PhD Thesis

APPLICATION OF DISCRETE-EVENT SIMULATION TO HEALTH SERVICES RESEARCH: ANALYSIS OF NEEDS AND DEMAND FOR ELECTIVE SURGERY

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Dedicat a la meva mare,
a la memòria del meu pare
i al Diego

"All models are wrong,
but some are useful"
George EP Box

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Chapter 0: Abstract

Computer simulation techniques have allowed the introduction of modeling methodologies that analyze complex systems through virtual experimentation to assess the potential impact of interventions on health services. Discrete-event simulation is a well-known technique in operations research, and has mainly been developed in the context of military research and manufacturing systems. In the medical setting, Markov models and decision trees have been extensively used despite their limitations in reproducing healthcare problems accurately. Discrete-event simulation is gaining popularity because of its flexibility in representing real systems by taking into account patient characteristics and the scarcity of resources present in health services provision. This technique has been used to analyze problems related to healthcare resource management, but its possibilities to analyze larger problems related to population dynamics have been hardly explored. Traditionally, needs and demand for health services have been analyzed separately. In the present application, the response of the health system to both the population with need for surgery and to the patients included on a waiting list was analyzed.

In this sense, the main contribution of this thesis is the application of discrete-event simulation to health services research from an epidemiologic point of view. Moreover, the model was statistically complex because the variety of sources and characteristics of data defining the main inputs and rules of the modeled system asked for a specific ad hoc methodology to collect and process them to generate the inputs that the simulation model needs. Therefore a relevant part of this work has been devoted to develop such input data analysis methodology.

A discrete-event simulation model was built for needs and demand for cataract surgery in the Catalan public sector. The model reproduced the process of cataract surgery, from incidence of need for surgery, through demand, inclusion on a waiting list and surgery. The input data analysis methodology was described in detail. The model's parameters were estimated from several sources, including administrative and research databases.

The implementation of the model in the software SIMUL8 and its link to Excel to make the model user-friendly for non-expert users were described in detail. Several sensitivity analyses were performed to assess the impact of the variability of the input estimations (validation), the impact of different waiting list management strategies according to different scenarios of mean waiting time, and to assess the transferability of the methodology. Transferability was evaluated by applying the methodology for calculating the input values to different settings (other regions of Spain). Then, results of the model were used to analyze geographical variations of the impact of introducing a waiting list prioritization system. Moreover, information of the different regions was combined to use the model to assess the volume of need for cataract surgery in Spain according to different indication criteria for surgery. Transferability of the methodology to other elective surgeries was assessed by adapting the model to analyze needs and demand for knee replacement in Spain.

Study of needs and demand for health services is important since substantial unmet needs are observed. The gap between needs and services provision may be too great to be resolved, but models that assess the impact of changes on the amount of resources used or the impact of health policies on the management of need and demand are useful in healthcare decision-making.

Chapter 1: Introduction

1.1: The research project

The present thesis was enclosed within a broader research project in the context of health services research. The name of the research project is "*Definition of a model to estimate demand and waiting time for elective surgery: cataract surgery and knee and hip arthroplasty*". It had funding from Agència d'Avaluació de Tecnologia Mèdica-AATRM (Catalan Agency of Health Technology Assessment and Research-CAHTAR), and from Fondo de Investigación Sanitaria-FIS (Health Care Research Fund), not only as a research project, but also within the research networks RedIRYSS (Spanish Network on Health Outcomes and Health Services Research) and RCESP (Epidemiology and Public Health Cooperative Network). Scientifically, RedIRYSS was focused on waiting lists for elective surgery and one of the research lines of RedIRYSS concerned analysis of needs and estimation of demand.

The principal investigator was Xavier Castells, from Institut Municipal d'Assistència Sanitària-IMAS (Municipal Institute of Health Care, Barcelona). The research team was composed by: Mercè Comas, Rubén Román, Lorena Hoffmeister, Francesc Cots, from IMAS; Mireia Espallargues, from AATRM; José Luís Pinto, from Universitat Pompeu Fabra-UPF; Javier Mar, from Hospital Alto Deba (Mondragón, Basque Country); Santiago Gutiérrez-Moreno, from Servicio de Planificación y Evaluación (Canary Islands); Enrique Bernal, from Instituto Aragonés de Ciencias de la Salud (Aragon); Alberto Jiménez-Puente, from Hospital Costa del Sol (Andalusia); and Darwin Minassian and Angela Reidy, from Institute of Ophthalmology (London). The research team was multidisciplinary as it included epidemiologists, statisticians, economists, sociologists, and also had collaborations of ophthalmologists and traumatologists.

The main contribution of this thesis is the application of discrete-event simulation in health services research. This technique has been used to analyze problems related to resource management, but its possibilities to analyze larger problems related to population dynamics have been hardly explored. Traditionally, needs and demand for health services have been analyzed separately. In the present application, the response of the health system to both the population with need for surgery and to the patients included on a waiting list is analyzed. The complexity of the model is mainly based in the fact that the information needed to characterize these two approaches comes from substantially different sources. While administrative data is available for utilization of elective surgery and waiting lists, the evidence on need for surgery is scarce and comes from specific research settings.

Study of needs and demand for health services is important since substantial unmet needs are observed. The gap between needs and services provision may be too great to be resolved, but models that assess the impact of changes in the amount of resources used or the impact of health policies on the management of need and demand are useful in decision-making[1].

The main objective of this thesis is to assist quantitatively the decision making process related to needs and demand for cataract surgery and knee arthroplasty. Quantitative decision making is based on the use of models of the systems on which decisions have to be made, Markovian models have been primarily proposed for the systems object of this thesis but, to be analytically tractable they have to rely on simplifications that severely limit their usefulness. Discrete-event simulation models appear as an alternative overcoming these drawbacks.

Moreover, the variety of sources and characteristics of data defining the main inputs and rules of the modeled system ask for a specific ad hoc methodology to collect and process it to generate the inputs that the simulation model needs. Therefore a relevant part of our work has been devoted to develop such input data analysis methodology.

1.2: Discrete-event simulation vs. Markov models

Computer simulation techniques have allowed the introduction of modeling methodologies that analyze complex systems through virtual experimentation to be used to assess the impact of complex interventions in health services. Discrete-event simulation is a well-known technique in operations research, and has mainly been developed in the context of military research and manufacturing systems. In the medical setting, Markov models and decision trees have been extensively used despite their limitations in reproducing healthcare problems accurately. Discrete-event simulation is gaining popularity because of its flexibility in representing real systems through time by taking into account patient characteristics and the scarcity of resources present in health services provision[2,3].

When assessing the impact of interventions on health outcomes, the standard technique to represent the natural history of diseases is Markov models. Nevertheless, our study shows the advantages of applying discrete-event simulation to analyze this specific problem in two key components of modeling. On the one hand, discrete-event simulation supplies model flexibility to represent epidemiological and care delivery events (a). On the other hand, the model output is more versatile (b).

Related to (a), when modeling health services, discrete-event simulation is a more flexible technique than Markov models. While in Markov models the system is conceptualized in terms of ‘states’ and the ‘transitions’ among them, in discrete-event simulation the central concept is the occurrence of events. Both can represent changes in patients’ health status: in discrete-event simulation the health status is carried in attributes that change according to the model events, thus, the health status can be continuous or discrete; in Markov models it is represented through discrete states only. Discrete-event simulation has few restrictions and allows transparent representation of the underlying model, enabling all the characteristics of the real system (including facilities and resources) to be represented. Consequently, events may represent several kinds of action or changes. Moreover, although changes in the system are discrete, they occur on a continuous time scale, as each event is scheduled to happen at a time value drawn from a continuous random distribution. In Markov models, time is managed through ‘cycles’, which length should be chosen (months, years …) and they need half-cycle corrections to calculate the results of the model. Queues are a specific tool of discrete-event simulation. In our case, they allowed waiting list management to be modelled, which could not have been done with Markov models. Finally, individual patients (with their individual characteristics) are simulated more straightforward with discrete-event simulation than with Markov models.

Related to (b), the output of discrete-event simulation models is not only survival (or time spent) by state as in Markov models, but also the number of incident cases, population prevalence according to health status variables, and their evolution through the simulation horizon, among others. Moreover, any output of the simulation can be reported at any time during the simulation time horizon, not at the end only, as in Markov models. Additionally, the Markovian assumption is overcome because, by using events instead of states, dependence on prior events or attributes can be included as appropriate. In a Markov model, information prior to the current state is lost because only the current state is taken into account.

In the application to the analysis of needs and demand for health services, an important feature of discrete-event simulation models is that they enable the incidence and prevalence of different health needs to be calculated over time in the whole population, allowing cost-utility analyses that take survival of the prevalent population into account. In contrast, Markov models analyze patients in the initial cohort only [4]. The key point when assessing health services is the prevalence of diseases and the availability and consumption of resources through time. The capacity of resources to meet needs and demand is limited and queues may arise. Waiting lists are a particular type of queue: patients are not physically queuing for the service, but they are waiting to receive a specific health service.

1.3: Importance of analyzing the cataract burden through simulation

During the last years, most of the rates of utilization in elective surgical interventions have increased in Western countries. This increase is a result from, on one hand, the aging of the population and, on the other hand, the introduction of less invasive technologies, which have decreased surgical risk and, therefore, enlarged indication criteria.[4] This fact applies not only for the elderly, but also for patients presenting a lower level of severity or disability.

Despite the increase of elective surgery rates in most of the European countries, a significant unmet need for surgery and long waiting lists (and times) have been observed, which would imply an unsatisfied demand.[5,6] Waiting lists in elective surgery are a characteristic of the public health services which have a lack of resources to face the increase of need and demand.

Related to needs assessment, special concern should be taken for the definition of need for surgery. A consequence of the widening in indication criteria is the great variations found in the level of visual impairment of the operated patients. Factors such as perceived need, variations in clinical practice or accessibility to health services play an important role in the opportunity of being operated of those patients with appropriate indication.

The concept of need is based on the expected benefit of the health care intervention rather than on disease or risk presence and its severity level.[7] However, the benefit of the intervention may vary according to patient sociodemographic and clinical characteristics. This fact is present in cataract surgery and knee arthroplasty, whose effectiveness has been proved, but its degree of benefit depends on the patients' characteristics.[8] For instance, the benefit of cataract surgery in two patients with the same visual acuity might be different if one of them presents a higher limitation in performance of daily life activities. This way, expected benefit, need and priority are treated as synonymous concepts. To sum up, a prioritization system based on the expected benefit from surgery allocates patients on a waiting list ordered according to their level of need.

The idea is to establish a function to allow a definition of need and waiting time related to the behavior of the remaining parameters of the model (basically incidence/prevalence for each level of need, the expressed need and the supply capacity). This function would allow obtaining the threshold of need that the system does not have the capacity to supply.

Cataracts, or lens opacity, are an important healthcare problem because of its high prevalence, especially among the elderly, and the disability associated with it. However, even though its treatment (surgical extraction of the lens and insertion of a calibrated intraocular lens) is one of the most frequent surgical procedures in developed and less developed countries, long waiting lists and waiting times are associated with the supply of cataract surgery.

Despite the increase in the rates of cataract surgery in most Western countries[9], there is a significant unmet need for surgery, explained by the widening of indication criteria and the ageing of the population[5]. Some population-based studies that analyze prevalence of cataract surgery[10-15] show that an important proportion (30%) of the population older than 65 would benefit from surgery. These studies found a weak association between waiting list and unmet needs. Several previous experiences have taken advantage of simulation to assess interventions on waiting list management, such as prioritization of patients requesting cataract surgery[16,17], but none from the needs assessment perspective.

In the last few years, the indication criteria for cataract surgery have been widened due to the introduction of less invasive technologies such as phacoemulsification and topical anesthesia, which have decreased surgical risk and improved the benefits of surgery. Thus, the relationship between benefit and risk [18] has been substantially modified. Broadening of the indication criteria has included lowering the threshold for visual acuity from 0.2 to 0.5 or 0.7[4]. However, the latest guidelines for cataract surgery indication[19] widen even more the indication criteria, as they take into account whether the decrease in visual function caused by cataracts influences the patient’s lifestyle, that is, whether the patient’s visual function cannot satisfy the patient’s needs, rather than a threshold for visual acuity.

A consequence of this change in the indication criteria is the wide variation found in the level of visual impairment in operated patients. Factors such as perceived need, variations in clinical practice, and accessibility to health services play an important role in the likelihood of undergoing surgery. Then, substantial differences are found among regions or even among hospitals of the same regions.

Recently, several governments have considered the need to prioritize patients on waiting lists for elective surgery, which would modify the principle of first-in, first-out (FIFO), i.e., prioritization according to waiting time [20-24]. Indeed, prioritization is based on the fact that the need for surgery differs in patients with appropriate surgical indication, and introduces levels of need. In fact, broadening the indication criteria for cataract surgery entails that the need for surgery differs in patients with appropriate surgical indication. In the specific context of elective surgery, several interventions may be tested. Elective surgery waiting lists reflect a situation in which scarcity (due to the gap between supply and demand) causes competition for resources and entries to and exits from the waiting list follow a stochastic law. Treating waiting lists as a queue allows patients to be prioritized and the impact of the time waited related to the level of need for surgery to be quantified. Prioritization of patients by an explicit criterion, based on need for surgery, other than the current FIFO principle would not only avoid unnecessary suffering but would also reduce the gap between demand and the available resources more efficiently, as the people who would receive a higher benefit from surgery will receive it earlier. In Spain, a project has recently been developed to work on prioritization criteria for cataract surgery and knee and hip replacement [25]. The resulting prioritization system includes clinical (severity and prognosis), functional (limitation of activities) and social (need or access to social support) criteria (see appendix 1). Possible scores range between 0 and 100, higher scores representing greater need. Thus, in this system, need and priority are equivalent. A pilot study to assess the introduction of the prioritization system in clinical practice was carried out in Catalonia[26], Andalusia and Aragon[27].

Important geographic variations in the utilization of elective surgery have been observed.[28,29] These geographic variations are explained by differences in supply and, specially, clinical practice. As a consequence, this might express problems in equity to the extent that they do not correspond to differences in need. Needs assessment models, as the one presented here, allow analyzing variations in utilization from a perspective of equity among geographic areas. The goal is to find whether the same waiting time in two geographical areas correspond to different levels of need. In Spain, each regional health system manages its own resources, probably involving substantial variations in resource utilization. The effect of introducing a prioritization system would differ in each region because health systems vary widely in terms of clinical practice and utilization rates. Studying these variations is of special interest within the Spanish health system.

1.4: Discrete-event simulation in health services research

Discrete-event simulation is an operations research technique that has been widely used and developed in different disciplines such as military research or manufacturing systems. Its potential has been little exploited in medical research. In health services research, other techniques such as decision trees and Markov chains have been used for cost-effectiveness analyses of new treatments.

A literature review was performed in order to assess to which extent discrete-event simulation models were used in health services research or, more generally, to solve healthcare problems. The reference database for searching the medical literature is MEDLINE, which was accessed through PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=PubMed). PubMed is a service of the U.S. National Library of Medicine that includes over 16 million citations from MEDLINE and other life science journals for biomedical articles back to the 1950s.

