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The development and practical application of a simulation model to inform musculoskeletal service delivery in an Australian public health service

T.A. Comans [a,b,*], A.T. Chang [c], L. Standfield [b], D. Knowles [d], S. O'Leary [e,f], M. Raymer [f]

[a] Metro North Hospital and Health Service, Queensland Health, Herston QLD 4029, Australia
[b] Menzies Health Institute Queensland and Centre for Applied Health Economics, Griffith University, Nathan campus, 170 Kessels Road, Nathan QLD 4111, Australia
[c] Centre for Allied Health Research, Royal Brisbane and Women's Hospital, Herston QLD 4029, Australia
[d] Anthrodynamics Simulation Services. Minus Fifty Software, Canada
[e] School of Health and Rehabilitation Sciences, The University of Queensland, Therapies Building 84a, St Lucia QLD 4072, Australia
[f] Physiotherapy Department, Royal Brisbane and Women's Hospital, Herston QLD 4029, Australia

HIGHLIGHTS

- Simulation modelling is a valuable and informative tool in health service planning.
- Existing services for patients with musculoskeletal conditions did not meet demand.
- Advanced physiotherapy-led clinics form part of an efficient outpatient service.

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ABSTRACT

Timely access to orthopaedic and neurosurgery services in public hospitals is difficult to achieve due to constrained resources and rising demand with the result that waiting time targets are often not met. Advanced physiotherapy-led clinics can assist in managing demand by directly assessing and managing many patients without the need for consultation with a medical specialist. The purpose of this study was to develop and apply simulation modelling to determine the scale and mix of services required to efficiently manage demand from patients with musculoskeletal conditions in one health district.

Design

We designed a simulation model to estimate service demand over five years and test different service configurations (medical specialist-led or advanced physiotherapy-led) to meet waiting time targets and reduce waiting lists in orthopaedic and neurosurgery services.

Results

Without intervention, the combined orthopaedic and neurosurgical outpatient waiting list is predicted to grow from 11,000 to over 15,000 patients over a five year period. To achieve waiting time targets within 2 years the scale of services would need to approximately double and the most efficient combination would be to direct approximately 50% of referrals to medical specialist clinics and 50% to advanced physiotherapy-led clinics.

Conclusions

In the health system modelled, a significant gap was identified between future demand and current provision of services. Simulation modelling was able to assist service planners understand the demand and identify effective management strategies.

* Correspondence to: School of Medicine, Nathan campus, Griffith University, 170 Kessels Road, Nathan QLD 4111, Australia.
E-mail addresses: t.comans@griffith.edu.au (T.A. Comans), angela.chang@health.qld.gov.au (A.T. Chang), lachlan.standfield@griffithuni.edu.au (L. Standfield), dylan.knowles@minusfiftysoftware.com (D. Knowles), s.oleary@uq.edu.au (S. O'Leary), maree.raymer@health.qld.gov.au (M. Raymer).

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1. Introduction

The demand for medical specialist outpatient services for patients with musculoskeletal conditions substantially exceeds supply. This imbalance over time has generated long waiting lists resulting in patients not being seen within clinically recommended timeframes. As a high proportion of these patients will not require surgery an initiative adopted in Queensland, Australia, has been the Neurosurgical and/or Orthopaedic Physiotherapy Screening Clinic and Multidisciplinary Services (NPSC and OPSC hereafter referred to as N/OPSC) [1]. In the N/OPSC model, a physiotherapist working with an advanced scope of practice undertakes assessment, diagnosis and case management for selected patients with non-urgent (category 2 and 3) musculoskeletal conditions who have been referred to either orthopaedic or neurosurgical specialist lists. Referrals are received predominantly from general practitioners (GPs) and consist of a standardised referral template, although the level of detail provided is variable, and are usually accompanied by imaging and test results. Referrals assigned to lower urgency triage categories may relate to conditions of many years duration. Physiotherapists working in these roles possess a high level of knowledge, skills and reasoning, developed through experience in relevant clinical practice areas and targeted post graduate professional development and education beyond Masters level. Studies specific to the N/OPSC, as well as studies evaluating similar services internationally, have shown this type of model to provide effective patient care and a high quality of service, as well as reduce waiting times and staff costs [1–6]. Furthermore, a recent analysis using discrete event simulation (DES) demonstrated that increasing the capacity of N/OPSC services within a single facility would be the most cost-effective way to improve non-urgent patient throughput and reduce waiting times without exceeding available surgical resources at that facility [7]. However, the current N/OPSC service provided in most facilities in Queensland is not of adequate scale to manage the proportion of those patients who would be suitable to be directed to this pathway of care.

