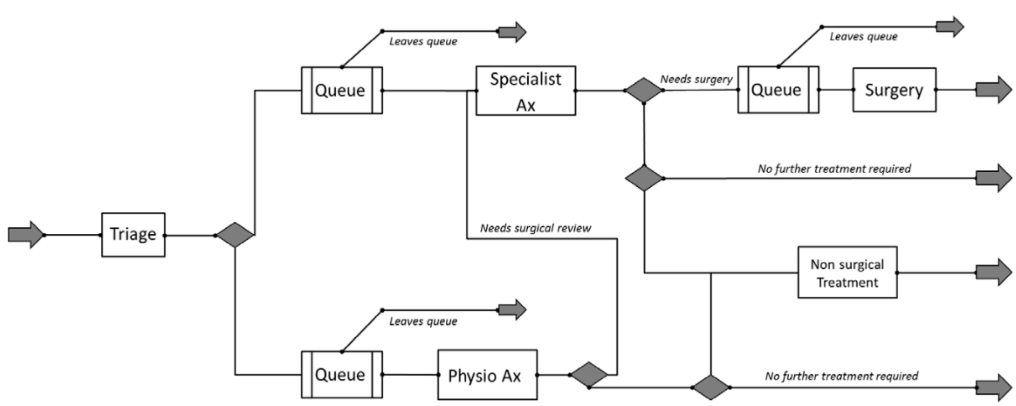

Figure 1: Conceptual model of musculoskeletal (orthopedic) services from Comans et al. (2017).

The key differences between the Figure 1 model and our study are summarized in Table 1. This is included to demonstrate that the model could theoretically be adapted with relatively minor changes. It is not intended to provide an exhaustive list of differences between the two models.

Table 1: Proposed adaptations to reuse the Comans et al. (2017) model in a different setting.

Comans et al. (2017)	**Current study**	**Proposed adaptation**
1. All orthopedic conditions plus neurology included.	Only knee conditions included.	Reflect with a lower arrival rate and reduced resource availability.
2. One type of specialist .	Two types of specialist.	Include another activity with queue.
3. Agent-based simulation used to model patient attributes.	Attributes not considered.	Remove attributes from model code.
3. Patients see specialist or physio (not both simultaneously).	Patients can have physio and other appointments concurrently.	Adjust the model routing logic to enable other pathways.
4. Patients see specialist or physio.	Patients can have physio.	Adjust the model routing logic.
5. Surgery not modelled.	Surgery is modelled.	Include another activity with queue.

We contacted the authors of Comans et al. (2017), who shared their AnyLogic model with us for reuse. At this stage it became clear that we would not be able to easily adapt their model within the project time-frame. The main barriers to reusing the model were as follows: (i) it was not constructed to visually align with the flow diagram in Figure 1, (ii) it was developed using multiple interlinked model structures, (iii) there were a large number of errors associated with transporting the model to a different computer operating system, (iv) the model was complex and difficult to decipher without detailed documentation, and (v) there were features of the model that were incompatible with the AnyLogic personal learning edition. It was therefore necessary to develop a new simulation model in AnyLogic to achieve the project objectives within an appropriate time-scale. The aforementioned barriers were taken into consideration throughout the model building process to minimize the difficulties involved with subsequent model reuse.

3 SIMULATION MODEL DESIGN

3.1 Conceptual Model

Figure 2 shows the conceptual model, from onset of knee pain to orthopedic surgery. The conceptual model was developed iteratively through analysis of data and discussions with various stakeholders, including orthopedic physiotherapists, physicians, and surgeons.

Patients develop knee pain and enter the system through a referral to orthopedic services (either through presentation to a General Practitioner (GP), emergency departments, or specialist clinics). The arrival of patients (referred for orthopedic services) is the only place where new entities are generated in the model. The majority of referred patients are added to a waiting list for an orthopedic review appointment. A small number of urgent cases are referred directly to the waiting list for an orthopedic surgeon.

