Journal of the Operational Research Society

ISSN: 0160-5682 (Print) 1476-9360 (Online) Journal homepage: www.tandfonline.com/journals/tjor20

Using OR to support the development of an integrated musculo-skeletal service

R B van der Meer, L A Rymaszewski, H Findlay & J Curran

Journal of the Operational Research Society (2005) 56, 162–172

www.palgrave-journals.com/jors

Using OR to support the development of an integrated musculo-skeletal service

RB van der Meer[1]*, LA Rymaszewski[2], H Findlay[2] and J Curran[1]

[1]*University of Strathclyde, Glasgow, UK; and* [2]*The Musculo-Skeletal Unit, Stobhill Hospital and Glasgow Royal Infirmary, Glasgow, UK*

This paper discusses the question of how operational research in general, and discrete event simulation in particular, can help to meet management challenges in hospital-based orthopaedics medicine. It focuses on the reduction of waiting times for elective patients, both for a first outpatient appointment and for the subsequent commencement of in-patient treatment. The research is based on a series of projects carried out by students from the Department of Management Science, University Strathclyde in Stobhill Hospital and the Glasgow Royal Infirmary between 1999 and 2003. An increasingly detailed and complex simulation model was developed for the musculo-skeletal service provided by these hospitals. The paper discusses the application of a modelling methodology—based on the idea of requisite models evolving over time—that is participatory, iterative and focused on enhancing the clients' understanding of the main performance drivers of the service. It concludes that this methodology fits well with successful strategies to sustain reductions in waiting times.

Journal of the Operational Research Society (2005) **56,** 162–172. doi:10.1057/palgrave.jors.2601893
Published online 17 November 2004

Keywords: simulation; hospitals; orthopaedic medicine; waiting times

Health challenges in orthopaedics

This paper discusses the question of how operational research (OR) in general, and discrete event simulation in particular, can help to meet management challenges in hospital-based orthopaedics medicine. There are two types of orthopaedics patients—elective and non-elective—that present quite different challenges for healthcare management. Non-elective patients are trauma and emergency patients requiring acute healthcare, which is subject to a large uncertainty in demand. The treatment required by elective patients is less acute and can, at least in principle, be planned (more or less accurately) in advance. Previous studies include papers by Bowers and Mould.[1,2]

At the point when we started these projects, patients with musculo-skeletal problems formed one of the largest groups waiting for a hospital outpatient appointment in the United Kingdom's National Health Service (NHS), and the time before being seen was one of the longest. The majority of these patients had to wait for months, if not over a year, before finally being seen by an orthopaedic surgeon, despite some 80% of the conditions being non-surgical.[3,4] But in 2000, the NHS Plan[5] set a maximum waiting time for an outpatient appointment of 3 months and for in-patients, 6 months.

Correspondence: RB van der Meer, Department of Management Science, University of Strathclyde, Glasgow, UK.
E-mail: robert@mansci.strath.ac.uk

In the NHS, the main strategy to achieve shorter waiting times has been to increase the number of orthopaedic surgeons, or to fund waiting list initiatives on a recurrent basis. However, without a major reconfiguration of traditional orthopaedic work processes, the growing demand for hospital consultation and surgery cannot be met adequately. In England, over the most recent 5-year period 2000–2004, the number of written referrals by general practitioners increased by about 25% for all specialities, and by about 26% for trauma and orthopaedics.[6] But the most recently available data (relating to the quarter ended September 2003) show that only 65% of orthopaedics patients wait less than 13 weeks from written referral by a general practitioner (GP) to outpatient consultation, as opposed to 80% for all specialities.[7] The situation is not dissimilar in Scotland.[8] In November 2002, the Scottish Health Minister stated that the long waiting times in orthopaedics constitute 'one of the toughest areas' that NHS Scotland has had to deal with.[9]

Meeting health challenges with OR

OR offers a range of analysis methods[10,11] that could be used in the present context. In practice, one of the most popular methods is discrete event simulation. In very general terms, a simulation model represents a transformation system—in the present case, a service system that uses resources of various kinds to provide appropriate health care to patients.[12] Simulation models are used to investigate two key aspects of managing a healthcare system.[10,13]

(1) the management of patient flows through the system;
(2) the allocation of the 'transforming resources' (staff, equipment, medicines and other materials), which are needed for the provision of the service to the patients.

These two aspects give rise to multiple performance measures, which may be grouped into two broad categories: the level of service provided to patients and the efficiency with which resources are utilized. A key issue for management concerns the potential trade-off between service level and resource efficiency. Simulation modelling is an effective tool for investigating the terms of the trade-off between these two broad objectives, both in a static and a dynamic (improvement) setting.

However, OR modellers must take account of the fact that healthcare management decision-making often takes the form of finding a consensus among different stakeholders involved.[14] In the context of hospital-based medicine, the key stakeholders are: patients, medical staff, other healthcare professionals (nurses, physiotherapists, etc.), and managers at various organizational levels—all of whom may have conflicting objectives.[15] In particular, decisions on resource allocation are traditionally taken by hospital managers.[16] But both resource efficiency and service level (including waiting times) are also strongly affected by decisions taken by senior medical staff regarding the management of patient flows. In any simulation project that focuses on the latter issue, hospital consultants should, therefore, be regarded as key players.[17]

We would argue that the concept of 'requisite' modelling, as developed by Phillips,[18] is highly relevant in this context. A model is 'requisite' when its form and content are sufficient to resolve the issues of concern. According to Phillips, a requisite model is generated through iterative and consultative interaction between the 'providers' of the model and the 'clients'. What constitutes a requisite model should not be regarded as a static concept. On the contrary, as the issues of concern evolve, then so should the form and content of the model.

The time and cost that is often involved in a relatively lengthy effort at building a simulation model of a complex system, together with the difficulty of holding the interest of the stakeholders involved, are important reasons why such studies might not be sustained.[19] And even if a study is brought to some sort of a conclusion, it might still be regarded as a failure by the intended users of the simulation model. Based on a survey of the academic literature, Robinson and Pidd[20] suggest a fairly long list of potential reasons for this latter eventuality.