The search was performed on November 27th, 2006. Entering the query *"discrete-event"[All Fields] AND simulation[All Fields]*, 128 references were retrieved. Of these, 14 were articles in which discrete-event simulation was not used (false-positive results of the search), 12 were reviews of methods and 102 were indeed applications of discrete-event simulation. The search was limited to these criteria, as the objective was to see which articles were directly accessible through Medline. An exhaustive search would have included reviewing the references lists of the retrieved articles, and making wider searches with different tools (Google searches, for example). This way, in addition to false-positive results, we would have acknowledged false negative results of the search on Medline only.

Of the 12 articles reviewing methodologies, 7 were focused on methods for pharmacoeconomics or economic evaluations[30-36], 8 included comparisons of discrete-event simulation with Markov models, decision trees or differential equations[30-34,36-38], 3 focused in modelling of systems[39-41] and one of them referred to veterinary medicine[37].

Of the 102 articles using discrete-event simulation as the methodology 67 (65.69%) applied it to epidemiologic or healthcare problems. The remaining articles applied it mainly to veterinary medicine, kinetics or biological models. The applications of discrete-event simulation in healthcare included models for economic evaluation of treatments or health technologies[42-44], planning of resources at different levels[45-49], screening programs[50-52] or transplants[2,53,54], among others; and were applied in specialties such as mental health[42,55], cardiology[43,44], oncology[50,52] or gastreoenterology[51].

Among the articles applying discrete-event simulation, some of them assess needs or demand of health services, focusing on planning of resources. Study of needs and demand for health services is important since substantial unmet needs are observed. The gap between needs and services provision may be too great to be resolved, but models that assess the impact of changes in the amount of resources used or of health policies on the management of need and demand are useful in decision-making[1].

Several previous experiences have taken advantage of simulation to assess prioritization of demand[16,17,56,57] and assessment of needs in health services[5,58,59]. But only three used discrete-event simulation[16,17,56]. The appropriate tool to analyze waiting lists for elective surgery is discrete-event (or queuing systems) simulation[60], as waiting lists reflect a situation in which a scarcity of resources causes competition for them and entries to and exits from the waiting list follow a stochastic law. Treating waiting lists as a queue allows prioritization.

1.5: Objectives

General Objective

To develop the methodology to define a mathematical model to analyze, through simulation, needs and demand of elective surgery related to the patients' level of need (or priority).

Specific Objectives related to the methodology

1. To choose the appropriate mathematical model to achieve the objectives.

2. To define and describe a general conceptual model for elective surgery and its refinement to fit the model for cataract surgery.

3. To develop an ad hoc methodology to estimate the necessary inputs to implement the model.

4. To describe the application of the technique to the cataract surgery model.

5. To validate the implemented model.

Specific Objectives related to the application

6. To assess the impact of introducing a prioritization system (based on need for surgery) for patients on waiting lists.

7. To estimate the volume of unmet needs for cataract surgery.

8. To verify the transferability of the model for cataract surgery:
   - 8.1. By changing the input data set (assessment of variations in the impact of introducing a prioritization system for cataract surgery waiting lists among different geographic areas).
   - 8.2. By adapting the model to other elective surgeries (application to needs and demand for knee replacement).

1.6: Structure of the thesis

Chapter 2 develops the methodology used. After an introduction to discrete-event simulation, it is divided into the Methods section, which includes the definition of the conceptual model and key concepts, and the estimation of the parameters of the model, which is structured with a first section of information sources and methods followed by results. The second section of Methodology is devoted to the techniques used, that is, it describes how the simulation model was implemented. Chapter 3 includes verification and validation of the computer model, analyses of results to achieve the mentioned objectives and assessment of its transferability. Chapter 4 includes discussion and limitations and Chapter 5 includes conclusions. Chapter 6 includes the list of bibliographic references, while chapter 7 includes a list of publications derived from this thesis.

Chapter 2: Methodology

2.1: Introduction to discrete-event simulation

Discrete-event simulation methodology is appropriate to model the present problem because of the different reasons outlined in section 1.2, specially the fact that waiting lists should be treated as queues. Moreover, the system's state changes at discrete instants of time, like transitions in Markovian processes. However, a Markov model for this type of problem would be analytically intractable, as it would have to deal with non poissonian and non homogeneous (i.e., time-dependent) transition probabilities, which will also be affected by queue prioritization. The mechanisms to generate the instants of occurrence of these events upon complex probability distributions -some time-dependent-, are based on Montecarlo processes computationally efficient, and treatment of priorities and their changes through time are also computationally direct.

The first step needed to build the model is a process of observation of the system in order to acquire knowledge about it. This knowledge should be formalized as a conceptual model, including a definition of each component of the model, that is, the events of the process to be studied, the subjects, their attributes and the parameters that should be estimated. The population and setting of the study must be defined, as well as the level of detail or the intended scope of the model.

The second step is to estimate the parameters needed to characterize the model according to the technique used and our capacity to translate the conceptual model into a computational model. The ideal situation would be to collect the data needed to estimate the parameters in the most appropriate manner to obtain such estimations. However, we find that data needed for models reproducing healthcare systems are usually collected systematically and for administrative purposes. Other type of data may be that obtained in research studies, such as clinical trials, with designs according to the objective of the study. Then, an effort should be made to set a systematic approach for the process of data collection in order to integrate data from different sources. This approach should take into account not only the goal of solving the problem, but also the goal of making the model transferable, that is, allowing to solve the model with different input data (from other settings, testing hypothetical scenarios or applying it to other processes). The present thesis shows the methodology to systematize the obtainment of different model parameters from both administrative and research data.

The third step is to translate the conceptual model into a computational model. Healthcare systems are complex. We were interested in modeling discrete events occurring at any point in time. Although the underlying model is a Markov process, the probabilities governing the transitions among states are not easy to determine. Those related to utilization of surgery are not constant through the time horizon, thus, they are not of the Poisson-type. Moreover, the transition probabilities are derived from complex relationships among several parameters of the model and attributes of the entities (or patients). Consequently, the analytical approach is unfeasible and simulation (stochastic and dynamic) should be chosen to analyze such systems. The event scheduling approach was used to model discrete changes in the system (events) in discrete moments in time. Moreover, in our case, waiting lists are, in fact, queues because patients wait for a scarce resource.

The present thesis develops and presents the methodology to apply the methods and the techniques needed to develop the model to analyze needs and demand for elective surgery. The model is thoroughly described for cataract surgery, however, it includes general issues applicable to most elective surgeries.

2.2: Methods

2.2.1: Definition of the conceptual model

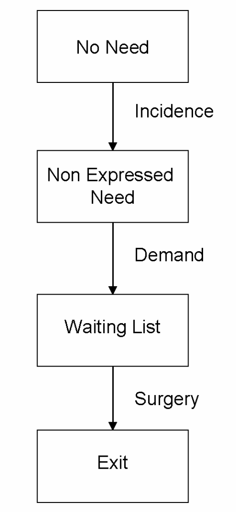
2.2.1.1: Definitions

- **Subjects:** General population, aged 50 years or older, who have or can develop cataracts needing surgery. This definition excludes cases operated on both eyes. However, these cases will have to be considered when calculating incidence from prevalence.
- **Setting:** Needs for the population and demand in the public sector of the regions studied.
- **Case definition (cataracts):** Visual impairment due to lens opacity.
- **Surgery indication criteria:** Any lens opacity and visual acuity of 0.5 or less.
- **No need:** A person has no need for surgery if he or she does not meet indication criteria for surgery. This includes people without cataracts or people with cataracts having visual acuity better than 0.5, and people presenting bilateral surgery.
- **Incidence:** We are interested in incidence defined as the moment in which a case that does not have need for surgery starts to meet indication criteria for surgery.
- **Need:** A person has need for surgery if he or she presents the pathology and meets indication criteria for surgery.

  - **Non Expressed Need:** People presenting need but not included on a waiting list.
  - **Expressed Need (or Waiting List):** We considered that a person having need for surgery has expressed his/her need if he/she has *demanded* surgery and, thus, has been included on a waiting list of the public sector. A given individual can't enter the waiting list without previously being through Non Expressed Need.
    - **Demand:** The concept of demand was assimilated to the inclusion on a waiting list, i.e., changing from Non Expressed Need to Expressed Need.
- **Use:** Surgery performed on patients included in the waiting list.

These last four definitions correspond to the basic stages of development and cure of the disease (not considering death). The following representation can be made:

Figure 2.1: Basic representation.

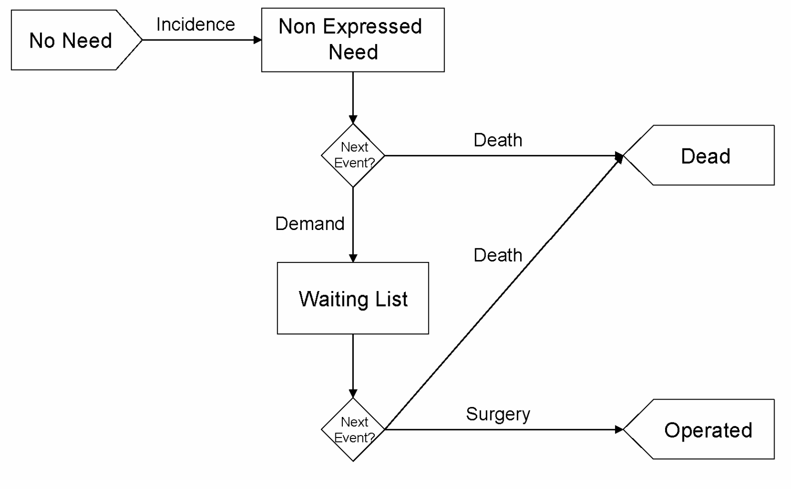


2.2.1.2: Model specification

However, we should translate the model in figure 2.1 to a discrete-event simulation model. Population will be classified into the categories 'No need', 'Non Expressed Need' and 'Waiting List'. Changing from one to the other should be represented as events such as 'Incidence', 'Demand' or 'Surgery'. In the following section, the basic model shown in figure 2.1 is developed in more detail. Later, each component of the model will be thoroughly defined: the cases included in each category and the events that change this categories.

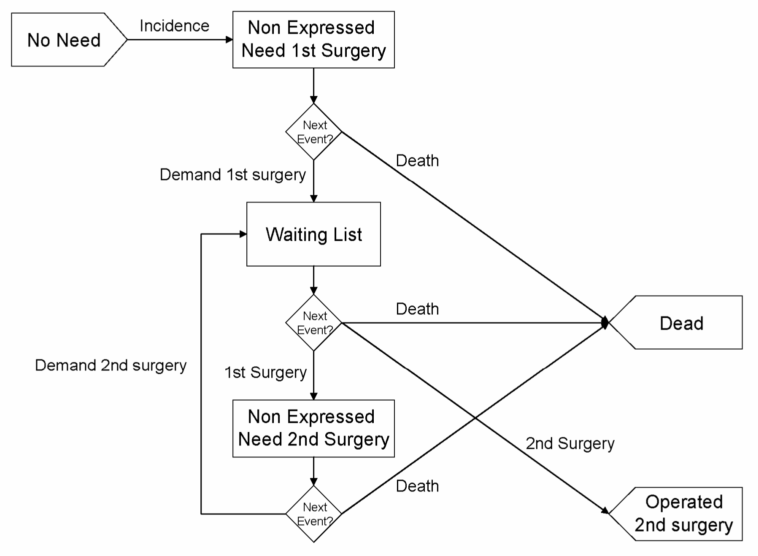
- **Dead:** It is an exit event from the system and applies to all cases in the model. The model in figure 2.2 includes 'Death' as an exit point, formalizes the events and includes 'Operated' also as an exit point.

Figure 2.2: Representation of the model adding the exit event 'Dead'.



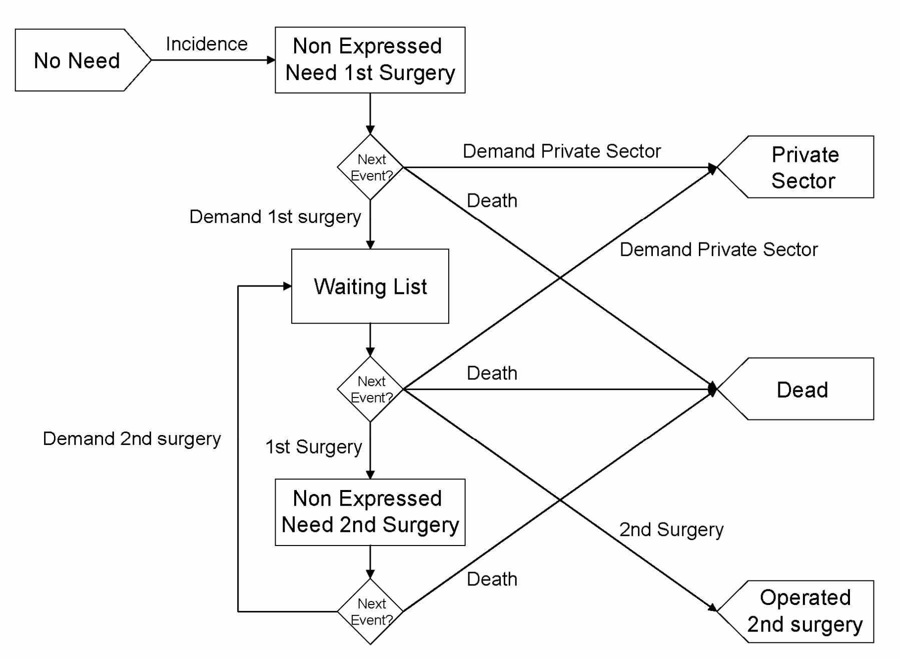
- **Second surgery:** Because cataracts affect a bilateral organ (eyes) and the eyes are usually operated on one at a time, the first and the second surgery were differentiated. The 'Non Expressed Need' category was divided into 'Non Expressed Need 1st Surgery' and 'Non Expressed Need 2nd Surgery'. The first surgery was considered as the event that changes the patient from being in a waiting list to have need for second-eye surgery (cataract surgery is usually ambulatory). For patients labelled as 'Non Expressed Need 2nd Surgery', the event 'Demand 2nd surgery' would include them back in the waiting list and they would wait to receive second-eye surgery. Those bilateral cases that never get their second operation will remain in 'Non Expressed Need 2nd surgery' until the event 'Death'. The exit point 'Operated' is called now 'Operated 2nd surgery' to distinguish that the exit event is second-eye surgery. The reason to be an exit event is that these patients, as they will never have need for cataract surgery again, are no longer of interest in the model (figure 2.3).

Figure 2.3: Model flow chart separating first and second surgery.



- **Private Sector:** Surgery in the private sector was also considered through the event 'Demand in the private sector' leading to the exit point 'Private Sector'. This event applies to patients who don't express need in the public sector, but they express it directly in the private sector (thus labelled as 'Non-Expressed Need 1st Surgery') and to patients included in a waiting list. It was assumed that a patient switched to the Private Sector to undergo both surgeries, thus, no return to the public sector was considered. It was considered as an exit point for this reason and because our interest focused on the demand in the public sector only (figure 2.4).

Figure 2.4: Final conceptual model (including 'Private Sector').