Patients queue for an orthopedic review appointment. Each year approximately 100 patients leave the waiting list (e.g., due to accessing private a healthcare service) and this process was replicated in the model. The orthopedic review takes one day and determines the next treatment actions for the patient. Patients can

1. withdraw from treatment (and therefore the system),
2. be discharged from the system (with or without attending community-based rehabilitation),
3. be added to the waiting list for a follow up orthopedic review appointment (with or without attending community-based rehabilitation), or
4. be referred to the waiting list for orthopedic surgical review (with or without community-based rehabilitation).

In pathways 2-4, patients can be simultaneously queuing for appointments and attending the community-based rehabilitation programme. This was modelled in the simulation by ‘splitting’ entities to allow progression simultaneously through both activities. Patients queue for the community-based rehabilitation programme, which lasts for six or twelve weeks.

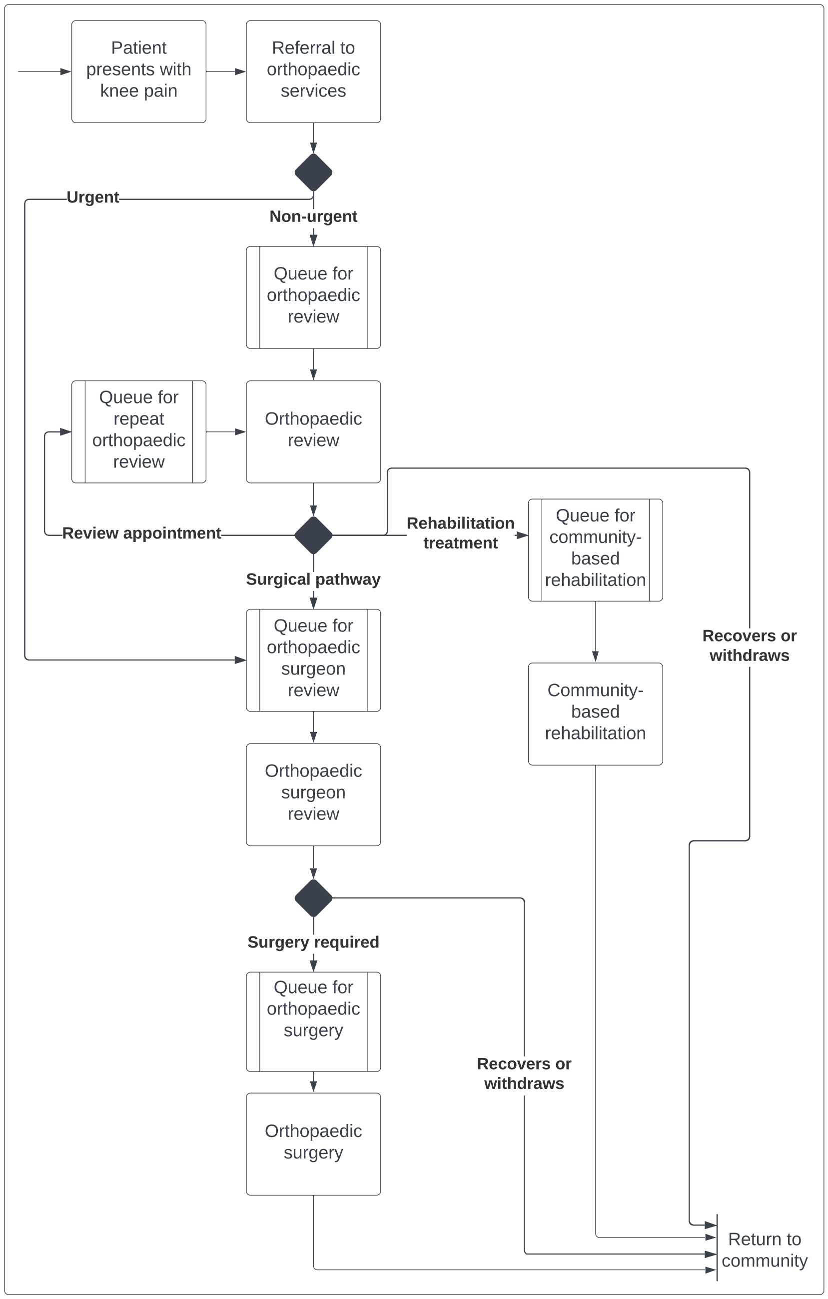

Figure 2: Conceptual model of orthopedic services.