The 'MAPIU' approach proposed by Eldabi and Paul[21] for the simulation modelling of healthcare systems is a possible way of resolving this problem. MAPIU stands for a Modelling Approach that is Participatory Iterative for Understanding. Eldabi and Paul criticize most of the existing modelling approaches to healthcare simulation for not giving enough attention to the problem formulation and structuring stage, which—they argue—is the most important stage for problem understanding in a healthcare system. Their MAPIU approach has three facets: its main purpose is to enhance stakeholders' understanding and intercommunications; its structure is participatory including the stakeholders; and its behaviour is interactive rather than step-based. The modelling process in MAPIU has three components: modeling–communication–information. A key step in the modelling component is experimentation, which lies at the heart of the iterative process.

Although Eldabi and Paul do not refer to the work by Phillips[18] on requisite modelling, the two approaches would appear to have strong similarities in their stress on iterative and consultative (or better: participatory) interaction between the modellers and the various stakeholders, and—through their use of the model—between the stakeholders themselves.

Outline of research methodology

In the Discussion section of this paper, we shall argue that the modelling methodology on which the present research is based is one that is meant to incorporate the key aspects of the 'requisite modelling'[18] and MAPIU[21] approaches. The research is based on a series of projects carried out by students from the Department of Management Science, University Strathclyde in Glasgow. In all, five consecutive projects have been completed so far, to be numbered I, II, III, IV and V. The first project started in September 1999. The last project discussed here was completed in April 2003 and was carried out by Curran. All projects were supervised by Van der Meer (project I jointly with Valerie Belton).

The setting of projects I, II and III was the musculo-skeletal unit at Stobhill Hospital, Glasgow. During the course of these projects, a process of increasing integration had begun between the Stobhill unit and the orthopaedics department at Glasgow Royal Infirmary (GRI). Therefore, projects IV and V were concerned with both Stobhill and the GRI. Both hospitals form part of the North Glasgow University Hospitals NHS Trust. Each project has had its own set of clients but Rymaszewski was a client for all of the projects. Findlay joined him as a client for projects III, IV and V. Both Rymaszewski and Findlay are members of the musculo-skeletal team of healthcare professionals, first at Stobhill only, and now also at the GRI. Project I was initiated by a manager connected with the Stobhill unit. But direct involvement from management was minimal in subsequent projects. Such involvement was only re-established in project V, but at a higher level of Trust management. There has as yet been no direct involvement from patients. Because all projects were carried out by students, the funding requirements were comparatively low (similar to the case intervention reported by Lehaney *et al*[19]).

Development of the Stobhill musculo-skeletal unit, until 2002

The basic design of the musculo-skeletal unit was developed by Rymaszewski and his fellow healthcare professionals at Stobhill hospital over a 7-year period in the latter part of the 1990s.[22] Stobhill is a District and General Hospital, with a catchment population of approximately 170 000 people, which *inter alia* provides musculo-skeletal outpatient care for elective patients. Until 2001 it also provided an in-patient service for these patients but that has since moved to the GRI. (All non-elective patients are treated at the GRI.)

The musculo-skeletal unit at Stobhill is an innovative concept that was designed to integrate the activities of orthopaedics and rheumatology with specialist physiotherapy and podiatry. The traditional consultant-based model, in which the consultant and his/her trainee saw all new patients referred to the hospital, was gradually replaced by a team approach based on a continuous reconfiguration of roles. On the one hand, the hospital consultants (orthopaedic surgeons and rheumatologist) accepted a retraction of their roles and became more specialized in their particular areas of expertise. On the other hand, the roles of the other team members (specialist nurses, physiotherapists and podiatrists) were extended through multi-skilling. Improving interdisciplinary communication aimed to facilitate the breaking down of professional barriers and the development of a shared vision (Figure 1).

More specifically, in the musculo-skeletal unit the traditional outpatient process was replaced by

- protocol-based daily triage (by nursing staff) for all referrals to the most appropriate health professional in the team; and
- allocation of appointments based on clinical priority, with a ‘fast-track’ for urgent cases.

Over the period 1995–1999, the typical waiting time for an outpatient appointment at Stobhill was reduced from 19 to 11 weeks, despite the number of new GP referrals virtually doubling, from 2226 to 4391 referrals.[22] One of the reasons for the steep rise in referrals was thought to be that GPs reacted to the lower waiting times and redirected referrals away from other hospitals.

Using OR to support the development of the Stobhill musculo-skeletal unit

The first project started in September 1999 and was completed in April 2000. The idea of doing a simulation project in the musculo-skeletal unit at Stobhill was first suggested by a manager who had been impressed by the results of OR projects carried out in other departments at the hospital. Together with Rymaszewski (who was recognized as one of the leaders in the development of the unit), this manager acted as a client for the project. Project I used the Simul8 package[23] to develop a discrete event simulation model for the overall musculo-skeletal service, including both the outpatient and in-patient parts of the system. The immediate problem faced by the service was that the decrease in outpatient waiting times had been accompanied by a steep increase in the number of outpatients seen, with a corresponding increase in the number of patients scheduled for in-patient treatment. Therefore, in-patient waiting times were increasing rapidly. The simulation model was intended to give the clients a better understanding of this problem and to examine a range of actions that might be taken to resolve it.

The model was kept as simple as possible. In particular, because the clients were mainly interested in reducing maximum waiting times, it was not necessary to distinguish between the different referral categories—urgent, soon and routine—given that the maximum waiting times would invariably be associated with the latter category. This first model also contained a number of other simplifications, some of which were rather less defensible and were removed in later versions. To a large extent, this reflected the early stage of the modelling process and the relative inexperience of the student modeller.