Operations research, and in particular DES, has a growing role in modelling and informing aspects of hospital and health service delivery [8]. A review found that most DES models in hospitals focus on emergency departments [9]. Where DES has been used for orthopaedic outpatient clinics, it has generally been focused on process improvement, including issues of patient flow such as patient arrival times, no show impacts and waiting times once the patient has physically arrived within the department [10,11]. Models using DES have not focussed on the time delay from GP referral to specialist appointment and the matching of overall service capacity and demand to ensure patients are seen within a clinically appropriate time from referral [12]. It is this latter concern that is the more significant priority for health services planning and achieving government targets [13].

The aim of this research was to estimate the scale and mix of services needed to effectively manage patients referred with musculoskeletal conditions within set time targets in a health service with multiple hospitals and clinics. Specifically, we applied a simulation model within the Metro North Hospital and Health Service (Metro North) which is the largest public health provider in Queensland serving 20% of the state's population (approximately 900 000 people) [14]. Three hospitals within Metro North (Royal Brisbane & Women's Hospital (RBWH), The Prince Charles Hospital (TPCH) and Redcliffe Hospital (Redcliffe)) offer orthopaedic services that include N/OPSC. Neurosurgery services are also provided at RBWH to which patients from rural and regional areas outside the health service are commonly referred. N/OPSC operates to manage a large proportion of these patients referred to neurosurgery with spinal pain conditions. At the end of 2015, the combined wait list for orthopaedic and neurosurgical assessment was approximately 11,000 referrals. It is therefore anticipated that the findings of this study may have a substantial influence on service planning and improved service delivery to many individuals with musculoskeletal disorders referred to these services in the future.

2. Experimental design

A mixed method simulation model was developed in Anylogic® to predict the demand for public specialist outpatient services for patients with musculoskeletal conditions in Metro North over five years. This time frame was chosen to allow sufficient time to assess the impact of changing levels of activity, while also recognising that longer timeframes rely on assumptions that may not hold true in the future. The main structure of the model relies on a simplified depiction of the clinic flow using DES. Individual characteristics of patients were modelled using agent-based methods. Monthly cycles were used for referrals and probabilities as this reflects usual reporting time frames in the health service. A number of scenarios were explored in the model over three experimental runs.

2.1. Scenarios explored in the model

Firstly, a base case of the future demand on services over five years was estimated. This model applied the current levels of activity in clinics and proportion of patients managed by advanced physiotherapists and incorporated increasing demand for services using projected population growth estimates over five years.

Secondly, an optimisation experiment with 1000 repeated simulations was conducted to estimate the scale and mix of services required to meet category specific waiting time targets 80% of the time within the first two years. For this experiment, activity levels of clinics and the proportion of patients managed by advanced physiotherapists were allowed to vary in each simulation with the goal of minimising the total number of appointments while meeting target waiting times. Parameter variation and goal seeking were performed by the OptQuest Optimization Engine included in AnyLogic [15,16].

Following the optimisation experiment, results were presented to stakeholders. Stakeholders were asked to consider what could feasibly be provided in terms of efficiency gains and increases in advanced physiotherapy services to better meet demand based on the optimisation results. Feasible changes to activity in medical specialist services were not within the scope of the study and were not modelled. The subsequent estimates of increased activity were then entered into the model as a comparison against the base case (no change) scenario.

2.2. Agents

Four types of agents operate in the model: clinics, patients, advanced physiotherapists and medical specialists (which represent, as is appropriate to each clinic, orthopaedic and/or neurosurgery). Advanced physiotherapists and medical specialists exist in the model to provide services but are not assigned any specific characteristics.

The patient population is assigned musculoskeletal problems that require referral for specialist consultation. A patient with a referral enters the model and proceeds to join the queue for the clinic with the current shortest waiting time. From here, they will proceed through the care pathway, which can result in surgical or non-surgical treatment, discharge without treatment, or "reneging" due to excessive wait times. Up to 30% of referrals are known to leave the current waiting lists (renege) and are never assessed. The reasons for removal from the waiting list include: (i) inability to contact the patient; (ii) treatment is no longer necessary (condition resolved or self-management); (iii) patient shifted to private care; (iv) patient moved away from the district; or (v) death.