Patients queue while waiting for an orthopedic surgical review appointment to become available, after which they can be referred for surgical joint replacement or can withdraw from the system. Patients who will undergo surgical joint replacement are added to a waiting list for a theater slot. The time they spend in theater and subsequent recovery was modelled using a probability distribution. The model assumes that treatment is completed and patients return to the community after surgical joint replacement.

3.2 Model Logic and Parameters

The model was written using AnyLogic software. This was chosen so that the model could be accessed and reused by anyone via the freely available personal learning edition, and because the visual interface would facilitate communication of the model findings with stakeholders in the healthcare system. The model logic was developed through iterative consultations with healthcare staff and stakeholders, facilitated by the conceptual model presented in Figure 2 above. A combination of expert opinion and hospital data was used to develop the model logic and to populate the model parameters. This information is summarized in Tables 2 and 3. Data from the system spanning January 2017 - December 2019 was used to calculate the model parameters. It was decided to omit the data from January 2020 onwards for this purpose due to the impact of COVID-19 on healthcare operations, including a reduction in the number of patients presenting for medical treatment and the cancellation of many elective appointments and operations (Australian Institute of Health and Welfare 2022). A future iteration of the model could include the impact of COVID-19 on the system during this time.

The entities of the model are patients who present as referrals to to orthopedic services. The model incorporates the assumption that patients do not have any attributes (e.g., age or priority grouping) that affect their progression through the system. This is an appropriate assumption because it was not relevant to the modeling objectives and it helps to reduce model complexity. Table 2 displays the logic for routing patients through the simulation model. All of the logic for routing patients is achieved by using a percentage profile, ascertained where possible from hospital data and otherwise from expert opinion. For example, expert opinion determined that 98% of patients are routed from referral to orthopedic review, with a minority 2% routed directly to orthopedic surgeon review.

Table 2: Model logic for routing entities through the various orthopedic pathways.

From node	To node	Baseline value	Data source
Referral	Orthopedic review	98 %	Expert opinion
	Orthopedic surgeon review	2%	
Orthopedic review	Withdraw from system	36%	Hospital data
	Discharged (with rehabilitation)	1%	
	Discharged (no rehabilitation)	29%	
	Follow up review (with rehabilitation)	3%	
	Follow up review (no rehabilitation)	1%	
	Orthopedic surgeon (with rehabilitation)	21%	
	Orthopedic surgeon (no rehabilitation)	9%	
Rehabilitation queue	6-week programme	83 %	Expert opinion
	12-week programme	17 %	
Orthopedic surgeon	Withdraw from system	11 %	Expert opinion
	Surgical joint replacement	89%	

Patients are assumed to arrive according to a Poisson process with an intensity of 10 referrals per week. This value was derived from the orthopedic referral data records (pre-pandemic). As shown in Table 2, there are 5 activities in the model. Referral to orthopedic services takes approximately one week. The orthopedic review and surgical consultations are modelled using a duration of one day. Community-based rehabilitation is either six or twelve weeks (determined using the probability profile in Table 2). Orthopedic surgery requires a length of stay in hospital between 1 and 14 days and is defined in the model as empirical distribution calculated using hospital data.

The authors adopted the assumption that all queues in the model have a first-in-first-out discipline. The queues for orthopedic review, community-based rehabilitation, surgical consultation, and orthopedic surgery were initialized with 1200, 0, 11, and 15 patients respectively (determined through expert opinion). Each year approximately 100 patients leave the waiting list for orthopedic review (e.g., due to accessing private a healthcare service) and this process was replicated in the model. The availability of places on the community-based rehabilitation programmes was modelled using a resource, where 20 spaces are available to be seized by patients for a duration of either six or twelve weeks (depending on the programme they have been routed to). Appointments for orthopedic review, surgical review, and theater were modelled using a 'booking process', where the time between bookable appointments was represented using recent hospital data.

Table 3: Parameters and distributions used in the orthopedic DES. The model time-scale is in weeks.