Experimentation with the model demonstrated that if a podiatry service was reinstated, the *maximum* outpatient waiting time for the consultant specializing in foot and ankle conditions could be reduced from 20 weeks (95% CI:

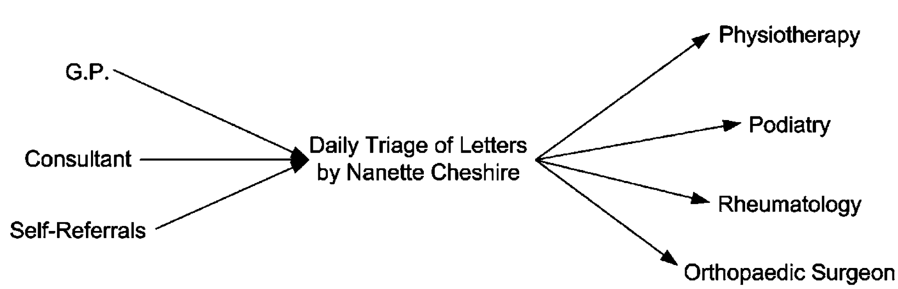


Figure 1 Integrated musculo-skeletal service.

Table 1 Comparison of alternative scenarios for Mr Rymaszewski

Alternative scenario	*Annual number of procedures performed (95% CI)*
A—current schedule (with 17 beds for elective in-patients)	195–202
B—1 extra theatre session per week; 17 beds for elective in-patients	235–244
C—2 extra theatre sessions per week; 17 beds for elective in-patients	244–254
D—current configuration, but with 21 beds for elective in-patients	218–221
E—1 extra theatre session per week, 21 beds for elective in-patients	246–255
F—2 extra theatre sessions per week, 21 beds for elective in-patients	247–257

Table 2 Comparison of alternative scenarios for the outcomes assessment (OA) service

	Number of patients seen at OA clinic per year			*Number of patients in OA system at end of year*			*Utilization of OA nurse (%)*		
Year	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
2001–2002	750	906	1012	984	1067	1116	36	44	49
2002–2003	1046	1171	1221	1321	1495	1588	50	56	59
2003–2004	1088	1342	1485	1679	1938	2077	52	65	71
2004–2005	1420	1607	1704	2029	2361	2535	68	77	82
2005–2006	1442	1755	1943	2378	2783	3010	69	84	93

19.6–20.4) to 15.8 weeks (95% CI: 15.7–15.9), with a *maximum* waiting time for the podiatry clinic of 18.1 weeks (95% CI: 17.4–18.9 weeks). The model was also used to examine the results of scheduling an additional (in-patient) theatre session for any of the other consultants and increasing the number of beds on the in-patient ward. Apart from the current schedule (scenario A), five alternative scenarios (B–F) were investigated (see Table 1). This demonstrated the possibility of substantially increasing the annual number of procedures performed by Rymaszewski, who is an elbow specialist—but the results were less convincing for the other consultants, given the likely costs involved.

None of these options were new, as all of them had first been suggested by the clients. Although both clients greatly appreciated the ability of the model to explore the likely consequences of these options, none of them were actually carried out at this early stage. (Actions to enhance the podiatry service were underway by the time of project IV and provided the focus for one of the most recent projects (project VI). Similarly, the issue of additional theatre sessions has remained under consideration ever since.)

The manager involved in the first project had to shift her attention towards preparing the impending integration of the Stobhill unit with the orthopaedic department at the GRI. But Rymaszewski felt that simulation modelling would be of continuing benefit. Therefore, Project II started in September 2000 and was completed in April 2001. The main focus was still on the problem of long waiting times for in-patient treatment. Project II examined a number of new strategies relating to the organization of the in-patient services, such as the possibility of using twin-track operating theatres and of increasing theatre capacity for day-surgery.

The idea behind a twin-track process is that by having the use of two operating theatres instead of one, the setup time between successive procedures can be eliminated and the consultant's time used more efficiently. It allows the consultant to focus on the complex elements in each operation, leaving a Registrar to carry out the more routine parts of the procedure, for example, closing and cleaning the wound. In all, 12 different scenarios were investigated based on using additional theatre capacity—assuming that it could be made available—for either twin-track procedures or additional day cases, or both. The most favourable scenario—according to which in-patient waiting lists could be cut by as much as 80%—proved to be one in which the consultants would adopt a twin-track approach as far as possible, as well as treating up to 20% of their inpatients as day cases. However, as had been the case in project I, it became apparent that the implementation of such longer-term changes would be impeded by severe constraints on the necessary funding. Instead, in order to meet the 12-month maximum waiting time for in-patient treatment, hospital management decided on a different, less radical solution of regular weekend theatre sessions.

Project III started in June 2001 and was completed in September 2001, having a more limited scope than the previous two (see Table 2). It took the form of a specific investigation of the expected workload of the Outcomes Assessment Nurse who had recently been appointed at the Stobhill unit. The specialist nurse involved (Findlay) joined Rymaszewski as a client for this and subsequent projects.

The role of the Outcomes Assessment Nurse is to provide long-term follow-up to certain categories of routine patients who have undergone surgery. In a traditional system, this work is all done by the orthopaedic surgeons themselves. In line with the overall strategy of the unit, the rationale for the appointment was therefore to enable the surgeons to spend more time in the operating theatres. Three alternative scenarios were investigated, based on differences in the total number of patients eligible for outcomes assessment. All joint replacement patients would be eligible in any case; but in scenarios A, B and C, *one-third*, *one-half* and *three-fifths* of other patients would also be eligible, respectively (with scenario A considered to be the least likely of the three). The results showed that the planned new Outcomes Assessment service could reach full capacity in as little as 5 years.

Project IV started in September 2001 and finished in April 2002. By now, the clients were focusing on the opportunities generated by the integration of the musculo-skeletal services across the two hospitals. All in-patient activities of the Stobhill unit was moved to the GRI. The situation also called for much closer cooperation between the two hospitals on the outpatient side. However, the changes in the musculo-skeletal unit at Stobhill unit prompted a similar reorganisation of the orthopaedics department at the GRI. Project IV was meant to model an integrated service across the two hospitals for all patients with foot and ankle conditions. Unfortunately, as it became apparent that the new model had not been properly validated and contained a number of serious flaws, this project was not completed satisfactorily.