- **Levels of Need:** The concept of 'need' is usually treated as a dichotomous variable: presence or absence of need. However, we introduced a quantification of need based on a priority score. The priority score was defined based on the CAHTAR (Catalan Agency of Health Technology Assessment and Research) proposal for cataract surgery (appendix 1.1), which assigns patients a score related to clinical (disease severity and recovery probability), functional capacity (difficulty in doing activities of daily living and limitation on ability to work) and social criteria (be a caregiver and having somebody to look after the patient). Each criterion has a different weight in the overall score, which has a range from 0 (lowest priority) to 100 (highest priority). The objective of the scoring system is to order the patients within a waiting list according to their priority, thus, it is a measure of priority and, therefore, of need. This prioritization score was developed in the context of patients on waiting lists of the Catalan public sector and it will only be applied to patients entering the 'Waiting List'. Although the priority score, as a measure of need, applies to all patients with need (expressed and not expressed), it would not be possible to know the distribution of priority scores for patients in ‘Non Expressed Need’. A function for worsening during wait (increase of the priority score) will be applied, provided that no improvement through time is assumed.

The following is a more detailed description of the cases included in each category and the possible events applying to each one.

- **No Need:** ‘No Need’ was defined as absence of indication criteria for surgery. It was treated in the model as the starting point, as ‘Incidence’ represents the event of changing from ‘No Need’ to ‘Need’.
  - ✓ *Includes:* Conceptually, it includes people free of cataracts or having the disease in a less severe stage than indication criteria. It would also include people operated on both eyes, although we would not take them into account in our model.
  - ✓ *Possible Events:* The event ‘Incidence’ represents changing from ‘No Need’ to ‘Need’.

- **Non Expressed Need 1st Surgery:** This category concerns those patients with bilateral disease (they meet indication criteria for surgery) who still have not demanded their first surgery.
  - ✓ *Includes*: Patients with bilateral disease presenting indication criteria for surgery but not included in the ‘Waiting List’. This is the case of patients who have barriers to access the health care system or patients who do not perceive their need for surgery.
  - ✓ *Possible Events*: The events ‘Death’, ‘Demand 1st surgery’ (in the public sector) and ‘Demand in the private sector’ apply. The ‘Non Expressed Need 1st Surgery’ category is acquired after the event ‘Incidence’.

- **Non Expressed Need 2nd Surgery:** This category concerns those patients already operated of the first surgery who still have not demanded their second surgery.
  - ✓ *Includes*: Patients who have undergone their first surgery and still have not demanded the second one.
  - ✓ *Possible Events*: The event ‘Demand 2nd surgery’ would return the patient to the ‘Waiting List’ to wait for second surgery. In absence of the event ‘Demand 2nd surgery’ (a patient may not demand second surgery for personal choice, for example), only the event ‘Death’ can happen. Those patients that enter the ‘Waiting List’ immediately after receiving the first surgery will spend a short time in ‘Non Expressed Need 2nd Surgery’. This category is acquired after the first surgery only (that is, after being in ‘Waiting List’).

- **Waiting List:** A patient is classified as ‘Waiting List’ after expressing his/her need for surgery, that is, after the events ‘Demand 1st surgery’ or ‘Demand 2nd surgery’. Patients in this category only can receive surgery in the public sector. Patients in 'Waiting List' have an additional feature, CAHTAR's priority score, which will be modified through the time a patient remains in 'Waiting List' before surgery.

- ✓ *Includes:* Patients included in a 'Waiting List' for first or second surgery. It is assumed that indication is always appropriate.
- ✓ *Possible Events:* The events of entering a 'Waiting List' were named as 'Demand 1st surgery' and 'Demand 2nd surgery' and are applicable to patients classified as 'Non Expressed Need 1st Surgery' and 'Non Expressed Need 2nd Surgery', respectively. The events that apply to patients in the 'Waiting List' are 'Death', 'Demand in the private sector', '1st surgery' and '2nd surgery'. The 'Waiting List' should be treated as a queue then, the strategy to select the patients to be operated (first-in, first-out (FIFO) or the prioritization system) and the supply capacity of the public sector should be taken into account.

- **Operated 2nd Surgery:** Exit point accessible to patients in the 'Waiting List' only, through the event '2nd surgery'. A patient that has had bilateral surgery leaves the system because he/she is no longer of interest for the model.

- **Private Sector:** Exit point accessible to patients in 'Non Expressed Need 1st Surgery' or in 'Waiting List' through the event 'Demand private sector'. It is assumed that patients demanding surgery in the private sector will receive both surgeries and, therefore, will never demand cataract surgery in the public sector again, thus, these patients leave the system.

- **Dead:** Exit point accessible to all patients through the event 'Death'.

- **Incidence:** Event representing the generation of a new case entering the model (from 'No Need' to 'Non Expressed Need 1st Surgery').

- **Demand:** Event representing the entry to a 'Waiting List' from 'Non Expressed Need 1st Surgery' (to wait for first surgery) or 'Non Expressed Need 2nd Surgery' (to wait for second surgery).

- **1st surgery:** Event representing the first surgery in patients waiting at the public sector. The patients classified as waiting for their first surgery are classified as 'Non Expressed Need 2nd Surgery' after this event.

- **2nd surgery:** Exit event representing the second surgery in patients waiting at the public sector. After this event, patients leave the system.

- **Demand private sector:** Exit event representing the demand for cataract surgery in the private sector. It is applicable to patients classified as 'Non Expressed Need 1st Surgery' and 'Waiting List'. After this event, patients leave the system.

- **Death:** Exit event applicable to all patients in the model. After this event, patients leave the system.

2.2.1.3: Model assumptions

The assumptions that will be considered for this conceptual model are summarized below:

(1) Demand, depends on the supply capacity (as the supply increases, entries to the waiting list increase as well).
(2) No differentiation will be made between unilateral and bilateral patients. All incident cases will be considered as bilateral. This assumption is based on the fact that cataract is an age-related pathology and, although the evolution of both eyes might be asymmetrical, a small proportion of cases older than 50 years present it unilaterally.
(3) The simulation time horizon will be small enough to consider that the evolution of the population (in age and gender) and incidence remain constant through the time horizon.
(4) When a patient switches to the Private Sector, no return to the public sector is allowed.
(5) The level of need does not improve through time, that is, the priority score can increase or stay the same, but not decrease while no surgery is performed.
(6) Indication is always appropriate.
(7) Patients are operated on one eye at a time.

2.2.2: Parameter estimation

2.2.2.1: Patient characteristics

The behavior of each patient inside the system depended on his/her characteristics. It also depended on the characteristics of the rest of patients, because the 'Waiting List' is, in fact, a queue: the inputs and outputs of the 'Waiting List' followed an order, either by waiting time or by priority score.

The characteristics taken into account when calculating the parameters of the simulation model were:

- Sex (Male / Female)
- Age
- Type: ● = in need; ⊕ = operated; ○= no need
    - Need: It is assumed that incident cases have the disease in its bilateral form.
        - ✓ Bilateral: ●● (includes ●○ cases).
        - ✓ Unilateral (or aphakic): ●⊕ (includes ○⊕ cases).
    - No need:
        - ✓ No cataract cases: ○○.
        - ✓ Bilateral operated: ⊕⊕ (these cases were not taken into account).

    This label is attached to all cases in the model. The cases were classified as follows:

    - No Need: ○○, ⊕⊕.
    - Non Expressed Need 1st Surgery: ●●.
    - Non Expressed Need 2nd Surgery: ●⊕.
    - Waiting List: ●●, ●⊕.
- Priority score (1st/2nd surgery): Level of need for patients in the 'Waiting List' waiting for 1st/2nd surgery.

2.2.2.2: Information sources and methods

The following sections include the sources of information and the methods used to calculate each parameter. 'Initialization' explains how the initial state of the model was created. 'Life Expectancy' relates to the calculation of the distributions of the time to death, that is, the event 'Death'. 'Incidence' relates to the event named 'Incidence'. 'Surgery rates' include both the surgery rates of the public and the private sector (events '1st surgery', '2nd surgery' and 'Demand private sector') and the probability of second surgery in the public sector (event 'Demand 2nd surgery'). 'Inclusion on a waiting list' addresses several issues related to the 'Waiting List' and the priority score in addition to the event 'Demand 1st surgery'. 'Disease progression' relates to the calculus of the change in priority through time.

Initialization

The objective of initializing the system was to create a non-empty starting point. That is, to include in the simulation model the backlog of prevalent cases classified as 'Waiting List' and 'Non Expressed Need'.

- ✓ Sources of information: Database of the Catalan population by age and sex from the census of 2001 obtained from IDESCAT (*Institut d'Estadística de Catalunya*) web page (http://www.idescat.net). Register of waiting lists in Catalonia, patients waiting at June, 2004, obtained from CatSalut web page (http://www10.gencat.net/catsalut). Database of the North London Eye Study (NLES), a population-based study on prevalence of eye disease in North London[10]. CATHAR's pilot test of the introduction of the prioritization system in the clinical practice[26].

- ✓ Methods: The distribution according to age and sex of the Catalan population was obtained (N_{ij}, *i*=50, …,100, *j*=male, female). Prevalence estimates of bilateral and aphakic cases obtained from NLES data (P_{ijk}, *k*=bilateral, aphakic, $\sum_i \sum_j \sum_k P_{ijk} = 1$) were projected to the Catalan population (equation 2.1). All calculations were stratified by year of age and sex. The empirical distribution of age conditioned on sex was obtained through projected prevalent cases (n_{ijk}).

$$n_{ijk} = N_{ij} P_{ijk} \tag{2.1}$$

$$\sum_i \sum_j \sum_k n_{ijk} = \text{Overall Prevalence of Need}$$

The number of cases classified as 'Non Expressed Need' (NEN_1 and NEN_2, 1st and 2nd surgery respectively in equation 2.2) was calculated by subtracting the numbers in the waiting list, according to proportions of aphakic and bilateral cases obtained from CATHAR's pilot test data, from the number of projected prevalent cases ($n_{bilateral}$ and $n_{aphakic}$).

$$\begin{aligned} NEN_1 &= n_{bilateral} - (1 - p_{aphakic})WL \\ NEN_2 &= n_{aphakic} - p_{aphakic}WL \end{aligned} \tag{2.2}$$

Life expectancy

- ✓ Sources of information: Data on the number of deceased in Catalonia in the year 2001 was obtained from INE (*Instituto Nacional de Estadística*) web page (http://www.ine.es). Data on the population census of Catalonia of the year 2001 was obtained from IDESCAT web page.

- ✓ Methods: For the discrete-event simulation model, the mortality rate should be transformed into lifetime. See appendix 2.1[61] for a detailed description of the following calculations. The model that has been shown as most appropriate to adjust the instantaneous mortality rate by age is a Gompertz[62] function (equation 2.3).

$$h(age) = \alpha e^{\beta age} \tag{2.3}$$

The number of deceased was divided by the volume of population by year of age (from 50 to 95 or more) and sex. Then, two Gompertz models were adjusted to obtain the coefficients α and β for men and women. According to survival theory, the cumulative hazard function (equation 2.4), the survival function (equation 2.5) and the distribution function (equation 2.6) can be obtained from the hazard function. However, as we wanted to condition lifetime to current age, the integration limits of the cumulative hazard function took current age as the lower bound (equation 2.4). The upper bound was current age plus a time variable which also depended on current age, as it took lower values as current age was higher ($t_{age} \geq maximum\ age - age$).

$$H(t_{age}) = \int_{age}^{age+t_{age}} h(u)du = \int_{age}^{age+t_{age}} \alpha e^{\beta u} du = \left[\frac{\alpha}{\beta} e^{\beta u} \right]_{age}^{age+t_{age}} = \frac{\alpha}{\beta}\left[e^{\beta(age+t_{age})} - e^{\beta age} \right] \tag{2.4}$$

$$S(t_{age}) = e^{-H(t_{age})} = e^{-\frac{\alpha}{\beta}\left[e^{\beta(age+t_{age})} - e^{\beta age} \right]} \tag{2.5}$$

$$F(t_{age}) = 1 - S(t_{age}) = 1 - e^{-\frac{\alpha}{\beta}\left[e^{\beta\left[age+t_{age}\right]} - e^{\beta age} \right]} \tag{2.6}$$

Being age the current age, the cumulative distribution function represents the probability of dying before t_{age} years of a person age years old. The following step, as shown in appendix 2.1, was to calculate the density function for lifetime by taking derivatives of $F(t_{age})$. However, for software requirements (the Gompertz distribution was not implemented), a formula was found to create a discrete probability mass function approximating the density function (equation 2.7). To achieve smoothness, the values of the probability mass function were calculated by month, from current age to 105 years (i.e., it doesn't allow simulated patients to be 105 years or older). Then the time units were transformed to $t_{age} = {}^{i_{age}}\!/_{12}$, because the coefficients of the model were calculated upon year units.

$$f\left(age+\frac{i_{age}}{12}\right)=F\left(age+\frac{i_{age}}{12}\right)-F\left(age+\frac{i_{age}-1}{12}\right)=$$

$$=1-e^{-\frac{\alpha}{\beta}\left[e^{\beta\left[age+\frac{i_{age}}{12}\right]}-e^{\beta age}\right]}-\left[1-e^{-\frac{\alpha}{\beta}\left[e^{\beta\left[age+\frac{i_{age}-1}{12}\right]}-e^{\beta age}\right]}\right]=$$

$$=e^{-\frac{\alpha}{\beta}\left[e^{\beta\left[age+\frac{i_{age}-1}{12}\right]}-e^{\beta age}\right]}-e^{-\frac{\alpha}{\beta}\left[e^{\beta\left[age+\frac{i_{age}}{12}\right]}-e^{\beta age}\right]} \tag{2.7}$$

$$i_{age}=0,1,2,...(105-age)$$

By using equation 2.7, a discrete probability function (by month of age) of varying number of values according to current age was obtained. Adjusting a discrete probability function implies that the mortality rate is constant over periods of one month. The density function for lifetime represents the probability of a person aged age years of dying at age $age+i_{age}/12$ given he/she has survived until age $age+(i_{age}-1)/12$. Different functions will be adjusted for men and women.

☞ There are published studies providing evidence of a higher mortality rate in patients with cataract. One of this studies[63] concludes that women with cataract have higher mortality than women without cataract. The hazard ratio was 1.7 (95% confidence interval from 1.1 to 2.7) for women and 0.9 (95%CI from 0.6 to 1.5) for men. As we estimated the mortality rate for overall population (including cases with cataract), the mortality rate for women was multiplied by 1.5, as less differences were expected between overall population and population with cataracts than between population with and without cataracts.

Incidence

✓ Sources of information: Raw data on prevalence of cataracts of the North London Eye Study (NLES)[10]. Data on the population census of Catalonia of the year 2001.

✓ Methods: In the absence of incidence data, it was calculated through prevalence of the NLES. Incidence and its variability were estimated through the method developed by Leske et al.[64]. This method assumes that the disease is irreversible, that incidence rate is constant over the simulation time horizon and that mortality is not different in presence of the disease. Although we have considered a higher mortality rate for women with cataracts, we have applied this method because results are similar to those taking into account the estimation of differential mortality[65]. Due to the irreversibility assumption, prevalence should include operated cases. The formula for groupings of 5 years of age is the following:

$$I_i = \frac{P_{i+5} - P_i}{1 - P_i}\,, \tag{2.8}$$

where I_i is the five-year cumulated incidence in age group i, P_i is prevalence in age group i and P_{i+5} is the prevalence in the following five-year older age group. Yearly incidences will be obtained by applying equation (2.8) to the smoothed yearly prevalence obtained by adjusting a logistic model to the observed prevalence. The number of monthly incident cases (N_I in equation 2.9) will be obtained by projecting the annual incidence to the Catalan population by age and sex, and dividing the total number by 12. The inverse of this average will be the parameter of an exponential distribution for the time between two incident cases (t_I in equation 2.9).

$$f(t_I) = \frac{1}{N_I} e^{\frac{1}{N_I} t_I} \tag{2.9}$$

Surgery rates

✓ Sources of information: Minimum Data Set (CMBD/AH) of the Catalan Health System including cataract extraction procedures (according to ICD9-MC classification) from 1999 through 2003, obtained from the Health Authority. The database structure allowed differentiating public from private sector and identifying bilateral operations between 1999 and 2002. CATHAR's pilot test of the introduction of the prioritization system in the clinical practice[26].