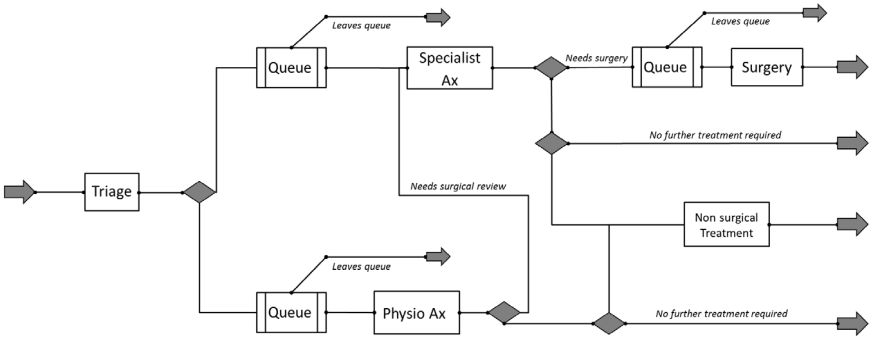

Fig. 1. Simplified clinic structure.

Table 1
Range of services provided in each clinic.

Clinic	Medical specialist covers	Physiotherapy led (N/OPSC) service covers
RBWH ortho	Orthopaedics all patient conditions	Cat 2 & 3 lower and upper limb[a]
RBWH neuro	Neurosurgery all patient conditions	Cat 2 & 3 spinal pain
TPCH	Orthopaedic all patient conditions	Cat 2 & 3 all patient conditions
Redcliffe	Orthopaedic all patient conditions	Cat 2 & 3 all patient conditions
Primary Care (OSiP)	No specialist	Cat 2 & 3 all patient conditions

N/OPSC = neuro/orthopaedic physiotherapy screening clinics; RBWH = Royal Brisbane and Women's Hospital; TPCH = The Prince Charles Hospital; OSiP = Orthopaedic Screening in Primary Care; Cat = Urgency category.
[a] Spinal pain patients from orthopaedics requiring physiotherapy led services are referred to the RBWH Neuro clinic N/OPSC service.

The modelled population begins with the current pool of referrals waiting across the district. New referrals arrive based on the rate of referrals recorded at each facility in 2015 and assuming referral numbers increase in line with projected population growth over time (8.6% over five years) [17]. Patients are assigned two characteristics that affect demand and flow through each clinic:

- Condition (either lower limb, upper limb or spinal).
- Urgency Category (either 1, 2, or 3).

Category 1 referrals are considered Urgent and an appointment is recommended within 30 days. Category 2 is for Semi-urgent referrals recommended for review within 90 days. Lastly, Category 3 referrals are considered Non-urgent and should be seen within 365 days. These outpatient urgency categories are standard across Queensland public hospitals [18].

Five clinics were modelled within the three hospitals providing Musculoskeletal Services. Four of these clinics provide both medical specialist and N/OPSC services. These services are a mix of orthopaedic and neurosurgery services, therefore patients with spinal pathology may be referred to either orthopaedic or neurosurgical services, as opposed to lower or upper limb cases which would only be seen by orthopaedics. Table 1 presents the five clinics and the treatment options available.

2.3. Model structure

The full structure of the hospital clinic model is shown in Fig. 1.

The initial decision point in the model splits patients to be seen either by a medical specialist or by an advanced physiotherapist. All category 1 patients are seen by a medical specialist and the remainder (Cat 2 and 3 referrals) are allocated between the two pathways depending on a facility-specific probability given in Table 2, "Proportion of new patients referred to N/OPSC".

After assessment in the advanced physiotherapy-led arm of the model, a chance node moves the patient to either discharge, conservative treatment or back to the medical specialist for either review or additional treatment (e.g. injection) as the problem may be worse than anticipated or require consideration of additional treatment options, including surgery. Movement back to the medical specialist happens within the same clinic at RBWH, TPCH and Redcliffe, with primary care/OSiP patients returned for assessment at TPCH. After assessment by the medical specialist, a patient may be referred for conservative management and/or review, be referred for surgery or be discharged.