To sum up, by the summer of 2002, four separate simulation projects had been attempted—the first three were considered a success by their respective clients, the fourth one rather less so. But it is important to note what the term ‘success’ means in this context. As Lagergren[24] has noted, actual policy planning and decision-making in the health service depend on a lot of factors, many of which will never be captured by a quantitative model. In the ‘power game’ between the different stakeholders—in this context, principally medical staff and other healthcare professionals versus managers in control of financial resources—model results may be used more as ‘instruments for persuasion’ rather than analysis.[25] But, although model results cannot shift the fundamental power balance in the healthcare system, they can successfully change the nature of the debate by demonstrating the likely consequences of different options.[24]

In the present case—and ignoring the fourth project—the form and content of each successive model had been sufficient to allow the clients to conduct simulated experiments with respect to the management of the musculo-skeletal unit and to predict their likely impact on service level (especially patient waiting times) and resource efficiency. However, it became clear that as the nature of the client’s questions was evolving, the simulation models were steadily increasing in size and complexity.

Outline design of the new triage process, 2002–2003

By the summer of 2002, the organization of the musculo-skeletal service at the GRI had moved towards the Stobhill model. The full integration of outpatient services across the two hospitals now became a key issue of concern. In consultation with the medical staff and other healthcare professionals at both hospitals, Rymaszewski began to outline the design for a new triage process, based on the establishment of sub-specialities among the orthopaedic surgeons.

In general, each consultant orthopaedic surgeon will have a preference for a particular type of surgery, based on a specific part of the body. For instance, and as already noted, Rymaszewski specializes in elbow conditions. Other specializations might relate to foot and ankle conditions, knee, spine, etc. However, in the traditional approach this specialization is relatively unimportant for the purpose of assigning outpatient referrals to the various consultants. At the GRI, for instance, referrals had been divided equally among all the orthopaedic consultants (with the exception of patients with hand conditions who were all directed to one particular surgeon specializing in that area).

In the outline design for the new triage process, a number of sub-specialities were established across the two hospitals. The consultant(s) working in a particular sub-speciality are to get the main share—but not necessarily 100%—of the referrals related to that particular condition. However, there are a number of common surgical procedures—such as total hip or knee replacement surgery—that generate very high numbers of referrals. Responsibility for these patients is still to be shared between the consultants, although not necessarily on an equal basis—because the workload that each consultant derives from his/her sub-speciality will not, in general, be equal either.

The new triage process entails an extension of the existing single-stage process to a two-stage process. In the new process, all outpatient referral letters are sorted on a daily basis by senior nursing staff. Each letter is routed to the appropriate sub-speciality, or to a physiotherapist for assessment, or to another department in the hospital for investigation or treatment. All letters received in a particular sub-speciality are subsequently triaged by a consultant in charge of that sub-speciality and directed to a relevant outpatient clinic. That clinic may be in the consultant’s own sub-speciality or, if appropriate, in another sub-speciality. In summary, the main aim of the two-stage process is for consultants to spend less time viewing patients with conditions that are outside their main area of expertise and more time applying their specialist skill—that is, performing

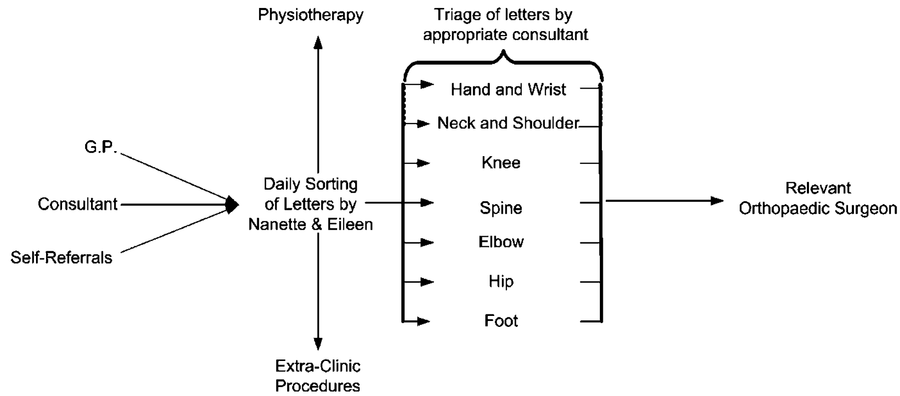


Figure 2 Triage by sub-speciality (two-stage process).

surgery relating to their own particular sub-speciality (Figure 2).

Using OR to support the design of the new triage process

Project V was started in September 2002 and completed in April 2003. By the autumn of 2002, the clients had developed an outline design for the new triage process—corresponding to a significant change in the basic design of the musculo-skeletal services across the two hospitals. This design was approved in principle by their colleagues (medical staff and other healthcare professionals). Project V was intended to enable the clients to perform simulated experiments with respect to specific design parameters to find answers to the following questions (relating to resource efficiency and service level, respectively):

- What are the likely effects of the new process on the workloads of individual consultants and the other health professionals in the team? Will they be able to cope? What rules should be put in place for determining the precise patient mix for each member of the musculo-skeletal team?
- What are the likely effects on waiting times and on the quality of care provided?

Before an attempt could be made to deal with these issues, the model had to undergo the usual routine 'maintenance' to take account of various changes—relating to the number and timings of clinics and the availability of a specialist physiotherapist at the GRI, for instance—that had occurred since the last revision. But as well as this, the issues raised by the clients again shifted the definition of what constituted a requisite model towards the inclusion of greater detail. In particular, whereas in previous versions, urgent and non-urgent (soon, routine) patients had all been lumped together, the clients were now interested in the waiting times associated with each individual category (Figure 3).

The growing complexity of the model had an important impact on the technical skills required from the student modeller. So far, all models had been constructed using only standard Simul8 functions. But it now became necessary to write substantial amounts of additional code in Visual Logic (a form of Visual Basic used in Simul8). This means that any modellers working on future projects must have, or be willing to acquire, more advanced programming skills. Also, the same factor made it more and more difficult for the clients to understand the underlying structure of the model. In particular, when the routings were shown they tended to obscure most of the picture (Figure 4).

It became necessary to reorganise the graphical presentation of the model in order to hide most of the routing complexity in sub-windows (Figure 5).

The experiences gained from the successive projects suggested an important modelling issue: how to improve the model's maintainability and long-term accuracy. A clearer distinction had to be made between the two main aspects of the model:

- Its underlying logical/physical structure;[21] principally the nature of the work entry points, work stations (activities), and storage bins (queues), the potential routings between all of the former, and the statistical distributions used.
- The input data required; that is the actual numbers of patients entering the system, the capacities and timings of clinics, the percentages following one route or another, etc. These data are used to determine the precise values of the model parameters, such as the parameters of the statistical distributions, the routing-out percentages, etc.