☞ Methods: The inverse of the average number of surgeries per month in the public (N_S) and the private sector (N_P) were used as the parameters of two exponential distributions for the time between two successive surgeries in each sector (t_S and t_P in equations 2.10 and 2.11, respectively).

$$f(t_S) = \frac{1}{N_S} e^{\frac{1}{N_S} t_S} \tag{2.10}$$

$$f(t_P) = \frac{1}{N_P} e^{\frac{1}{N_P} t_P} \tag{2.11}$$

Surgeries in the private sector were applied to patients classified as ‘Non Expressed Need 1st Surgery’ and ‘Waiting List’ (event ‘Demand private sector’ in figure 2.4). The number of surgeries in the public sector was modeled to increase through time by adjusting a linear model to the number of monthly surgeries (equation 2.12) by the logarithmic transformation of time.

$$N_S(t) = \beta_{0S} + \beta_{1S} \ln(t) \tag{2.12}$$

Predictions using the estimated model were used for the parameter of the exponential distribution of equation 2.10 (N_S) through the 60 months following year 2003.

Appendix 2.2[66] includes a detailed description of the following calculations. The 4-year horizon was used to match pairs of 1st and 2nd surgeries of the same patient and to assign a label of 1st or 2nd surgery to the patients with a single operation within those 4 years. The latter assignment was decided according to the time between surgeries of the paired interventions, that is, the waiting time (t) before which 95% of these patients have had second surgery was taken into account to decide that single surgeries performed t or more months after January 1999 were considered as first surgeries. This procedure was used in the public sector only. To know the proportion of second surgeries over the total number of operations (in the public sector) through time, the period from t months after January 1999 and further was considered. The probability of undergoing second-eye surgery (p) was calculated as follows:

$$p = \frac{q}{1-q} \tag{2.13}$$

where q is the proportion of 2nd eye surgeries over the total number of surgeries of the period. The parameter p was the parameter of a Bernouilli distribution to indicate that the patient enters again the waiting list for second-eye surgery. Again, a logarithmic model was adjusted to the probability of second-eye surgery through time (equation 2.14).

$$p(t) = \beta_{0p} + \beta_{1p} \ln(t) \tag{2.14}$$

The probability that a case having surgery in the private sector comes from ‘Waiting List’ or from ‘Non Expressed Need 1st Surgery’ was calculated using data from CAHTAR’s pilot test, which contained the reasons for leaving the waiting list.

☞ For the event ‘Demand private sector’ from ‘Waiting List’, dependence on the waiting list discipline (on the time spent waiting or on the level of priority) was considered.

Inclusion on a waiting list

- ✓ Sources of information: Register of waiting lists in Catalonia, patients entered during the year 2003, obtained from the Health Authority. CATHAR’s pilot test of the introduction of the prioritization system in the clinical practice[26].

- ✓ Methods: The times between successive inclusions in the waiting list (t_E) were modeled as an exponential distribution, with a parameter equal to the inverse of the average number of patients entered in the waiting list per month (N_E in equation 2.15). As second surgeries are entered to the waiting list after having first eye surgery, the distribution for entries to the waiting list will take into account first eyes only, that is, patients with bilateral disease. The parameter N_E was considered to increase through time parallel to the number of surgeries (with a difference of d units, representing both the gap between supply and demand and the volume of second eyes) and with a delay in time (lag, in equation 2.16, lag≥0). If lag is greater than 0, the interpretation is that the current number of entries to the waiting list depends on the number of surgeries lag months before.

$$f(t_E) = \frac{1}{N_E} e^{\frac{1}{N_E} t_E} \qquad (2.15)$$

$$N_E(t) = (\beta_{0S} - d) + \beta_{1S} \ln(t - lag) = N_S(t-1) - d \qquad (2.16)$$

$$d = N_S(t=0) - N_E(t=0) \qquad (2.17)$$

Waiting lists behave in a rather stable way. This leads to think that they have some sort of “self-regulation”. That is, ophthalmologists may indicate more surgeries when they know that the waiting list has reduced or when the surgery supply has increased. However, when this practice leads to an excessive increase of the waiting list volume, they may be required to reduce their number of indications, and then, the waiting list volume would reduce to reach for the previous equilibrium.

In order to reproduce this behavior, a function has been defined to introduce in the simulation model to modify the entries to the waiting list (from ‘Non Expressed Need 1st

Surgery' or from 'Non Expressed Need 2nd Surgery'). The function (ϕ in equation 2.18) starts to be active when a maximum value for the number of patients on the waiting list is reached (Max_{WL} in equation 2.18). This maximum is defined as a percentage over the starting number of patients in the waiting list ($N_{WL}(t=0)$ in equation 2.18. For example, if the maximum permitted is a 15% more of the initial contents, and the initial contents were 19,586, then the self-regulation of the waiting list will start when its volume exceeds 22,524 patients. The formula used to reduce the entries to the waiting list is shown in equation (2.18).

$$\phi(N_{WL}(t=0), Max_{WL}) = \frac{1}{\sqrt{N_{WL}(t=0) - Max_{WL} + 1}} \qquad (2.18)$$

To assign a priority score, the empirical distributions of CATHAR's pilot test data were used, stratifying by type of patient (bilateral, aphakic). In order to account for correlations between the priority scores of the first and second surgery of the same patient, the priority score for the second surgery of bilateral cases was calculated as a function of the priority score of the first surgery plus a random value sampled from a normal distribution (equation 2.19).

$$PS_2 = \rho * PS_1 + e_i \qquad (2.19)$$

Where $e_i \sim N(\mu,\sigma)$ and ρ can be interpreted as the correlation we want the two priority scores to have. Obviously, scores resulting in values higher than 100 will be assigned a value of 100.

Disease progression

- ✓ Sources of information: Comparison of CATHAR's priority score of patients included in the waiting lists of Hospital de l'Esperança for cataract surgery: assessments at entering the waiting list and after a period of waiting between 3 and 9 months.
- ✓ Methods: The difference in priority score was modeled through time in order to detect the speed of increase in priority.

2.2.2.3: Results of parameter estimation

Initialization

Population distribution

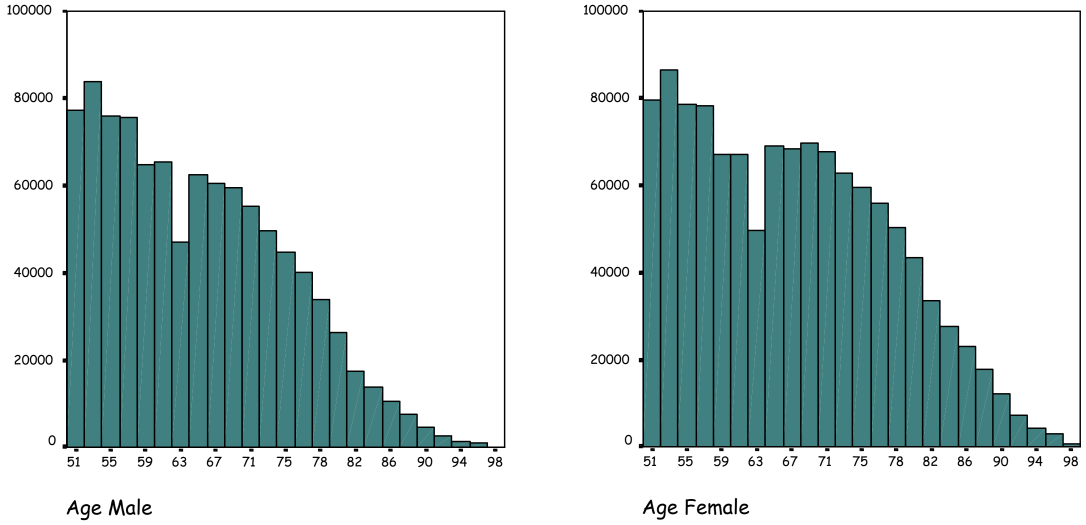
Although it is not used in the simulation model, we should take a look at the distribution according to age and sex of the Catalan population, which would be the general population of the conceptual model (table 2.1 and figure 2.7).

Table 2.1: Distribution of Catalan population 50 years or older, by sex (year 2001).

	N	%
Male	981,432	45.3
Female	1,183,030	54.7
Total	2,164,462	100

Population 50 years or older represents 2,164,462 people, a 34.12% of the total population (6,343,110 inhabitants).

Figure 2.5: Histogram of age by sex, population 50 years or older, Catalonia 2001.



The shift that appears in both graphics (figure 2.5) corresponds to the effect of the Civil War (1936-39).

Disease prevalence

The **North London Eye Study (NLES)** is a population based, cross sectional study of prevalence of serious eye disease and visual impairment in a North London population. It consisted in a random sample of 1,547 people aged 65 or older drawn from a defined population registered with 17 general practice groups[10,67].

People were classified as having need for surgery when visual acuity in one eye or both was equal or poorer than 6/12 and the impairment was attributable to lens opacity.

Table 2.2: Prevalence of need for cataract surgery by age and sex, NLES.

	Prevalence of Need (%)	
Age	**Male**	**Female**
65-69	14.45	16.43
70-74	25.56	28.57
75-79	36.62	44.62
80-84	42.86	65.41
>=85	62.75	60.50

Prevalence was divided into the following groups ●= cataractous eye; ○ = non cataractous eye, and ⊕ = aphakic (or operated) eye:

- Cases needing cataract surgery:
  - ✓ Bilateral cataracts: ●● (includes ●○ cases, 9.8% of total NLES sample).
  - ✓ Unilateral aphakic: ●⊕ (includes ○⊕ cases, 1.8% of total NLES sample).
- Cases not needing cataract surgery:
  - ✓ No cataract: ○○
  - ✓ Bilateral aphakic: ⊕⊕

Table 2.3: Prevalence by age, sex and group of need, NLES.

MALE

	Need		No Need	
AGE	**Bilateral**	**Unilateral**	**No cataract***	**Bilateral Aphakic**
65-69	11,56	2,89	82,08	3,47
70-74	23,33	2,22	71,11	3,33
75-79	30,28	6,34	56,34	7,04
80-84	36,36	6,49	48,05	9,09
85-100	52,94	9,80	33,33	3,92

FEMALE

	Need		No Need	
AGE	**Bilateral**	**Unilateral**	**No cataract***	**Bilateral Aphakic**
65-69	12,68	3,76	80,75	2,82
70-74	24,37	4,20	69,75	1,68
75-79	39,49	5,13	50,26	5,13
80-84	59,12	6,29	28,30	6,29
85-100	48,74	11,76	21,85	17,65

*: means no indication criteria

Each row represents a probability mass function conditioned to age group and sex (it sums up to 100%).

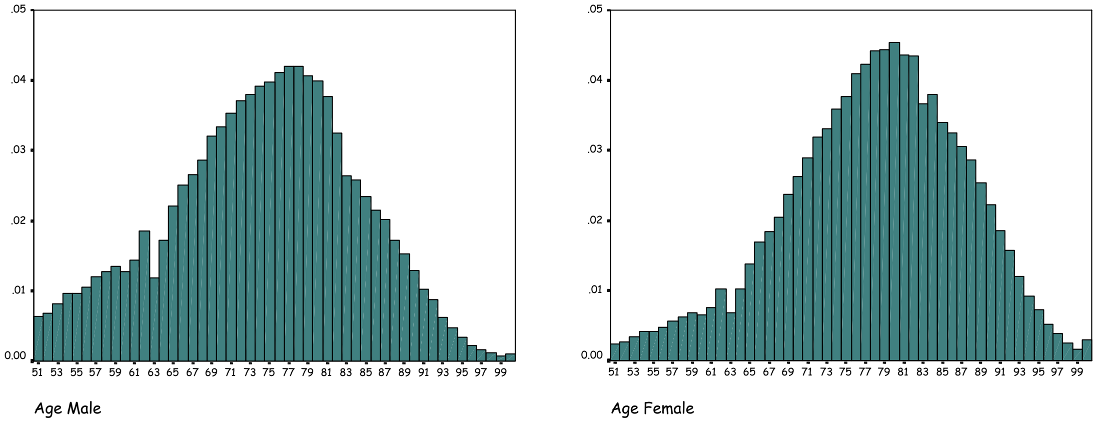
Age and sex distribution

Counts according to age and sex of the Catalan population were obtained from the census of Catalonia in the year 2001. Prevalence was projected to the population of Catalonia (through equation 2.1) and the distributions of sex and age conditioned on sex for prevalent cases were obtained from these projections. Table 2.4 shows the distribution of sex and figure 2.6 shows the distribution of age by sex.

Table 2.4: Distribution of prevalent cases, by sex (projected on Catalan population, year 2001).

	N	%
Male	192,137	38.1
Female	312,733	61.9
Total	504,870	100

Figure 2.6: Age distribution of projected prevalent cases, by sex.



Like in figure 2.5, the effect of the Civil War (1936-39) was observed.

Non expressed need

In order to calculate the number of prevalent cases classified as 'Non Expressed Need', information from two different populations was combined. Basically, our purpose was to estimate the number of prevalent cases included in 'Non Expressed Need' by subtracting the number of cases in the waiting list (people who has demanded surgery) from the number of cases with need for surgery, that is, prevalent cases (equation 2.2).

Projections of bilateral and aphakic cases were obtained through NLES proportions. They were applied, according to age and sex, to the 2,164,462 Catalan people aged 50 years or older. Available data on cases within the waiting lists does not include whether they are waiting for first or for second-eye surgery, thus, the proportions observed in CAHTAR's pilot study (table 2.13) will be applied to the total number in the waiting list. The resulting numbers are shown in table 2.5.

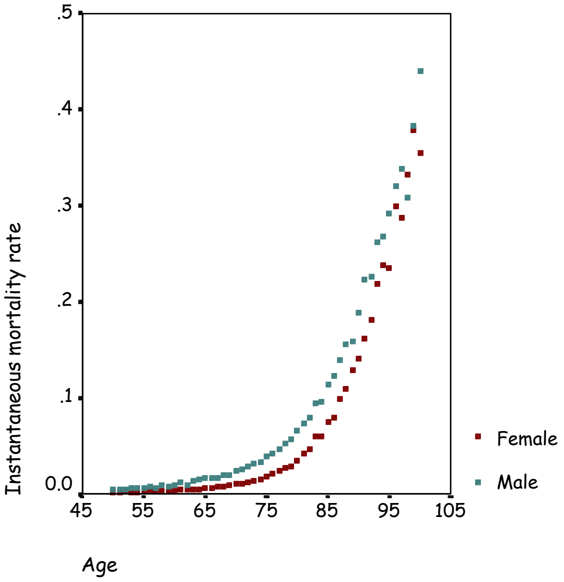
Table 2.5: Initial numbers of cases classified as 'Non Expressed Need'.