2.4. Data inputs

Data was collated from routinely collected administrative data from the five clinics over the financial year 2014–15. Information was obtained from the services directly and from hospital data management systems. Table 2 presents the key parameters used in the model. Fixed parameters represent those that are fixed for all runs of the model. Variable parameters represent those whose values are allowed to vary with different runs. The minimum represents the base case scenario value and the maximum represents the maximum value that the variable was allowed to vary to in subsequent scenarios. This maximum value was set by expert opinion at a level that would support timely convergence to a solution while still allowing a number of appointments that would enable all patients to be treated in time.

To determine the maximum proportion of patients that could be appropriately directed to N/OPSC, an internal audit of 1441 referrals across the various clinics was conducted. This audit found that up to 65% of referrals usually directed to orthopaedic surgeons and up to 40% of referrals usually directed to neurosurgeons could be suitable for advanced physiotherapy assessment and management. Therefore, for the modelling analysis, the proportion suitable for physiotherapy management was varied between current provision and the maximum proportion as identified in the audit (Table 2).

2.5. Model validation

The pathways that patients follow were recorded and verified in conjunction with clinicians working within the services, using process content diagrams and flowcharts as described in Jen et al. [19]. A previous version of this model was extensively validated against

Table 2
Variables used in the model.

Category	Parameter description	Clinics						Source (Year)
		RBWH ortho	RBWH neuro	TPCH	Redcliffe	Primary care clinic	Total metro north	
Fixed parameters								
Patient characteristics	Age (mean (sd))	57 (13.9)						Standfield et al. [7]
	Gender (f%)	56%						Standfield et al. [7]
	Proportion category 1	0.07						R-Track (2015)
	Proportion category 2	0.47						R-Track (2015)
	Proportion category 3	0.46						R-Track (2015)
	Population growth	8.6% over 5 years						Population projections [17]
Patient currently on waiting list	Awaiting initial assessment at SOPD	2406	2909	2360	3029	N/A	10,704	HBCIS/OSIM (2014–2015)
	Awaiting initial assessment N/OPSC	300	890	82	58	94	1424	HBCIS/OSIM (2014–2015)
	Awaiting surgery	603	61	810	519	N/A	1993	HBCIS/OSIM (2014–2015)
Referral rate	Referral arrivals per month	337	93	256	312	17	1015	HBCIS/OSIM (2014–2015)
Probabilities								
Reneging	% drop out (per month)	0.02	0.02	0.02	0.02	0.02	0.02	Audit data (2015)
Conversion to surgery rate	Assessed by medical specialist	0.25	0.25	0.25	0.25	0.25	0.25	HBCIS (2015)
	Assessed by N/OPSC and returned to medical specialist	0.27	0.27	0.27	0.27	0.27	0.27	MARS and QHAPDC (2012–2015)
Patients discharged to GP	After assessment and treatment by N/OPSC	0.29	0.30	0.41	0.35	0.49	0.62	MARS (2014–2015)
Patients referred for medical specialist follow up	After assessment and treatment by N/OPSC	0.25	0.28	0.46	0.53	0.32	0.36	MARS (2014–2015)
Surgical slots	Surgery	50	40	70	70		230	Expert opinion
Variable parameters								
Assessment %	Current proportion of new patients referred to N/OPSC	0.12	0.34	0.13	0.16	0.13	N/A	HBCIS/OSIM (2015); R-Track (2015)
	Maximum proportion of new patients referred to N/OPSC	0.55	0.40	0.64	0.65	0.64		
Appointments given per month (range)	Medical specialist—minimum	165	91	222	158	N/A	636	HBCIS (2014–2015); Expert opinion
	Medical specialist—maximum	495	273	666	474	N/A	1908	
	N/OPSC—minimum	40–160	79–316	35–140	51–204	35–140	240	HBCIS (2014– 2015); Expert opinion
	N/OPSC—maximum						960	

RBWH = Royal Brisbane and Women's Hospital; TPCH = The Prince Charles Hospital; N/OPSC = Neuro/orthopaedic physiotherapy screening clinic; SOPD = specialist outpatient department; HBCIS = hospital-based corporate information system; OSIM = Outpatient Services Information Management; MARS = Measurement Analysis and Reporting System; QHAPDC = Queensland Hospital Admitted Patient Data Collection; R-Track = R-Track referral management system.

a Markov cohort model with queuing enabled and disabled in order to perform data validation [20].