The clients readily agreed that the underlying structure had to remain under the control of expert modellers; that is, people educated in the theory and practice of simulation modelling and the use of the Simul8 package. However, if the model were to be used on an ongoing basis by the clients themselves, then it would no longer be practical for the modellers to collect and enter the necessary input data on an

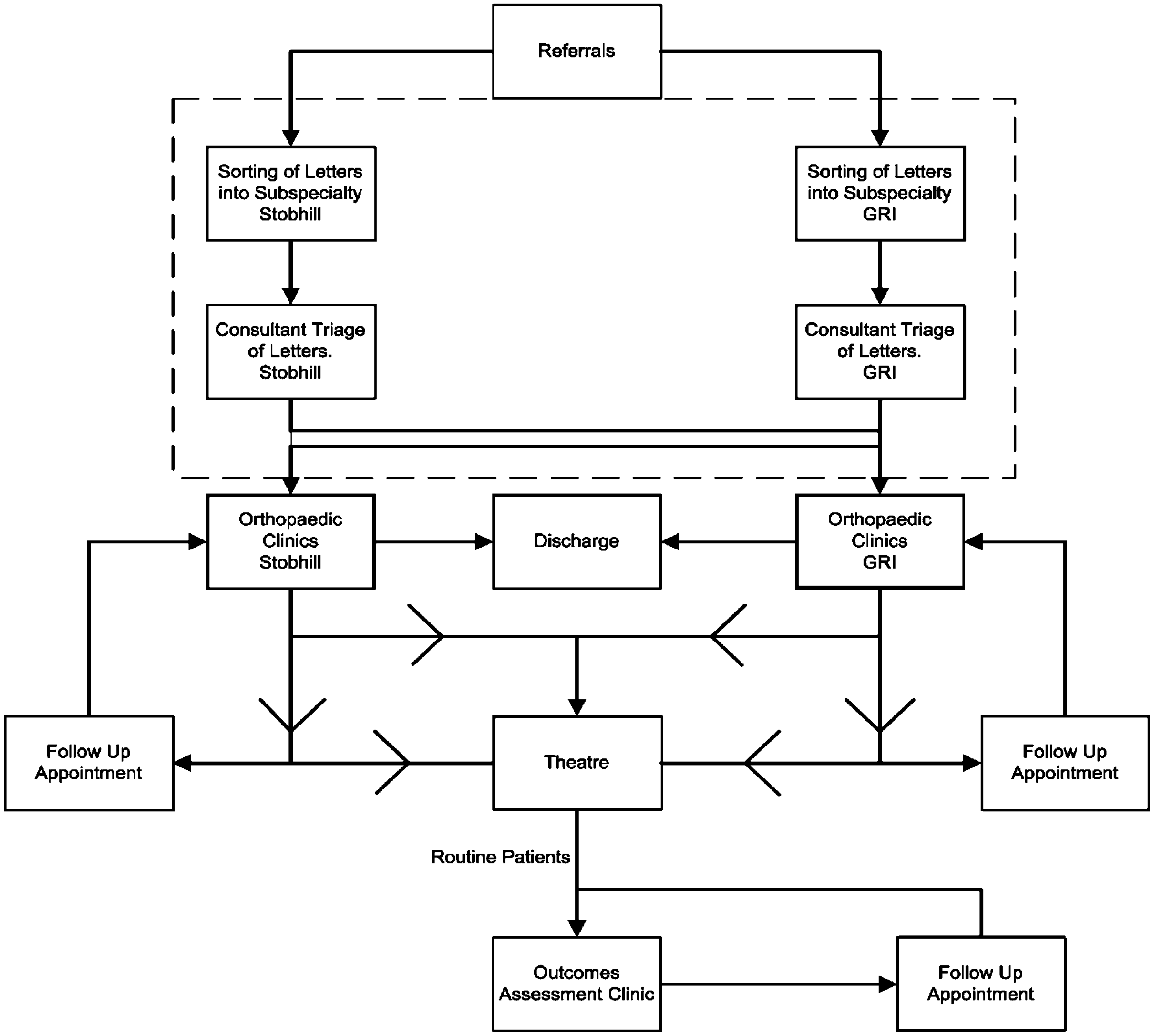


Figure 3 Patient flows within the integrated unit.

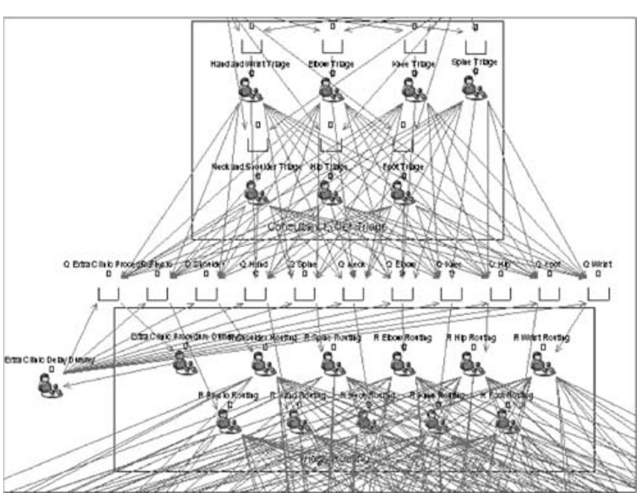


Figure 4 Complexity of some of the routing in the simulation model.

occasional basis. Instead, the end-users would have to take responsibility for that aspect of model maintenance.

Accordingly, an important aim was added in the course of project V, namely the definition and creation of a number of spreadsheet-based input data interfaces (Figure 6). These are to be employed by the end-users to input the necessary data on a regular and frequent basis. To facilitate this, the underlying structure of the model has been made as flexible as possible. For instance, patient routings have been included that are not yet used in practice, but that could become relevant at some future stage. A member of the musculo-skeletal team has already started collecting data on a weekly basis for the two hospitals, giving a comprehensive view of the actual activity of the integrated unit and how this shapes the service provided to patients. These data are currently recorded in an Excel spreadsheet. One of the objectives of the current projects (see below) is to feed these weekly data directly into the simulation model.