	1st Surgery	2nd Surgery	Total	% over total population
Projected prevalent cases	334,244	85,679	419,923	19.4%
- Cases in the waiting list	15,492	4,094	19,586	0.9%
Non Expressed Need cases	**318,752**	**81,585**	400,337	18.5%

Life expectancy

Figure 2.7 shows the exponential increase of the mortality rate through ages 50 or older, by sex.

Figure 2.7: Mortality rate by age and sex, Catalonia 2001.



Different models by sex were estimated according to the Gompertz function of equation 2.3. The estimated coefficients by sex are shown in table 2.6. Goodness of fit is clearly seen in figure 2.8.

Table 2.6: Coefficients for the Gompertz models for the instantaneous mortality rate.

MALE

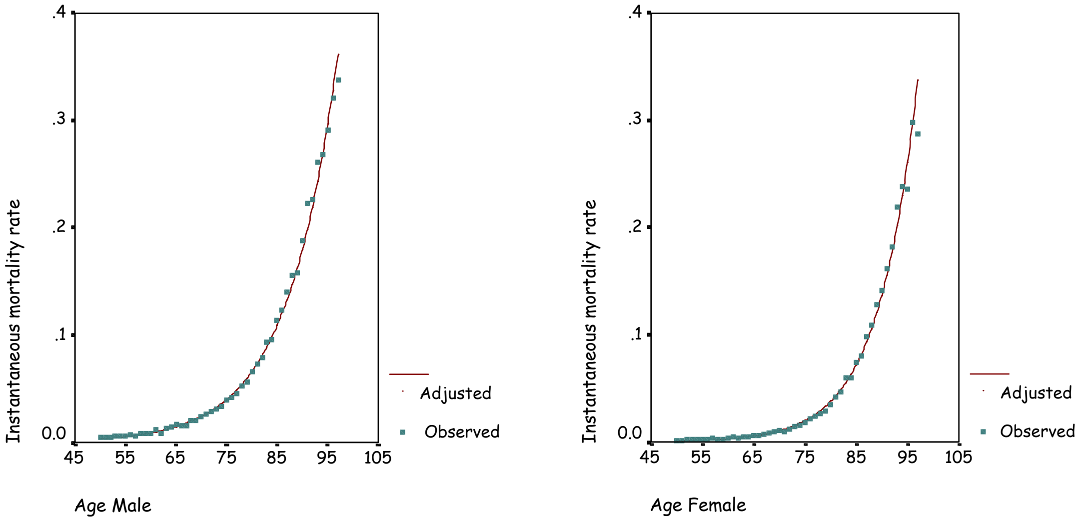
	Coefficient (SE*)	**95%C.I.**
α	0.000018286 (0.00000151633)	[0.000015234; 0.000021338]
β	0.102374095 (0.000968446)	[0.100424715; 0.104323475]
R^2	99.6%	

FEMALE

	Coefficient (SE*)	**95%C.I.**
α	0.00000124309 (0.000000193852)	[0.000000852883; 0.00000163329]
β	0.129010243 (0.001737254)	[0.125513332; 0.132507153]
R^2	98.8%	

*: Asymptotic Standard Error (Levenberg-Marquardt estimation method).

Figure 2.8: Observed and adjusted instantaneous mortality rate by age and gender, Catalonia 2001.



The estimated coefficients of the Gompertz functions were used in equation 2.7 to obtain an approximate density function for each simulated individual conditioned on his/her age and sex.

Disease incidence

Due to the irreversibility assumption, prevalence was modified to include aphakic cases. Incidences in table 2.7 were calculated using equation 2.8.

Table 2.7: Prevalence and five-year incidence of need for cataract surgery by age and sex, NLES.

	Male		Female	
Age	Prevalence (%)	Incidence (%)	Prevalence (%)	Incidence (%)
65-69	17.92	13.36	19.25	13.63
70-74	28.89	20.77	30.25	27.95
75-79	43.66	14.71	49.74	43.69
80-84	51.95	30.63	71.70	22.80
85+	66.67		78.15	

*: Prevalence calculated as visual impairment due to cataracts with VA equal to 6/12 or worse or previous surgery in almost one eye.

The resulting five-year incidences were not monotonically increasing through age, which is an effect of the age grouping. To avoid this, we planned to calculate incidence through observed prevalence for each year of age. But observed prevalence was not increasing monotone through age, which would result in negative yearly incidences for some particular cases. We fitted a model to smooth observed prevalence in order to calculate incidence from the predicted values. The ‘natural’ model to fit prevalence of age-related diseases is the logistic model[68].

We faced two main problems with the calculations:

- The small sample size for older ages, especially for those over 80 years, led to an excess of uncertainty in the incidence estimation.
- In the North London Eye Study there was no available data for people younger than 65, therefore, we had to estimate their prevalence by extrapolation of the fitted model (with the subsequent uncertainty) and we validated it through bibliographic review of other prevalence studies[69].

In order to reduce variability for the incidence calculation, people of 87 years or older were grouped. This seemed to be a logical grouping since the fitted model is similar to that fitted by grouping at 90 years or older and uncertainty reduced substantially.

The fitted model parameters and the graphics of the observed and adjusted values are shown in table 2.8 and figure 2.9, respectively. The models show a good fit with the Hosmer-Lemeshow goodness of fit test (table 2.8). The model has been extrapolated in the intervals from 50 to 64 years and from 87 to 100 years (figure 2.9).

Table 2.8: Adjusted logistic model parameters for prevalence by age and sex, NLES.

MALE

Parameter	Coefficient (Standard Error)	95% Confidence Interval
Intercept	-8.92348 (1.07914)	[-11.038601; -6.808355]
Age	0.11121 (0.01432)	[0.0831372; 0.139277]

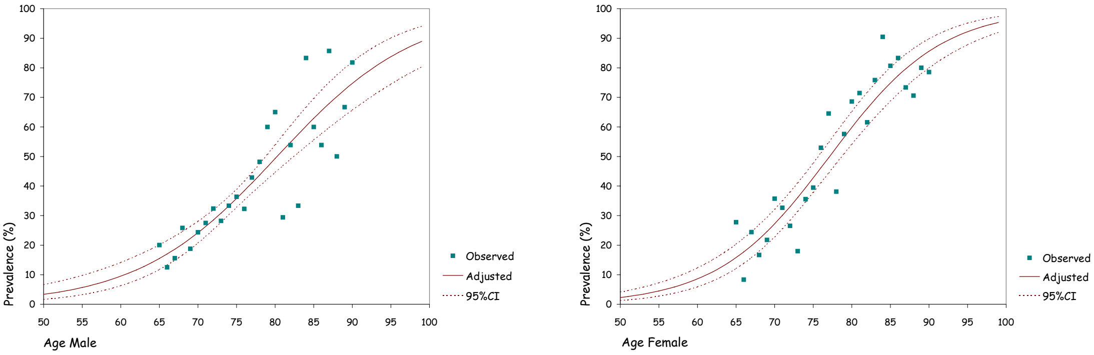
Hosmer-Lemeshow test: Chi-square=1.755; degrees of freedom=7; p_value=0.972.

FEMALE

Parameter	Coefficient (Standard Error)	95% Confidence Interval
Intercept	-10.65621 (0.88559)	[-12.39197; -8.920457]
Age	0.13818 (0.01166)	[0.115327; 0.161033]

Hosmer-Lemeshow test: Chi-square=13.23; degrees of freedom=8; p_value=0.104.

Figure 2.9: Observed and estimated prevalence of need of cataract surgery by age and sex, NLES.

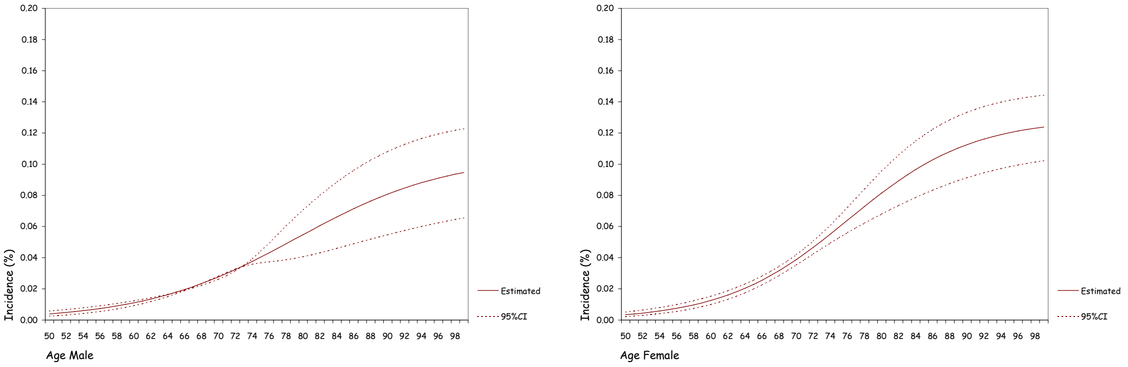


We adapted Podgor and Leske formula (equation 2.8) to one-year intervals to estimate the yearly incidence:

$$I_i = \frac{P_{i+1} - P_i}{1 - P_i}, \qquad (2.20)$$

Where I_i is the cumulated incidence for a given age i, P_i is the estimated prevalence associated with age i and P_{i+1} is the estimated prevalence for the next age group, which is i+1. We obtained the 95% confidence interval for incidence by applying equation 2.20 to the 95% confidence interval of the prevalence estimation shown in figure 2.9. The distribution of the number of incident individuals and its 95% confidence interval by age and sex is shown in figure 2.10.

Figure 2.10: Estimated yearly incidence of need for cataract surgery and 95% Confidence Interval by age and sex (NLES).



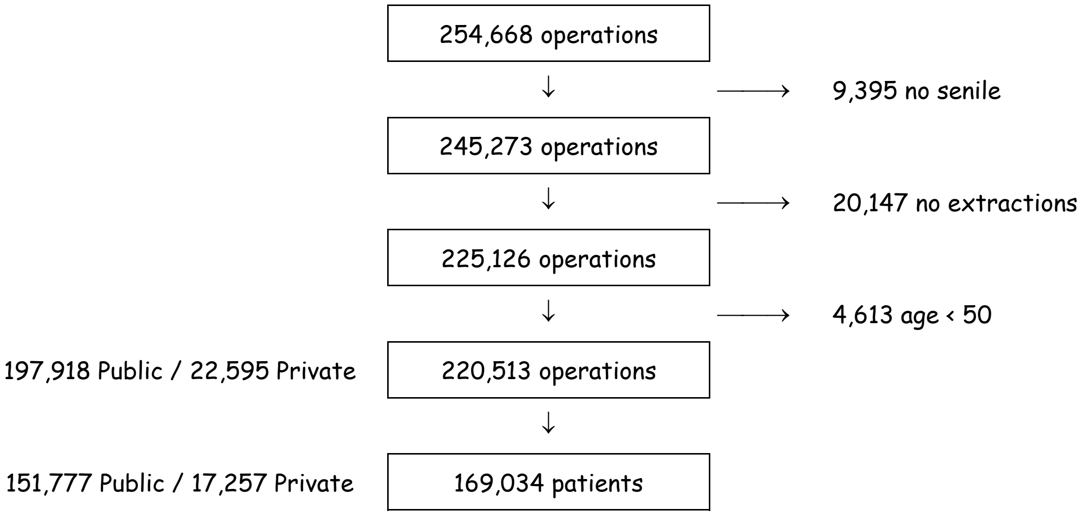
In order to calculate the average number of incident cases per month, the incidence by age and sex was projected into the Catalan population and it was divided by 12. This added up to

5,695.0433 incident cases per month. Thus, the parameter of the exponential distribution for the interarrival times of equation 2.9 was 1/5,695.0433. By projecting the confidence limits to the population, we obtained a 95% confidence interval for incidence from 4,610.3423 to 6,293.1234.

Surgery rates

In order to select registries of cataract surgeries in the Minimum Data Set, the procedures selected were ICD9-MC codes from 13.1 to 13.9 (intracapsular and extracapsular lens extraction, intraocular lens insertion and other). From these registries a new subset were selected according to a diagnosis of senile cataract (diagnosis codes from 366.10 to 366.19, 366.8 and 366.9). In order to exclude secondary insertions of intraocular lens, only those presenting an extraction (procedure codes from 13.1 to 13.59) were selected. This resulted in 225,126 registries, or interventions, from 1999 to 2003. Of these interventions, 4,613 (2.1%) corresponded to patients younger than 50 years. The 220,513 interventions of patients of 50 years or older represented (aggregating by clinical history number, hospital code, sex and area) 169,034 patients.

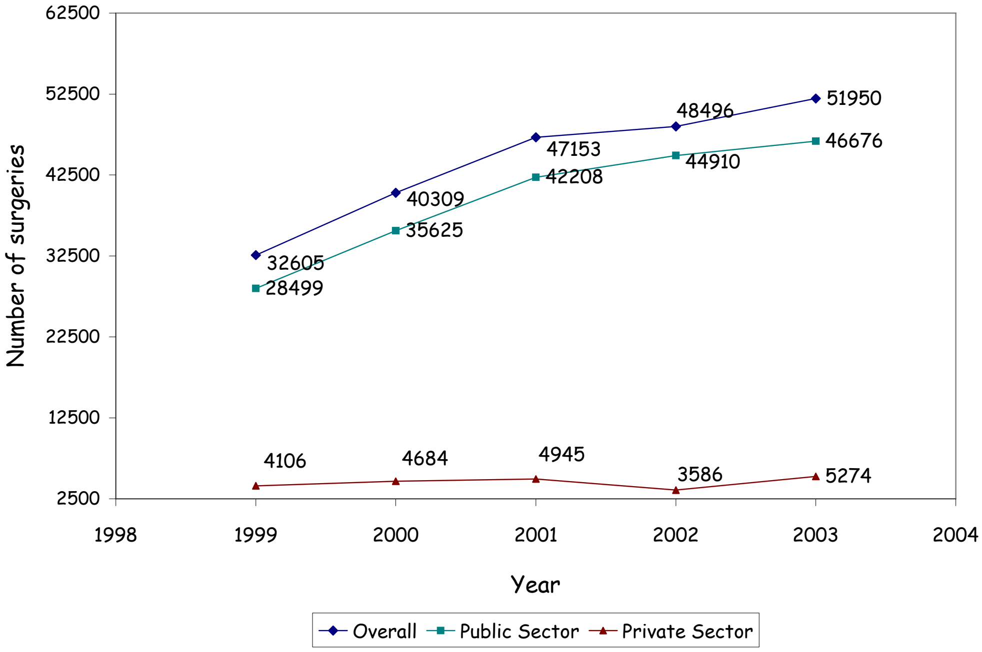
Figure 2.11: Flow chart of the selection of cases of cataract surgery, CMBD/AH Catalonia 1999-2003.



Number of cataract surgeries

Figure 2.12 shows a logarithmic-increasing tendency through time of the number of cataract extractions in the public sector and overall: there is a strong increase between 1999 and 2001 and a less marked, but still increasing tendency after 2001. No tendency was observed in the number of interventions in the private sector.

Figure 2.12: Number of cataract extractions (age≥50) overall and by sector (public/private), CMBD/AH, Catalonia, 1999-2003.