Parameter	**Distribution**	**Baseline value**	**Data source**
Arrival process			
Patient arrivals	Poisson	$\lambda = 10$	Hospital data
Activities			
Referral	Deterministic	1 week	Expert opinion
Orthopedic review		1 day	
Community-based rehabilitation		6 or 12 weeks	
Surgical consultation		1 day	
Orthopedic surgery	Distribution	Empirical	Hospital data
Queues			
Orthopedic review	FIFO	Initial length = 1200	Expert opinion
Community-based rehabilitation	FIFO	Started from empty	
Surgical consultation	FIFO	Initial length = 11	
Orthopedic surgery	FIFO	Initial length = 15	
Resources			
Physiotherapists	20 physiotherapist resources		Expert opinion
Assumptions	1. First-in-first-out discipline for all queues.		
	2. 100 patients per year removed from orthopedic review queue.		
	3. Availability of orthopedic review appointments, surgical review appointments, and theater slots modelled using a 'booking process'.		
Simplifications	1. No patient attributes are modelled (e.g., priority grouping/age).		

3.3 Model Verification and Validation

The model outputs of interest were the *mean waiting time* and *mean number of waiting patients* in each of the 'orthopedic review', 'community-based rehabilitation', 'surgical consultation', and 'orthopedic surgery' queues. It was also of interest to examine the *mean length of the queue for orthopedic consultation* after 5 years of simulated time.

Model verification was performed to ensure that the conceptual model was accurately translated into AnyLogic software (Banks et al. 2000). This was achieved by (i) updating and maintaining documentation throughout the model building process, (ii) exploring the model output under various changes to the input parameter distributions to make sure that it behaved as expected, (iii) making use of the AnyLogic visual interface to visually check the model logic (in collaboration with hospital staff and stakeholders).

Validation was carried out by comparing the baseline model outputs against data from the real system. The baseline model was run 50 times using different random number streams in AnyLogic and the model outputs are presented in the following section.

3.4 Model Reusability

This model was designed to be re-usable for simulating other orthopedic services in Australia and internationally. The following steps were taken to achieve re-usability:

1. the conceptual model was designed to be as simple as possible;
2. all aspects of the STRESS-DES guidelines (Monks et al. 2019) for strengthening the reporting of simulation studies were used;
3. an open-source version of AnyLogic was used so that the model can be shared;
4. the AnyLogic model was designed to visually resemble the conceptual model in a simple flow diagram format;
5. all of the AnyLogic model components and variables were meaningfully labelled.

Some modifications to the conceptual model may be necessary for re-use. Given the simplicity of the model, this could easily be achieved by changing any activities and routing arrows as necessary. The model could also be used for any other orthopedic service pathways (e.g., patients presenting with hip pain).

4 RESULTS

Table 4 shows the baseline model outputs. The results demonstrate that mean waiting times from the simulation were a close match to those from the real system - in most cases the 95% confidence interval (CI) includes the mean waiting time from the data. The exception to this was the mean waiting time for orthopedic surgery, which was underestimated because the competing demand in theater for other types of operations was not modelled. The mean queue lengths were validated through discussions with the hospital staff, who confirmed them to be a reasonable match to the real system. The involvement of stakeholders in model validation is typically used in health care projects when data from the system is not available (Eldabi 2009).

Table 4: Results obtained from the baseline simulation model.

Queue	Mean - data	Mean (95% CIs) - simulation
Orthopedic Review		
Waiting time (weeks)	100	107.9 (104.6,111.2)
Queue length		1389.5 (1346.3,1432.7)
Community-based rehabilitation		
Waiting time (weeks)	5	4.135 (1.1,7.1)
Queue length		6.1 (1.4,10.8)
Surgical consultation		
Waiting time (weeks)	20	17.8 (14.9,20.7)
Queue length		56.5 (44.3,68.6)
Orthopedic surgery		
Waiting time (weeks)	4	1.2 (0.9,1.5)
Queue length		2.2 (1.9,2.5)

The validated simulation model was used to explore two types of scenario which would reduce the backlog of patients waiting for an orthopedic review appointment:

1. Scenario Type A: the availability of orthopedic review appointments was increased to examine the expected reduction in queue length. This was achieved by routing a proportion of patients to additional appointment slots.
2. Scenario Type B: at the point of referral, a proportion of patients were routed directly to community-based rehabilitation services. The experiment assumes that these patients recover and return to the community based on an early rehabilitation and education-based intervention.