To calibrate the model for rates of drop out, the monthly rate of reneging was varied over a range of plausible estimates to approximate the recorded 30% of all new referrals over the time period of five years. A rate of 2% per month gave the closest approximation to audit data and was therefore used in the model.

Final model outputs were verified by stakeholders who agreed that the model was performing as they would expect and that results were representative of their system.

3. Results

The base case model predicts an increase in waiting lists by 25% to over 15,000 patients over five years if activity levels remained unchanged from baseline (Fig. 2 and Table 3). At this level only 35% of category 3 patients would meet target waiting times by the end of the five year model period.

The optimisation experiment solution for meeting category-specific target waiting times 80% of the time within two years (Table 3) would require approximately double the number of specialist outpatient appointments currently provided per month. The most efficient combination of services to achieve this level of activity would be delivered by directing approximately 50% of patient referrals to the specialist medical consultants (932 of 1847 new cases), and 50% of referrals to the advanced physiotherapy-led services (915 of 1847 new cases). This would require almost tripling the existing physiotherapy services (281% increase to 915 new cases per month) with an additional 47% increase in specialist medical services (increase to 932 new cases per month). This solution is only suitable for the short term as following this, excess capacity is found in the system, waiting lists would drop to zero, and staff would be idle at times.

In response to the optimisation experiment results, stakeholders identified that it would not be possible to expand existing physiotherapy and specialist medical services to the levels identified in the experiment. However, they identified that it would be feasible to increase physiotherapy-led services in the short to medium term through increases in efficiency, using current resources, and through additional funded activity. The efficiency gain was modelled and would improve waiting list size slightly but

Table 3
Results of the three experiments—total across all five clinics.

	Baseline	Optimised model (% change from baseline)	Feasible model (% change from baseline)
Average new case appointment provided per month			
Medical specialist led service	636	932 (47%)	636 (0%)
N/OPSC	240	915 (281%)	537 (123%)
Total	**876**	**1847** (**111**%)	**1173** (**34**%)
Waiting list impact of the appointments provided			
Number of patients waiting at year 0	12,128	12,128 (0%)	12,128 (0%)
Number of patients waiting at end year 5	15,160	1 (−100%)	9613 (−37%)

N/OPSC = Neuro/orthopaedic physiotherapy screening clinic.

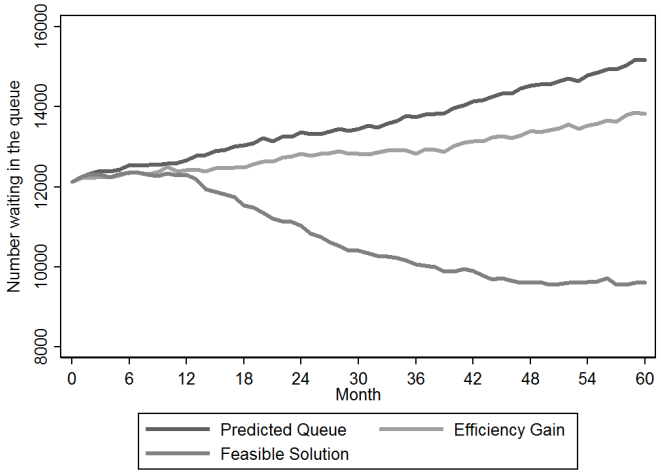

Fig. 2. Estimated growth in total wait lists over five years.

would not reduce the waiting list over time (Fig. 2). The stakeholders identified an overall increase in activity in the physiotherapy-led service of 123% (to 537 new cases per month) would be possible to achieve within two years if additional funding was available (Table 3).

If implemented, the model identifies that this solution would result in a downward trend in the size of the waiting lists up until year four to five where this stabilised at around 9,600 persons still waiting assessment (Fig. 2 and Table 3). This solution would also mean that waiting time targets could be achieved for all Category 1 and 2 patients and for approximately 50% of Category 3 patients.

4. Discussion

The simulation model identified that current levels of service delivery in Metro North are inadequate to manage demand for patients referred with musculoskeletal conditions to specialist outpatient services. If services remain unchanged a further growth in waiting lists by 25% will occur over five years with only 35% of Category 3 patients seen in clinically recommended timeframes.