In order to have a model to forecast the monthly number of interventions, a logarithmic model (equation 2.12) was fitted to monthly data (figure 2.13). Although data show a clear seasonality, it won't be taken into account in the model because it is not within the objectives of the study. The moderate R^2 value of the model in table 2.9 may be due to not adjusting for seasonality.

Figure 2.13: Observed data and adjusted model for the number of cataract extractions per month, CMBD/AH, Catalonia, 1999-2003.

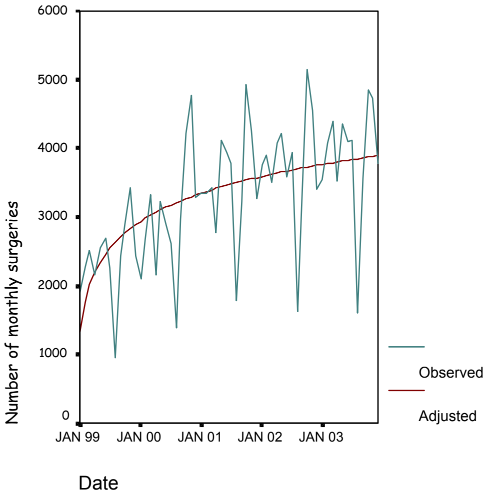


Table 2.9: Estimated parameters of the logarithmic model (equation 2.12) for the monthly number of cataract surgeries, CMBD/AH, Catalonia, 1999-2003.

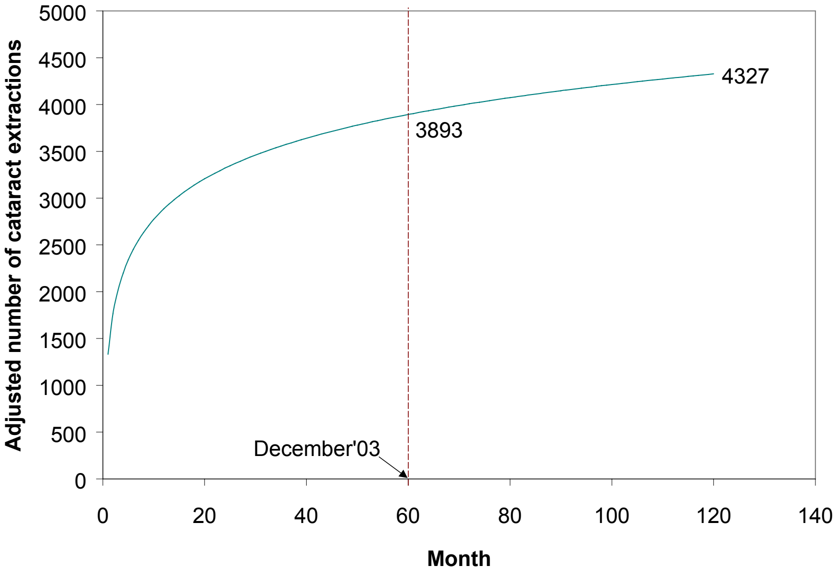
Parameter	Estimate	Standard Error	95% Confidence Interval
β_{0S}	1331.27	371.47	[587.69; 2074.86]
β_{1S}	625.78	113.66	[398.26; 853.30]
R^2	34.3%		

Thus, the model for the parameter of the exponential distribution for the time between successive surgeries in the public sector (equation 2.10) was:

$$N_S(t) = 1{,}331.27 + 625.78\, ln(60+t) \qquad (2.21)$$

Time starts at 60 because it takes into account the tendency from December 2003 onwards. Figure 2.14 shows the predicted values for the years 1999 to 2003 (first 60 months) and for the following 5 years. The predicted number of interventions for the first month after December 2003 and five years after are shown in figure 2.14.

Figure 2.14: Predicted number of interventions before and after December 2003.



As no tendency was observed in the private sector (figure 2.12), the mean number of surgeries per month was calculated using the information of the last three available years (2001-03), resulting in a mean of 383.47 surgeries per month (standard deviation of 37.17 and 95%CI from 341.41 to 425.54). Then, the parameter for equation 2.11 (density of an exponential distribution for the time between surgeries in the private sector) was 1/383.47 for the private sector.

Access to the private sector should be divided between patients coming from 'Non Expressed Need 1st surgery' and from 'Waiting List' (figure 2.4). According to reasons for leaving the waiting list obtained from patients included in CAHTAR's pilot test, a 1.2% of patients included in the waiting list during 10 months left the waiting list to switch to the private sector. Thus, a 0.12% per month can be considered. If the waiting list includes 19,586 patients, a 0.12% represents 23.5 patients. Knowing that 383.47 surgeries are performed in the private sector, a 6.13% (23.5/383.47) will be assumed to come from the public sector waiting list.

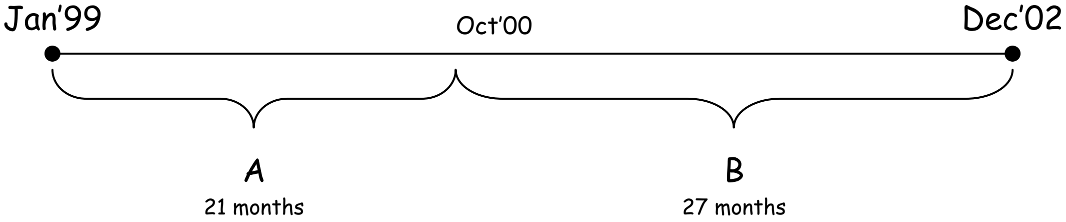
Probability of second-eye surgery

In order to calculate the probability of second-eye surgery, first and second surgeries included in the Minimum Data Set should be identified. Some hospitals with a high volume of cataract surgery changed the identifiers of their clinical records in 2003, thus, we could only match cases from 1999 to 2002 in order to look for bilateral surgeries. The resulting number of interventions was 151,009.

Surgeries of duplicate patients were labeled as first or second, depending on the discharge date. For patients with more than 2 occurrences (195 had 3 and 7 had 4 occurrences), only the first and the last intervention were considered.

For patients with one surgery only, a threshold of 21 months was considered to differentiate first from second surgeries because a 95% of the cases that had two surgeries between 1999 and 2002 had second surgery within 21 months after the first one. Moreover, during 1999 and 2000 the average waiting time for cataract surgery in the public sector was 2 years.

Figure 2.15: Identification of first- and second-eye surgeries.



Cases in period A were only used to label the corresponding second surgeries of period B. Unilateral cases of period B were considered as first surgeries.

The probability of second-eye surgery (event 'Demand 2^{nd} surgery' in figure 2.4) was calculated using equation 2.13 upon the proportion of second-eye surgeries in period B (Oct'00 – Dec'02). Of 98,047 surgeries, 29,507 were second surgeries, thus, the proportion was 30.1% and the probability of second-eye surgery was 43.1%. A description of the calculation of the proportion of second-eye surgeries is included in appendix 2.2[66].

Like the number of surgeries, the probability of second-eye surgery has increased in the last years, and it is expected to increase in the following years (see discussion in appendix 2.2). In order to estimate the tendency through time, the probability of second-eye surgery was calculated for each of the 27 months of period B (figure 2.16). A logarithmic model (equation 2.14) was fitted to the probability of second-eye surgery. The estimates are shown in table 2.10.

Figure 2.16: Observed and adjusted values for the probability of second-eye surgery (source: CMBD/AH, Catalonia 1999-2002).

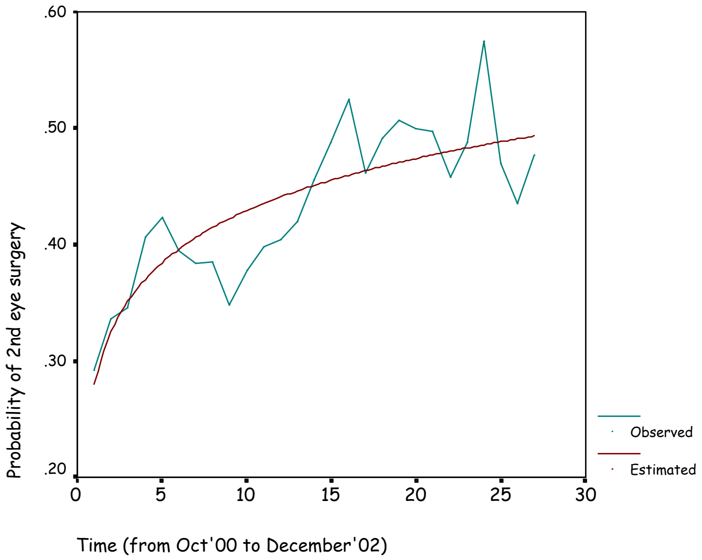


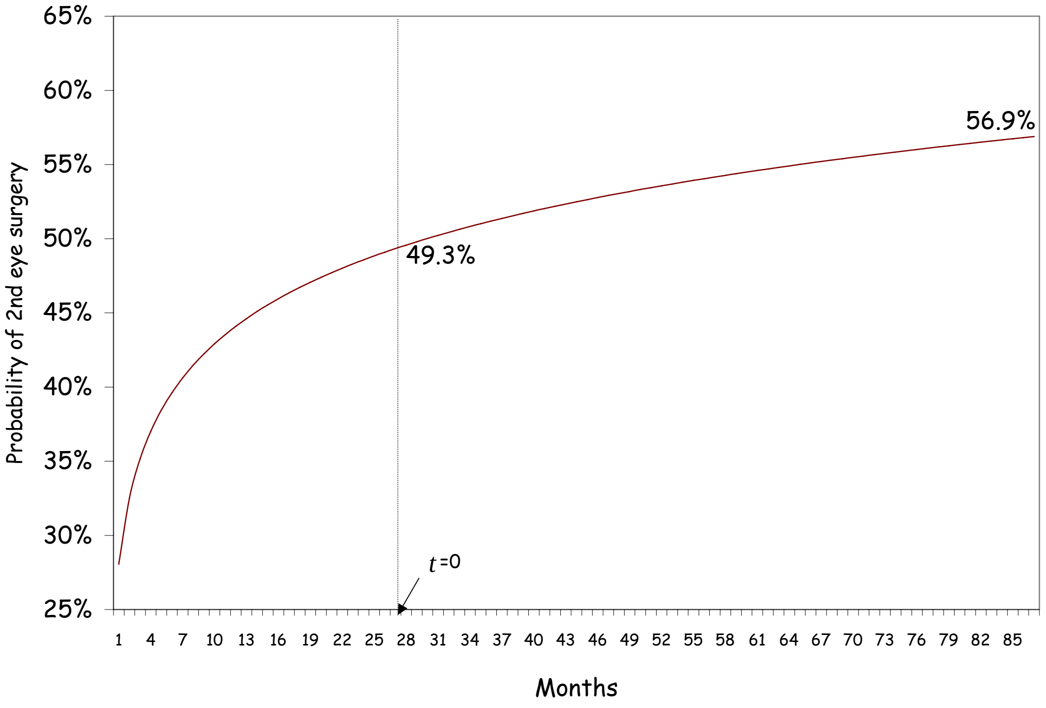
Table 2.10: Estimates of the coefficients for the logarithmic model for the probability of second-eye surgery (equation 2.14).

Parameter	Estimate	Standard Error	95% Confidence Interval
β_{0p}	0.2805135	0.022499411	[0.2341751; 0.32685194]
β_{1p}	0.0645725	0.00889473	[0.0462534; 0.0828916]
R^2	66.5%		

The projected 5-year probability of second-eye surgery ranged from 48.5% at time zero to 51.3% at the end of the 5 years (figure 2.17). The formula for the parameter of the Bernouilli distribution for the probability of undergoing second-eye surgery was the following:

$$p(t) = 0.2805135 + 0.0645725 * ln(27+t).$$

Figure 2.17: Logarithmic-increasing function for the probability of second-eye surgery. Predicted values for a 5-year horizon.



Inclusion in the waiting list

The average number of patients entering the register of waiting lists (year 2003) per month was 3,459.83 (standard deviation of 802.7). The number of patients included in the register of waiting lists in December 2003 was 3,872. Knowing that a 32% of the interventions were performed on the second-eye (on December'02, data from CMBD Catalonia, 1999-2002), the number of patients included in the waiting list for their first surgery are:

$$N_E(t=0) = (1-0.32)*3{,}872 = 2{,}632.96.$$

Thus, following equation 2.17:

$$d = 3{,}893.445 - 2{,}632.96 = 1{,}260.485;$$

and, taking lag=1:

$$N_E(t) = (1{,}331.27-1{,}260.485) + 625.78 ln(60+t-1) = N_S(60+t-1) - 1{,}260.485.$$

Self-regulation of the waiting list

The maximum waiting list volume permitted was set to be a 15% more than the initial waiting list contents: Max_{WL} =1.15 $N_{WL}(t=0)$ = 1.15 * 19,586 = 22,523.9.

The resulting reductions in the waiting list are shown in table 2.11. The reader may think that reducing the entries by steps of only one patient is little relevant given the volume of the waiting list, however, the numbers to be entered in the model are so big that a smaller proportion should be simulated. Then, the steps to update the reducing factor will translate into the inverse of the proportion that is being simulated. For example, if we simulate a 1% of the Catalan population in need for surgery, the steps will represent 100 patients of the real waiting list.

Table 2.11: Reduction factor and percentage of reduction according to number of patients exceeding the maximum permitted for the waiting list.

Number of patients exceeding maximum permitted	Reduction factor (ϕ)	%reduction
Maximum permitted	100%	0%
+1	71%	29%
+2	58%	42%
+3	50%	50%
+4	45%	55%
+5	41%	59%
+6	38%	62%
+7	35%	65%
+8	33%	67%
+9	32%	68%
+10	30%	70%
+11	29%	71%
+12	28%	72%
+13	27%	73%
+14	26%	74%
+15	25%	75%

Priority score distribution

The priority score includes clinical, functional and social criteria, but not age or sex of the patient. Thus, the distribution of the priority score at inclusion on the waiting list was assumed to not depend on age[70] or sex. However, we should take into account whether the patient is waiting for first or for second-eye surgery, because patients waiting for second-eye surgery are expected to have a lower score (less priority). The ‘type’ of patient will be used to control if patients are waiting for first-eye surgery (bilateral patients) or for second-eye surgery (aphakic patients).

Table 2.12: Distribution (%) at inclusion on a waiting list according to 'type' of patient, CAHTAR's pilot test.

	MALE		FEMALE	
AGE	Bilateral	Aphakic	Bilateral	Aphakic
50-64	88.10	11.90	74.19	25.81
65-69	79.63	20.37	80.33	19.67
70-74	71.95	28.05	85.59	14.41
75-79	77.91	22.09	84.85	15.15
80-84	74.14	25.86	72.03	27.97
85+	75.00	25.00	79.49	20.51

Results on the proportion of aphakic cases in the waiting list didn't show a tendency to be taken into account either by age (Chi-square, p=0.295) or sex (Fisher's Exact Test, p=0.272). Thus, the proportions (overall) to be considered are included in table 2.13. A Bernouilli distribution with parameter equal to 0.209 will be used to assign 'aphakic' to the attribute 'type' of patients included on the initial state of the waiting list

Table 2.13: Proportion of bilateral and aphakic cases in the waiting list, CAHTAR's pilot test.