A range of parameter values were explored for each scenario type and the results of which are presented in Table 5. In Type A scenarios, routing a proportion of 0.05, 0.10, and 0.15 patients to additional appointments is equivalent to providing approximately 1, 2, and 3 additional appointments per week of simulated time respectively.

Table 5: Baseline model results compared to output from Scenario Type A and Scenario Type B.

	Orthopedic review		Community-based rehabilitation		Surgical review		Orthopedic surgery	
Baseline	**107.9**	(104.6,111.2)	**4.135**	(1.1,7.1)	**17.8**	(14.9,20.7)	**1.2**	(0.9,1.5)
Type A								
0.05	**98.1**	(95.2,101.1)	**10.2**	(7.7,12.8)	**22.3**	(19.2,25.4)	**1.56**	(1.1,2.1)
0.10	**88.9**	(86.1,91.7)	**20.1**	(17.8,22.4)	**36.2**	(31.2,41.1)	**1.2**	(1.0,1.4)
0.15	**71.5**	(66.1,76.8)	**36.3**	(31.2,41.3)	**47.6**	(42.4,52.7)	**1.6**	(1.2,2.1)
Type B								
0.05	**98.9**	(96.2,101,6)	**29.6**	(25.3,33.8)	**20.0**	(17.7,22.4)	**1.3**	(1.1,1.5)
0.10	**93.5**	(89.1,98.0)	**47.6**	(42.9,52.3)	**18.2**	(13.6,22.9)	**1.4**	(1.0,1.7)
0.15	**85.6**	(80.6,91.1)	**50.4**	(53.3,65.2)	**20.1**	(15.7,24.6)	**1.3**	(1.0,1.6)

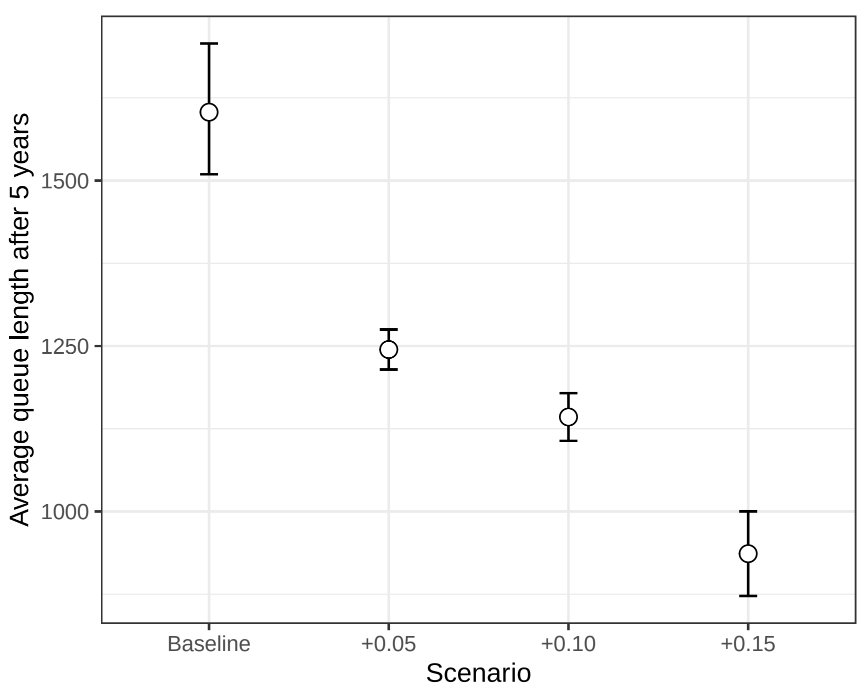

Figure 3: Mean and 95% CIs of the orthopedic review queue length after 5 years of simulated time.