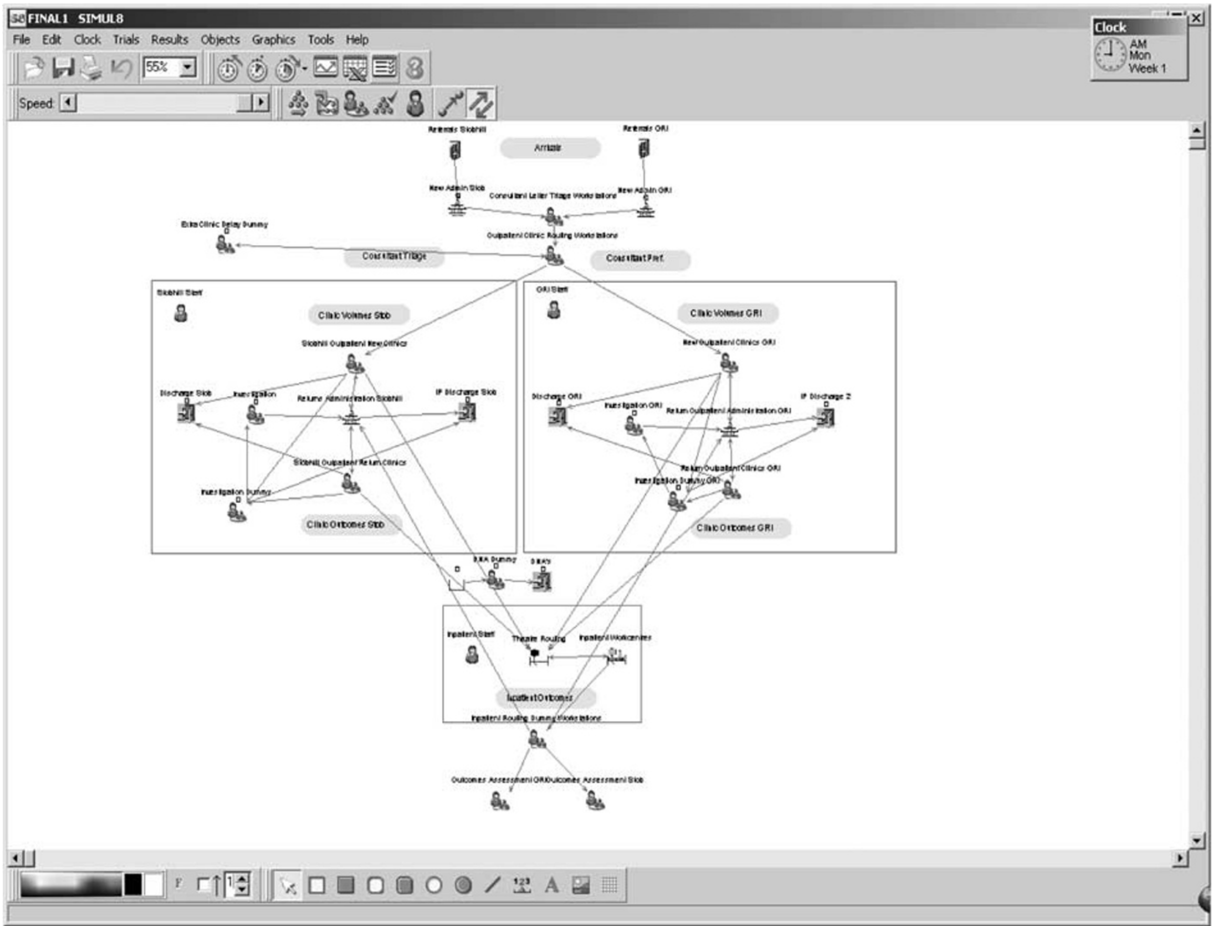
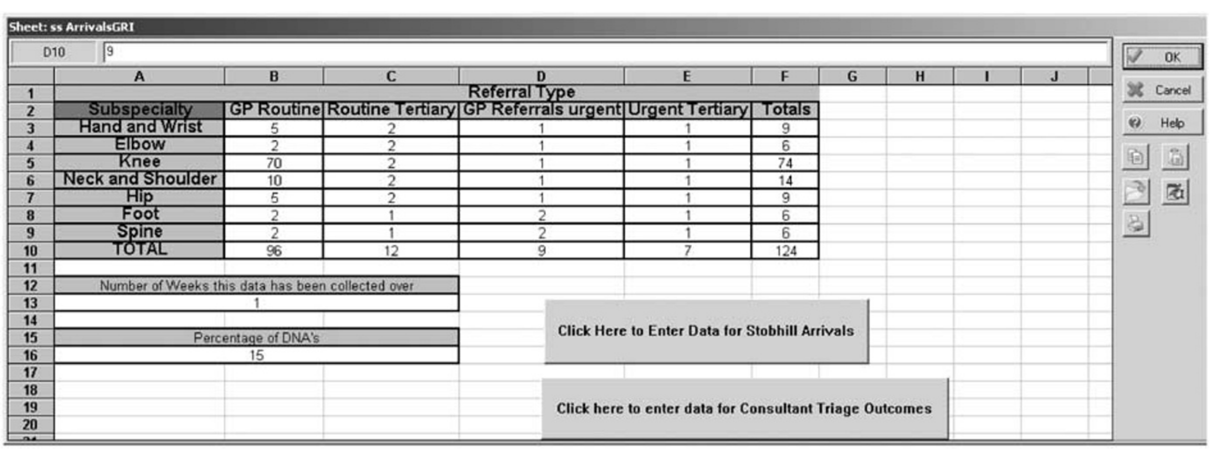


Figure 5 Simulation model with sub-windows and buttons.