	N	%
Bilateral	699	79.1%
Aphakic	185	20.9%
Total	884	100%

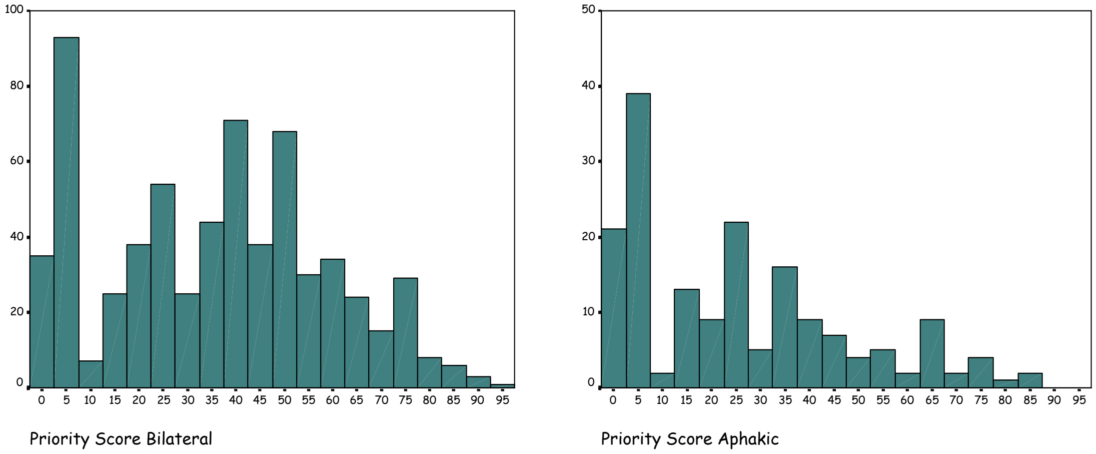
As bilateral cataract patients have a statistically significant higher priority score (table 2.14), the empirical distributions of priority score by 'type' of patient were estimated (figure 2.18).

Table 2.14: Priority score according to 'type' of patient, CAHTAR's pilot test.

	N	Mean	Median	Standard deviation	Minimum	Maximum
Bilateral	699	36.49	39	22.82	0	93
Aphakic	185	26.06	26	22.17	0	87
Total	884	34.30	35	23.07	0	93

Mann Whitney's test: p<0.001

Figure 2.18: Priority score distribution according to type of patient (bilateral, aphakic), CAHTAR's pilot test.



The priority score will be treated as a discrete distribution, as it is a result from a combination of 6 criteria that may take 2, 3 or 4 different scores (according to levels of criteria, see appendix 1.1).

For patients in the initial state, no previous prioritization was assumed, that is, they were assigned the priority score from the same distribution as cases entering the waiting list. This means that the possible increase in priority score due to the time spent waiting will not be taken into account for the backlog cases. Moreover, the waiting time of these cases will be truncated. Because of these two reasons, the initial cases in the waiting list backlog will not be used for calculating results related to priority scores and waiting time.

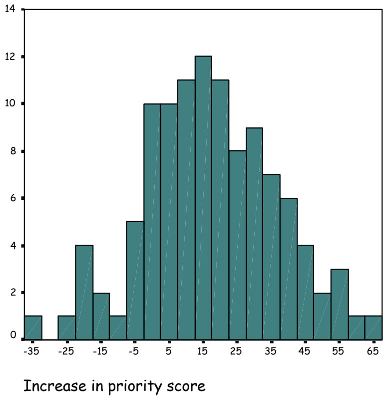
To simulate priority scores for second eyes (equation 2.19), a Normal distribution with parameters μ=7 and σ=15 was used. The correlation for the two priority scores was chosen to be ρ = 0.55. However, as the priority score for second-eye surgery shows a clear bimodality (figure 2.18), the resulting second-eye priority distribution was similar to the empirical one for values over 27 points only. Then, when the resulting value for the second-eye priority was lower than 27 points, a new value was sampled from the distribution taking into account only the subset of values lower than 27.

Disease progression

The progression of cataracts should be taken into account to update the priority score while patients are waiting in the waiting list. In order to study which factors influence the increase in the priority score through time, a second assessment of the priority score was performed in a subgroup (n=114) of patients of Hospital de l'Esperança who were included in CAHTAR's pilot test.

Several models were tested to model the increase in priority score through time. However, no clear association pattern was found, although a statistically significant (Mann-Whitney's test, $p<0.001$) increase of 17.39 points (SD 19.78) in the mean priority score was observed after a mean of 7.0758 months (SD 1.4412).

Figure 2.19: Increase in priority score after a mean waiting of 7 months.



The priority score was updated by 17.4/7=2.5 points, each month after inclusion in the waiting list and until surgery. We could assign the increase according to its empirical distribution (figure 2.19), it would, however, have conceptual problems. Increasing differently the priority score would compromise equity if we do not include revisions each month in the model. According to the current health system, including revision visits each month for the patients in the waiting list would be clearly unfeasible because of resources and budget constraints. Thus, it is better to consider the increase in the priority score to be a function to be applied automatically to all patients in the waiting list.

2.3: Techniques

2.3.1: General comments on the simulation model

Once the conceptual model and its parameter estimations were validated, they were implemented as a discrete-event simulation model.

The units of time were months and the time horizon 60 months (5 years). A five-year horizon was long enough to see how the system evolved without compromising the correctness of the estimations that aren't changed through the time horizon. No explicit warm-up period was considered, however, the cases of the initial waiting list backlog weren't used for results calculations, as their values of waiting time were left-truncated.

Although it was a continuous-time model, some changes were applied discretely at certain time intervals. That is, the updates of the dynamic inputs (number of surgeries, number of entries to the waiting list and probability of second-eye surgery) were done at the beginning of every month.

The software used was SIMUL8 Release 10 standard edition (SIMUL8 Corporation, http://www.simul8.com).

2.3.2: Model implementation

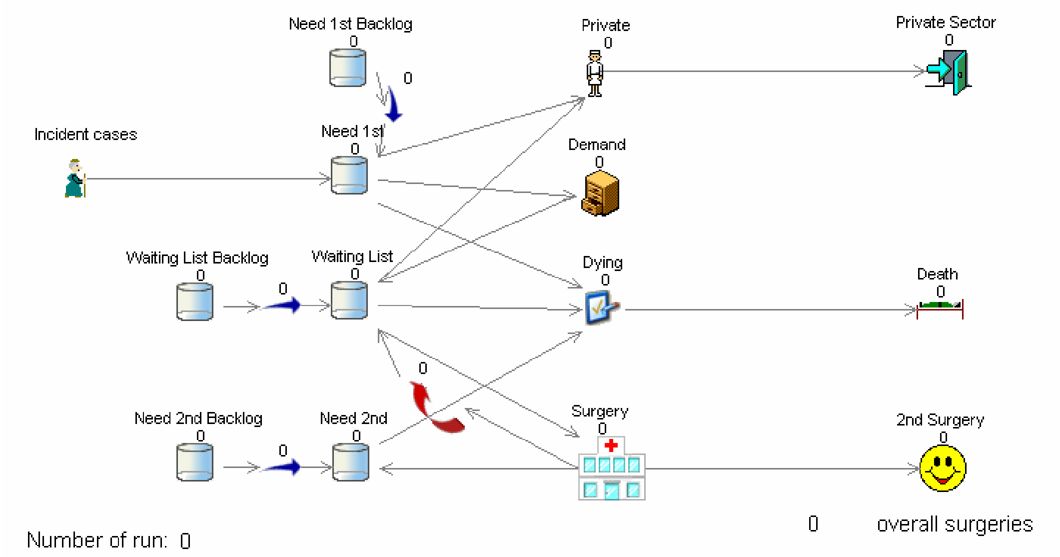
'No Need' was implemented as a generator of incident cases ('work entry point', in SIMUL8 nomenclature). Thus, all the entities of the model ('work items' in SIMUL8 nomenclature) will be patients (with need for surgery), that is, the age and sex structure of the simulated cases should follow that of the prevalent cases.

The pools of patients in 'Non Expressed Need' and 'Waiting List' were implemented as queues ('storage bins' in SIMUL8 nomenclature), although the only ordered queue was the 'Waiting List' (ordered by waiting time (in FIFO discipline) or priority score).

The events of the simulation are implemented within simulation objects called 'work centers' within SIMUL8 nomenclature. These include Visual Logic code to make patients go through the appropriate event. The work center 'Demand' controls the event 'Demand 1st surgery' (figure 2.4); the work center 'Surgery' controls the events '1st surgery', '2nd surgery' and 'Demand 2nd surgery'; 'Dying' controls the event 'Death'; and 'Private' controls the event 'Demand private sector' (figure 2.4).

The exit points 'Dead', 'Private Sector' and 'Operated 2nd surgery' were implemented as the 'work exit points' (in SIMUL8 nomenclature) 'Death', 'Private Sector' and '2nd Surgery', respectively. Figure 2.20 shows the interface of the model in SIMUL8.

Figure 2.20: Model in SIMUL8 for cataract surgery.



Each patient has a set of attributes, called 'labels', which include age, sex, priority for the 1st and the 2nd surgery (when applicable), 'type' of patient (bilateral or aphakic) and life expectancy. The rest of labels are used in programming and for getting results. They are described in more detail in section 4.2.4.

The queues are initialized at the start of each execution with their corresponding number of cases. When a case is generated (during the initialization or as an incident case), it is assigned the label 'Sex' according to the probability profile distribution of sex of prevalent cases (table 2.4). According to the value of 'Sex' assigned, the label 'Age' is generated from probability profile distributions for age of prevalent men and women (figure 2.6). According to age and sex, the time until death is sampled from the appropriate distribution, built for each case according to current age, sex and the parameters of the Gompertz distribution.

The label 'Type' of incident cases and cases from 'Non Expressed Need 1st Surgery' indicates that they are bilateral cases. For cases in 'Non Expressed Need 2nd Surgery' it indicates that they are aphakic. For cases in the 'Waiting List', its value is generated according to the distribution in table 2.13.

The priority scores are generated when a patient enters the waiting list and take into account whether it is bilateral or aphakic.

2.3.2.1: Excel workbook for input and output information

SIMUL8 can be linked to Excel in order to import and export data. For ease of use, the model was connected to an Excel file containing sheets to enter or change inputs (figure 2.21) and other sheets to collect and calculate results (figure 2.22). This made the model more flexible to be spread among other researchers, as they may enter their own data and obtain results without an expert knowledge of the simulation software. Another advantage is that it will allow obtaining results to 'what if?' questions easily.

Figure 2.21: Excel workbook for input and output information: input sheets.

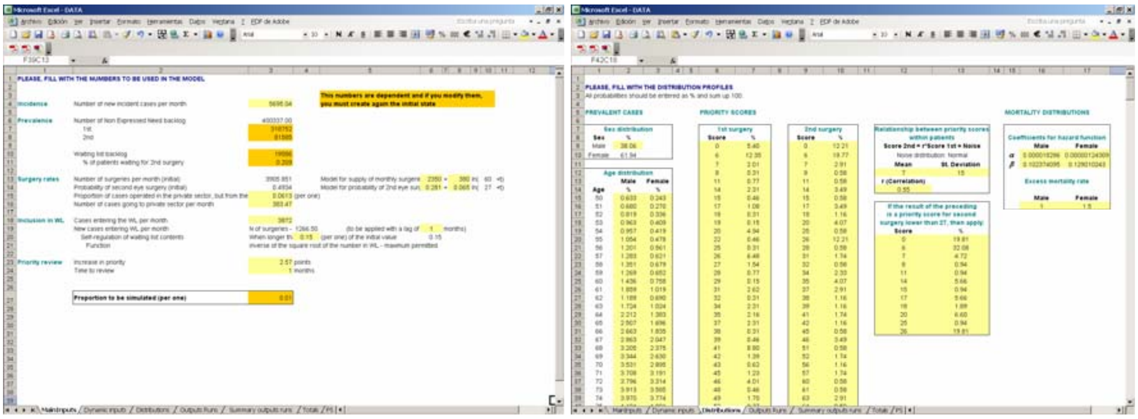
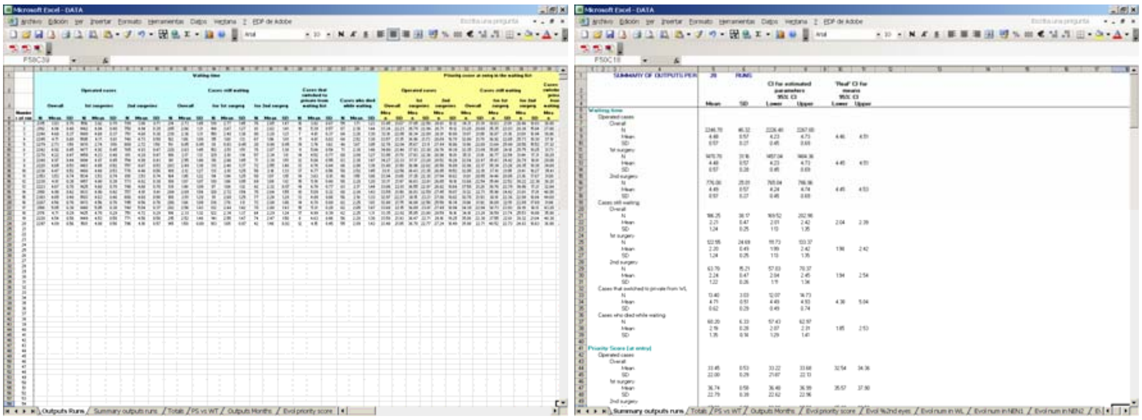


Figure 2.22: Excel workbook for input and output information: some output sheets.



A workbook was created, named DATA.XLS, including several sheets. The sheets are divided in two groups and are named as follows:

- **Inputs**
  - *'MainInputs'*: Includes those input values that are entered as point values: the values for initialization and the coefficients for the models for the dynamic inputs. They are marked in yellow, except for the parameters concerning the initial state, which are marked in orange.
  - *'Dynamic inputs'*: This sheet is informative. No data has to be entered; however, it includes calculus and graphics to show the shape of the dynamic inputs, whose models are entered in the sheet *'MainInputs'*, through a five-year horizon.
  - *'Distributions'*: Includes the probability distributions of the variables: sex, age conditioned on sex, priority score conditioned on type of patient (bilateral or aphakic)

  and the parameters to correlate the priority score of the second surgery with that of the first surgery within the same patient.