The simulation model identified that in the short term (within two years), the scale of outpatient services in Orthopaedics and Neurosurgery would have to approximately double for the majority of patients to be seen within their clinically recommended timeframes. In addition, the most efficient combination of services to deliver this level of activity would be to direct approximately half of all patients to the physiotherapy-led service, and half to medical specialists. This however, would require increases in existing physiotherapy (280%) and specialist medical (50%) services that were deemed unlikely to be possible by health service stakeholders and were not required in the longer term as waiting lists would reduce to zero. Consequently, the model was then used to predict the impact of advanced physiotherapy-led service changes deemed feasible to implement by health service stakeholders. We found that just a moderate increase in advanced physiotherapy-led services in conjunction with increases in efficiency within current constraints, would substantially control waiting list growth over a five-year period. These simulation results provide informed estimates regarding the optimal scale and mix of services required to achieve waiting time targets for key decision makers to support both short and longer term service planning.

There are a number of limitations within this study. This model was developed with the advanced physiotherapy-led service as the key stakeholder. Feasible changes to service delivery that were modelled took into account the ability to recruit to and accommodate additional advanced physiotherapy led activity. We did not consider or model changes to medical specialist activity in this project or strategies aimed to reduce demand such as changing referral patterns from general practitioners as this was outside the scope for this project. Modelling strategies designed to reduce demand is an important focus for future studies given that demand for musculoskeletal services is growing faster than the population growth. To adequately manage this demand, the need for a comprehensive strategic response has been highlighted [21]. There will need to be focus on the role of primary care, not just secondary referrals. One strategy that could assist is to shift the N/OPSC model out of hospitals and into a community setting where referrals can be received directly from general practice. Metro North has one such service currently operating successfully that was included in the modelling for this project. In this service, early community based assessment by an advanced physiotherapist and access to multidisciplinary care planning and treatment supports ongoing General Practitioner management. Other strategies that support improved primary care management would also be required including building the capacity of the primary care workforce in the management of musculoskeletal conditions, building the capacity of consumers to participate in self-management and reforming funding mechanisms to encourage preventive measures [22].

It is difficult to accurately predict changes in service demand over time. This study accounted for projected population growth in the catchment area, but did not take into account other possible increases in demand for musculoskeletal services. The prevalence of musculoskeletal conditions has been predicted to rise significantly, largely as a result of population ageing [23]. Additionally, Australia operates a public/private mix of approximately 50% and insurance premiums have been rising faster than inflation. People leaving the private system due to premium increases could put additional demand on publicly funded services. We had limited data to estimate the rate at which people drop out from waiting lists over time. However, we chose a range of plausible extremes to demonstrate that regardless of drop out rate, the current capacity to meet demand fell far short. Finally, the data used to inform the model was specific to one health service. Other health service districts will have a different range of facilities, services, case mix, and patient profiles, which would influence simulation results

and the transferability of these results. This study focussed on the use of simulation modelling to identify the scale and mix of services required to address current and projected demand and the predicted impact of making changes to physiotherapy-led service activity. Identifying feasible changes to medical service delivery was not within the scope of the study and was not modelled.

This project also has a number of strengths. The research team has wide experience in orthopaedic service delivery (specifically the N/OPSC) with detailed knowledge of patient pathways and simulation modelling. We were able to access administrative data to provide precise estimates of the number of referrals entering the system and the current resources available to meet that demand. Facility-specific stakeholders were consulted in the collection and analysis of the data which informed the model and were involved in determining activity levels used in the modelled service delivery changes.

5. Conclusions

This study identified that the scale of services provided for patients with musculoskeletal conditions in one health service was inadequate to manage demand and provided key decision makers with information on the most efficient combination of services to address the problem. By varying several key model parameters using an automated optimisation process, the study identified that to achieve waiting time targets in the short term the scale of services would need to approximately double and it would be most efficient to deliver this activity by directing approximately half of all referrals to medical specialist clinics and half to advanced physiotherapy-led clinics.

The use of simulation modelling in health service planning is valuable as it provides insights into the impact of changing the configuration of services at a glance, without the time and expense of implementing and waiting to evaluate changes. Results can deliver clear and meaningful information to decision makers when making service investment decisions about the scale and most efficient mix of medical specialist-led and advanced physiotherapy-led services required to manage demand.

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