	Referral Type				
Subspecialty	GP Routine	Routine Tertiary	GP Referrals urgent	Urgent Tertiary	Totals
Hand and Wrist	5	2	1	1	9
Elbow	2	2	1	1	6
Knee	70	2	1	1	74
Neck and Shoulder	10	2	1	1	14
Hip	5	2	1	1	9
Foot	2	1	2	1	6
Spine	2	1	2	1	6
TOTAL	96	12	9	7	124

Number of Weeks this data has been collected over
1
Percentage of DNA's
15

Figure 6 Example of spreadsheet interface for data entry.

In the end, the aims of project V had to be limited to building a logically correct simulation model of the basic structure of the new triage process and creating spreadsheets for the required input data. There had not been time to collect enough input data to provide quantitative results on consultant workloads, patient waiting times, etc. with an acceptable degree of confidence.

In any case, the new two-stage triage process is still being implemented, and there are many details to be worked out. Responsibility is being devolved to each individual consultant for setting out the work patterns relating to his/her sub-speciality. This prompted a request by the clients to develop a more detailed simulation model for each sub-speciality that can be used to support these efforts. In response, two further simulation projects (VI and VII) were started in the summer of 2003. The specific clients for these two projects are the consultant in charge of the sub-speciality relating to foot and ankle conditions and one of the consultants in charge of the sub-speciality relating to knee conditions, respectively.

Discussion

In the modelling methodology applied to the present research, the idea—first developed by Phillips[18]—of requisite models evolving over time has been a crucial theme from the very start. The form and content of the successive versions of the simulation model was very much determined by the specific questions that the clients wanted to ask at each particular stage. Then, as the clients' questions became more complex, so did the model. But as the research progressed, the key aspects of the methodology became increasingly similar to the three facets of a modelling approach that Eldabi and Paul[21] have termed 'MAPIU'—that is, a *Modelling Approach* that is *Participatory Iterative* for *Understanding*.

The modelling process used in this research has been characterized by close interaction between the 'providers' of the models and the clients. But the structure of the process was more than just consultative. As the clients became more and more closely involved in the modelling process—project V was a milestone in this respect—its structure became genuinely *participatory*. Of course, this depended on the clients' willingness to engage in the necessary learning process. Being involved in the practice of simulation modelling was a new experience for them. Hospital consultants and other healthcare professionals are not trained as managers and are not generally aware of appropriate scientific methods that are available to professional managers.[11]

Thinking about management problems in health care demands a certain discipline, in terms of stating clearly what the strategic and operational objectives are, what the basic structure of the overall healthcare system is, what explicit and implicit decision rules are followed—all in order to determine how efficiently and effectively the system currently operates, and what effects any changes in the system are likely to have on performance.[26] OR modelling in general, and simulation modelling in particular, provides the scientific discipline to tackle these issues, even for the majority of healthcare professionals who have not been formally educated in the use of such methods.[10,13]

In this research, the purpose of the modelling process was focused throughout on enhancing the clients' *understanding* of the main performance drivers of the musculo-skeletal unit. As the clients' understanding improved as a result of the information (output data) generated by the simulated

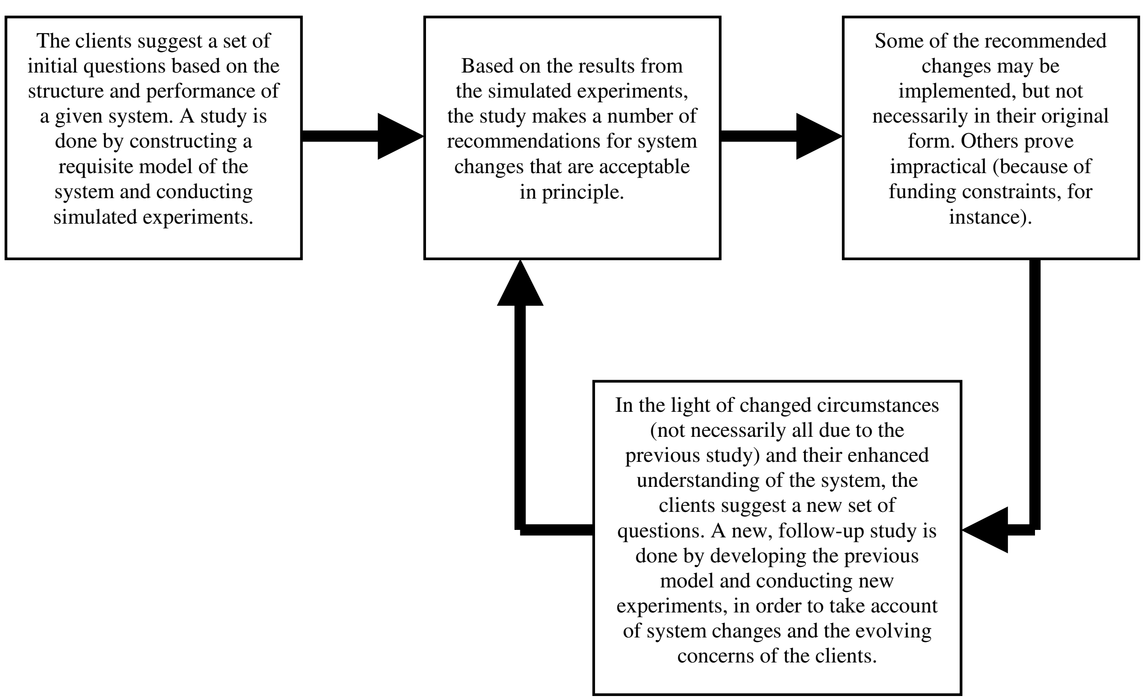


Figure 7 Cyclical model of success in healthcare simulation studies.

experiments conducted on the basis of each successive model, their requirements (in terms of the specific questions that they wanted to ask the next version of the model) became more complex. Therefore, the modelling process has been *iterative* in its behaviour, rather than step-based or episodic. (This is, of course, fully in line with the concept of requisite modelling.)

A very important component of the modelling process in the MAPIU approach[21] is communication. This consists not just of communication between the clients and the simulation model (with the clients stating their requirements and the model generating output data from simulated experiments), but also intercommunication between the clients and the other stakeholders connected with the musculo-skeletal unit. With the commencement of projects VI and VII, the model is becoming an important tool to facilitate intercommunication between all the clinical members of the musculo-skeletal team (that is, medical staff and other healthcare professionals), not just the original two clients. In line with this development, transferring ownership of the model—that is, full authority over its use—from the providers to the clients/end-users themselves has become one of the ultimate goals of the research.