The results for Scenario Type A in Table 5 show that providing three additional appointments per week (routing 15% of demand to additional appointments) reduces the mean waiting time in this queue by 34% from 108 weeks to 72 weeks. Figure 3 shows that the queue length for orthopedic review after 5 years is also significantly reduced, from an average of 1603 patients in the baseline scenario to an average of 936 patients. Although this is a promising method of reducing the queue length and waiting time for orthopedic review, the results show that the increased flow of patients through orthopedic review significantly increase the queue length and average waiting times for community-based rehabilitation places and surgical review appointments. In order to successfully clear the backlog of patients waiting for an orthopedic review appointment, the availability of community-based rehabilitation slots and surgical review appointments would need to be increased.

The results for Scenario Type B in Table 5 show that routing 15% of patient demand directly to community-based rehabilitation successfully reduces the mean waiting time for orthopedic review by 21% from 108 weeks to 87 weeks. Without increasing the number of community-based rehabilitation slots, this leads to a sizeable increase in the average waiting time for this service by 41% from 30 to 50 weeks. In order for this strategy to be successful, the provision of community-based rehabilitation would need to be increased in line with demand. Future work will consider (i) investigating the number of community-based rehabilitation resources required to meet the higher level of demand without increasing the average waiting time, and (ii) a mixture of the Type A and B scenario modeling.

5 CONCLUSION AND FUTURE WORK

5.1 Discussion

This paper presents a discrete event simulation model of a public hospital orthopedic service in Australia, which includes multiple interacting components of the treatment pathway from the point of referral to surgical intervention. The baseline simulation model was verified and validated as an accurate representation of the current orthopedic service delivery for patients presenting with knee pain, and the projected pressure on the system over a five-year time horizon was presented.

Two types of scenario experiments were proposed to investigate the increase in capacity required to reduce waiting times for orthopedic review and to clear the current backlog of waiting patients. Results from the scenario experiments showed that a slight increase in the weekly number of orthopedic review appointments over a five year period significantly reduces the queue length and mean waiting time for this service, but leads to an increased waiting time and queue length for other services further downstream. The results further demonstrated that increasing the provision of community-based rehabilitation services early in the patient journey reduces the queue length and mean waiting time for orthopedic review, whilst also increasing the proportion of patients who recover through rehabilitation and therefore do not require surgery. The use of discrete event simulation to model this problem is advantageous here because interventions to fix queuing problems in one area of the system can have unintended consequences further downstream. In this study, such unintended consequences further along the patient pathway were able to be detected and measured.

In this research, reusing an existing simulation model of Australian orthopedic services was attempted and the major barriers to reusing this model were discussed. In this case, model reuse was not feasible and a new model was developed. Throughout the model building process we aimed to make the model reusable both within the health system under study for other orthopedic services (e.g., the model can be customized with new data for patients presenting with hip pain), and within other public health systems, such as in other Australian states or internationally. In order to reduce the friction associated with model reuse we undertook a number of steps intended to remove or minimise barriers to re-use (see Section 3.4). It is intended that future studies on simulation modelling for orthopedic waiting lists could re-use this model. Future work could evaluate the re-usability of this model and discuss any associated challenges.

5.2 Future research

Future scenario modeling will look at (i) implementing multiple interventions simultaneously, (ii) examining the number of resources required to prevent bottlenecks forming further downstream, (iii) incorporating costs into the model to advise on the financial implications of each strategy, and (iv) investigating the impact of COVID-19 on service delivery, which saw a reduced number of referrals during lockdown followed by a surge in demand. The simulation model will be made available on GitHub along with documentation and reproducible output for future reuse in other studies.

5.3 Conclusion

In this study, a new discrete event simulation was developed to model an orthopedic treatment pathway in Australia. The modeling demonstrated how various strategies could be used to reduce the initial waiting list and highlighted that further interventions would need to be made downstream in the system. It further showed that the introduction of community-based rehabilitation could reduce pressure on the system while improving outcomes for patients. The results from scenario experimentation were used to advise the health service on the expected improvement in queue length and waiting times through various interventions, and this modeling was used to support a business case for increased resources. This model is reusable and will be made publicly available with documentation and reproducible output.

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