To sum up this discussion, in contrast to the linear sequence suggested by the 'four-stage model of success in simulation studies' proposed by Robinson and Pidd,[20] as described in Figure 7 our research has progressed in an iterative—or cyclical—fashion.

Conclusions

In this research, we have applied a modelling methodology that is meant to incorporate the key aspects of the 'requisite modelling'[18] and 'MAPIU'[21] approaches. Based on our review of the professional and academic literature, the nature of the challenges considered here appear to be very similar to those experienced in other orthopaedics departments in the NHS. In particular, our methodology fits well with the five main themes identified by the King's Fund in its recent report on successful strategies to sustain reductions in waiting times,[17] as shown below:

- The need for understanding whole systems—*by focusing the modelling process on enhancing the clients' understanding of the main performance drivers of the musculo-skeletal service.*
- The importance for sustained action over time—*by carrying out successive projects in order to make the modelling process iterative in its behaviour.*
- The need not just to 'catch up' but also to 'keep up'—*by enabling stakeholders to conduct simulated experiments with respect to the overall management of the musculo-skeletal unit and the specific design parameters of the new triage process.*
- The ability to deal with unexpected shocks—*again, by enabling stakeholders to conduct simulated experiments.*
- The importance of clinical ownership and involvement—*by making the structure of modelling process genuinely participatory and, ultimately, transferring ownership of the simulation model to the clients/end-users.*

Although the research is still ongoing and, in particular, the new two-stage triage process is still being implemented, some lessons can be drawn at this stage. Even though the successive simulation projects have already spanned a period of 5 years, our modelling methodology has been effective in holding the interest of the key stakeholders involved (namely, the clinical members of the musculo-skeletal team). Moreover, as all projects were carried out by students, the cost of the modelling effort has been comparatively low. The combination of these factors appears to have contributed significantly to its sustainability.

References

1 Bowers J and Mould G (2002). Concentration and the variability of orthopaedic demand. *J Opl Res Soc* **53**: 203–210.
2 Bowers J and Mould G (2002). The deferrable elective patient: a means of reducing waiting lists in orthopaedics. *J M Med* **16**: 150–158.
3 Government Statistical Service (1999). *Health and Personal Social Services Statistics.*. Government Statistical Service: London.
4 NHS Executive (2000). *NHS Trust Outpatient Waiting Times (Red Book), Index 1999/00*. NHS Executive: London.
5 Department of Health (2000). *The NHS Plan*. HMSO: London.
6 Department of Health (2004). *Hospital Waiting Times/List Statistics*. Available on-line at www.performance.doh.gov.uk
7 Department of Health (2004). *Health and Personal Social Services Statistics—England*. Available on-line at www.performance.doh.gov.uk
8 Audit Scotland (2002). *Review of the Management of Waiting Lists in Scotland*. Auditor General for Scotland: Edinburgh.
9 Scottish Executive Health Department (2002). NHS urged to focus on longest waiting times. *Scottish Executive: News Online, 28/11/2002*. Available on-line at www.scotland.gov.uk
10 Davies R and Davies HTO (1994). Modelling patient flows and resource provision in health systems. *Omega Int J Mngt Sci* **22**: 123–131.
11 Young T, Brailsford S, Connell C, Davies R, Harper P and Klein JH (2004). Using industrial processes to improve patient care. *BMJ* **328**: 162–164.
12 Davies HTO and Davies R (1995). Simulating health systems: modelling problems and software solutions. *Eur J Opl Res* **87**: 35–44.
13 Jun JB, Jacobsen SH and Swisher JR (1999). Application of discrete event simulation in health care clinics: a survey. *J Opl Res Soc* **50**: 109–123.
14 Rauner MS and Vissers JMH (2003). Editorial—OR applied to health services: planning for the future with scarce resources. *Eur J Opl Res* **150**: 1–2.
15 Sanchez SM, Ferrin DM, Ogazon T, Sepulveda JA and Ward TJ (2000). Emerging issues in healthcare simulation. In: Joines JA *et al* (eds). *Proceedings of the 2000 Winter Simulation Conference*. IEEE, Piscataway, New Jersey, USA, pp 1999–2003.

16 Delesie L (1998). Bridging the gap between clinicians and health managers. *Eur J Opl Res* **105**: 248–256.
17 Appleby J, Boyle S, Devlin N, Harley M, Harrison A and Locock L (2003). *Sustaining Reductions in Waiting Times: Identifying Successful Strategies*. King's Fund: London.
18 Phillips LD (1984). A theory of requisite decision models. *Acta Psychol* **56**: 29–48.
19 Lehaney B, Clarke SA and Paul RJ (1999). A case of an intervention in an outpatients department. *J Opl Res Soc* **50**: 877–891.
20 Robinson S and Pidd M (1998). Provider and customer expectations of successful simulation projects. *J Opl Res Soc* **49**: 200–209.
21 Eldabi T and Paul RJ (2001). A proposed approach for modelling healthcare systems for understanding. In: Peters BA *et al* (eds). *Proceedings of the 2001 Winter Simulation Conference*. IEEE, Piscataway, New Jersey, USA, pp 1412–1420.
22 Rymaszewski LA, McGill PE, Sharma S, Murdoch A, Freeman S and Loh T (2004). *A Team Approach to Musculo-Skeletal Disorders*. Musculo-Skeletal Unit, Stobhill Hospital: Glasgow.
23 Simul8 Corporation (2004). *Simul8 Standard R10* http://www.simul8.com
24 Lagergren M (1998). What is the role and contribution of models to management and research in the health services? A view from Europe. *Eur J Opl Res* **105**: 257–266.
25 Jones LM and Hirst AJ (1987). Visual simulation in hospitals: a managerial or a political tool? *Eur J Opl Res* **29**: 167–177.
26 Ginter PM, Swayne LE and Duncan WJ (2002). *Strategic Management of Health Care Organizations*, 4th edn. Blackwell Publishers: Oxford.

Received September 2003;
accepted August 2004 after three revisions