- **Outputs**
  - *'Outputs Runs'*: Includes, for every run, results on waiting time, priority score (at entry and at exit of the waiting list), correlation between waiting time and priority score (at entry to the waiting list), priority thresholds for warranty times, summary statistics on occupation of queues, waiting time weighted by priority score (at entry and at exit of the waiting list), waiting time conditioned on levels of priority at entry and exit of the waiting list and percentiles of the waiting time distribution.
  - *'Summary outputs runs'*: This sheet calculates summary statistics (means, standard deviations and confidence intervals) on the outputs collected in the previous sheet.
  - *'PS vs WT'*: This sheet contains a graphic of the thresholds of priority score according to eventual warranty times summarized in the previous sheet. These thresholds meant that all patients with higher priority scores underwent surgery in less than the warranty time.
  - *'Outputs Months'*: Includes outputs collected monthly through the time horizon: mean priority score of the cases in the waiting list, proportion of patients waiting for second-eye surgery and number of cases in the waiting list, in non expressed need for 1st surgery and in non expressed need for 2nd surgery. The total number of patients in need (prevalent cases) is calculated in this sheet.
  - *'Evol priority score'*: Includes a graph of the mean and 95% confidence interval of the priority score of patients that are still waiting at intervals of one month. The priority score is the one at entry to the waiting list. Original data is included in the previous sheet.
  - *'Evol %2nd eyes'*: Includes a graph of the evolution of the proportion of patients waiting for second-eye surgery every month through the simulation time horizon. Data is included in the sheet called *'Outputs Months'*.
  - *'Evol num in WL'*: Graph of the evolution of the number of patients included in the waiting list every month through the simulation time horizon. Data is obtained from the sheet called *'Outputs Months'*.
  - *'Evol num in NEN1'*: Graph of the evolution of the number of patients included in non expressed need for 1st surgery every month through the simulation time horizon. Data is obtained from the sheet called *'Outputs Months'*.
  - *'Evol num in NEN2'*: Graph of the evolution of the number of patients included in non expressed need for 2nd surgery every month through the simulation time horizon. Data is obtained from the sheet called *'Outputs Months'*.
  - *'Evol num in Need'*: Graph of the evolution of the global number of patients included in the queues of the system, that is, number of prevalent cases (in need for surgery) every month through the simulation time horizon. Data is obtained from the sheet called *'Outputs Months'*.

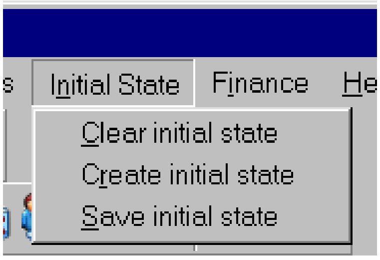
2.3.2.2: System initialization

Early simulations showed that the system was not stationary, as the volume of individuals with need for surgery showed an increasing tendency through the simulation horizon. Moreover, being a problem related to health services utilization, we were interested in analyzing the system within a specified time horizon. According to this, it must be analyzed as a terminating simulation. Thus, the n independent replications to analyze results should begin with the same initial conditions[60].

The initial state is saved in three spreadsheets that will be used to reset each run of the simulation. The three spreadsheets contain the information of the cases to be included in the queues for the initial 'Backlogs'. The spreadsheets names are: *'Initial state Waiting List'*, *'Initial state Need 1st'* and *'Initial state Need 2nd'*.

In order to get a fixed initial state to be used in all replications, a menu was created with the purpose of creating an initial state, with a determined stream of random numbers independent of the random stream used in the replication. The menu 'Initial State' is shown in figure 2.23 and contains 3 dialogs: 'Clear initial state', 'Create initial state' and 'Save initial state'.

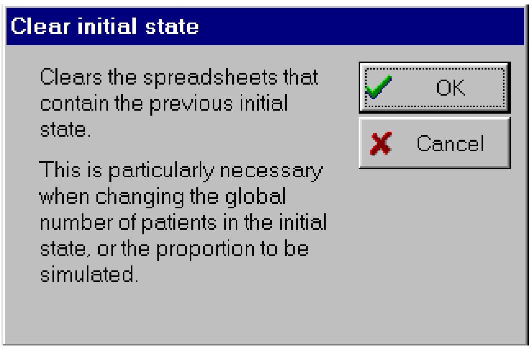
Figure 2.23: Contents of menu 'Initial State'.



The parameters concerning the initial state are marked in orange in the sheet called *'MainInputs'* of the Excel workbook DATA.XLS. In case of changing any of the parameters in orange, the initial state should be generated again by using the three dialogs consecutively.

- *'Clear initial state'*: In order to prevent errors due to the stored information of previous executions initialized with different numbers, the three spreadsheets that contain the initial state should be cleared. See visual logic code in appendix 3.1.1.

Figure 2.24: 'Clear initial state' dialog.



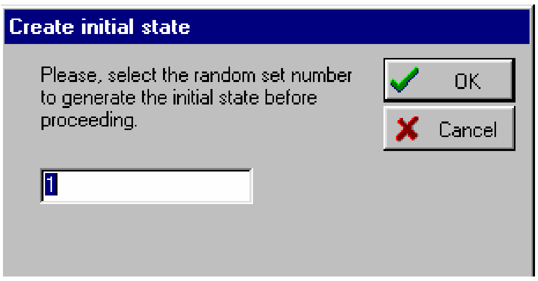
Clear initial state

Clears the spreadsheets that contain the previous initial state.

This is particularly necessary when changing the global number of patients in the initial state, or the proportion to be simulated.

- *'Create initial state'*: Asks the user the number of the random set to be used to generate the initial state (this random set is independent of those, changeable within SIMUL8 menu options, which will be used to run the replications of the simulation). Then, the system is initialized and the contents of the queues are shown in the display (see visual logic code in appendix 3.1.2).

Figure 2.25: 'Create initial state' dialog.



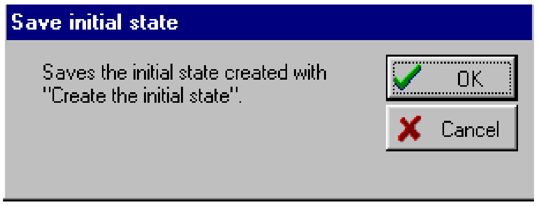
Create initial state

Please, select the random set number to generate the initial state before proceeding.

1

- *'Save initial state'*: Saves the contents of the queues (after creating the initial state) into the three spreadsheets that will be used at the reset of each run of the simulation to collect the characteristics of the patients included in the initial state (see visual logic code in appendix 3.1.3).

Figure 2.26: 'Save initial state' dialog.



Save initial state

Saves the initial state created with "Create the initial state".

The reset code of the model runs differently according to the value of the global data item *'Reset for saving initial state'*. A value of 1 means that the user wants to create an initial state, while a value of 0 means that the user wants to run the simulation using the values already stored in the three spreadsheets of the initial state. See the visual logic code on reset in appendix 3.3.2. This code initializes fixed values and distributions and generates the initial number of patients in the 'backlog' states, assigning them their characteristics, such as age or sex. The random sampling of the distributions involved uses the random stream currently selected.

2.3.2.3: Objects

The model consists of the following objects (the SIMUL8 nomenclature was included within parentheses):

Generators ('work entry points')

- *'Incident cases'*: Is the only generator of new entities of the simulation. It generates incident cases and randomly assigns to the new cases the main labels of the work items (see visual code in appendix 3.2.1). The new cases are automatically routed to the queue *'Need 1st'*.

Queues ('storage bins')

- *'Need 1st Backlog' / 'Waiting list Backlog' / 'Need 2nd Backlog'*: These queues are auxiliary and are used to initialize the system. Patients with the characteristics stored in the spreadsheets *'Initial state Need 1st'*, *'Initial state Waiting List'* and *'Initial state Need 2nd'* are added to this queues on reset (when *'Reset for saving initial state'* equals 0). At time 0, all cases are automatically routed to the queues *'Need 1st' / 'Waiting list' / 'Need 2nd'*.
- *'Need 1st'*: Represents the category 'Non Expressed Need 1st Surgery'. Its cases are collected by the work centers *'Demand'*, *'Private'* and *'Dying'* through the corresponding events. It only receives incident cases from the generator.
- *'Waiting List'*: The changes in the prioritization of the waiting list are applied in this queue. Cases are brought by the work centers *'Demand'* (bilateral cases, event 'Demand 1st surgery') and *'Second'* (aphakic cases from the waiting list, event 'Demand 2nd surgery'), and collected by *'Surgery'*, *'Private'* and *'Dying'* (events '1st surgery' or '2nd surgery', 'Demand private sector' and 'Death', respectively).
- *'Need 2nd'*: Represents the state 'Non Expressed Need 2nd Surgery'. Its cases come from the work center *'Surgery'* (event '1st surgery') and are collected by the work center *'Dying'* only (event 'Death'). The cases that are routed to this queue are not allowed to go back to the waiting list to wait for their second-eye surgery.

'Next event?' nodes ('work centers')

- *'Demand'*: Represents the event 'Demand 1st surgery', that is, the inclusion on a waiting list of bilateral cases (in 'Non Expressed Need 1st Surgery' – *'Need 1st'* queue). For calculations at this stage, such as the assignment of the priority score, see the visual logic code in appendix 3.2.2.

- *'Surgery'*: Represents the event of being scheduled for surgery, called '1st surgery'/'Demand 2nd surgery' for bilateral patients or '2nd surgery' for aphakic patients. This work center picks up cases from the waiting list only, according to the surgery rate. The routing out of this work center depends on the 'type' of the patient. Aphakic cases are routed to *'2nd surgery'* (event '2nd surgery') and bilateral cases are routed back to the waiting list (through the auxiliary work center *'Second'*) if they are assigned to receive second-eye surgery (event 'Demand 2nd surgery'), or, if not, routed to *'Need 2nd'* ('Non Expressed Need 2nd Surgery') through the event '1st surgery'. When the option 'Increase in priority score' is switched on (see section 4.2.6.3), this work center updates the priority scores of the patients in the waiting list before picking up the next one. For calculations, see the visual logic codes in appendix 3.2.3.
- *'Private'*: This work center represents the surgery rate in the private sector. It picks up cases from *'Need 1st'* and *'Waiting list'* (event 'Demand private sector') routes them to the exit point *'Private Sector'* and collects results. For calculations, see the visual logic code in appendix 3.2.4.
- *'Dying'*: This work center picks up the patients that have arrived to their time of death (modeled as expired work items in SIMUL8) from all the queues of the system and collects results. They are routed to the exit point *'Death'* (event 'Death'). For calculations, see the visual logic code in appendix 3.2.5.

Exit points ('work exit points')

- *'2nd Surgery'*: Collects the patients that leave the system because they have received surgery in both eyes. They are routed from the work center *'Surgery'* through the event '2nd surgery'.
- *'Private Sector'*: Collects the patients that leave the system because they have received surgery in the private sector. They are routed from the work center *'Private'* through the event 'Demand private sector'.
- *'Death'*: Collects the patients that leave the system because they have reached their time of death. They are routed from the work center *'Dying'* through the event 'Death'.

2.3.2.4: Entities ('work item types')

Only one type of entity (or 'work item type') is used in this simulation, it is named as *'Patients'* and represented as . The labels attached to every *'patient'* are listed below.

Main labels

- *'Sex'*: The values are 0 for Male and 1 for Female. It is assigned when a new case is created (an incident or backlog case). It is drawn from the distribution *'Sex dist'* and is not modified through the simulation.
- *'Age0'*: The age assigned to the new cases when they are created (initial age). It is drawn from the distributions *'Age Male'* and *'Age Female'* taking into account the value of *'Sex'*.
- *'Age'*: The age of the cases when they leave the system or at the end of the simulation horizon (final age).
- *'Time of death'*: The simulated lifetime of a *'patient'*. It is drawn from a probability distribution, *'Time to Death Female'* or *'Time to Death Male',* that are defined according to the *'Age0'* and *'Sex'* of each patient and the parameters of the Gompertz distributions for male and female.
- *'Type'*: Its values are: 11, 12, 21 and 22. The first digit means Non Expressed Need (1) or Waiting List (2). The second digit means bilateral (1) or aphakic (2). Cases in 'Need 1st' are of type 11, those in 'Need 2nd' are of type 12 and those in 'Waiting List' are of type 21, if they are waiting for first surgery, and of type 22 if they are waiting for second surgery. The label 'Type' is changed according to the events of every patient within the model. Patients in the waiting list backlog are assigned type 21 or 22 according to the probability distribution *'Prob Aphakic WL'*.
- *'PriorityScore1'/'PriorityScore2'*: These labels store the priority score assigned at entry to the waiting list for the first/second surgery of the patient.
- *'Priority score 1 surg'/'Priority score 2 surg'*: These labels store the priority score for the first/second surgery at the moment of leaving the waiting list. They will be different from *'PriorityScore1'/'PriorityScore 2'* if *'Increase in priority score'* is switched on (see section 4.2.6.3) and if the patient has waited more than the time needed to update the priority score.
- *'PriorityScore'*: This label contains the current priority score of the patient.
- *'Backlog need 1st'/'Backlog need 2nd'/'Backlog WL'*: These labels indicate whether the patient was a case included in the initial state and, if so, in which state.

Auxiliary labels

- *'Born'*: For incident cases, indicates the moment of the simulation in which the case was generated.
- *'Entry WL1'/'Entry WL2'*: Stores the moment of the simulation in which the patient entered the waiting list for first/second surgery.
- *'Exit WL1'/'Exit WL2'*: Stores the moment of the simulation in which the patient left the waiting list while waiting for first/second surgery.
- *'Expire time'*: This label is used as *'Shelf life'* in all queues. The work center *'Dying'* picks up only the expired work items. It is recalculated every time a patient moves from one queue to

another. As the *'Shelf life'* utility only takes into account the time that a work item has spent in a determined queue, *'Expire time'* is calculated as *'Time of death'* minus *'Simulation time'* plus the label *'Born'* and is updated every time a patient moves from one queue to another.

- *'Inc Prior 1'*/*'Inc Prior 2'*: These labels are needed in the process of updating the priority score while waiting.
- *'Next transition'*: This label is used for routing out of the work center 'Surgery'.
- *'SecondNoYes'*: This label collects the result of drawing a value from the distribution *'Prob second'*. A value of 1 means that the patient will go back to the waiting list to wait for the second surgery (event 'Demand 2nd surgery'), while a value of zero means a transition to *'Need 2nd'* (event '1st surgery').

2.3.2.5: Distributions

All distributions are initialized before reset (see visual logic code in appendix 3.3.1).

- *'Access Private'*: Bernouilli distribution, defined using a probability profile distribution. The event is that a patient who is operated in the private sector has previously been in the waiting list of the public sector. This distribution is used in the work center 'Private' to choose the storage bin from where the next patient is collected between 'Need 1st' and 'Waiting List'. That is, it chooses to which patient the event 'Demand private sector' should be applied.
- *'Age Female'*/*'Age Male'*: Probability profile distributions defined by the empirical distribution values of age, by sex, of prevalent cases. Their values are picked up from the spreadsheet *'Input distributions'*. They are used when a new case is generated, at initialization, or at *'Incident cases'* (event 'Incidence').
- *'Difference in priorities noise'*: Normal distribution for the noise to be added when correlating the priority score of the second-eye with the priority score of the first-eye of the same patient. Its parameters are picked up before reset from the spreadsheet *'Input distributions'*. This distribution is used when a case is assigned to go back to the waiting list to wait for second-eye surgery (see appendix 3.2.3).
- *'Entries to WL'*: Exponential distribution with parameter equal to the inverse of *'Monthly cases entering the WL'* (see global data items). This is the timing distribution for the work center *'Demand'* (or the event 'Demand 1st surgery').
- *'Incidence rate'*: Exponential distribution with parameter equal to the inverse of *'Monthly Incident cases'* (see global data items). This is the distribution for the inter-arrival times of the cases generated at *'Incident cases'* (or the event 'Incidence').
- *'Priority dist Aphakic'*/*'Priority dist Bilateral'*: Probability profile distributions defined by the empirical distribution values of the priority scores for first surgery (bilateral) and for second

surgery (aphakic). Their values are picked up from the spreadsheet *'Input distributions'* and they are used when a patient enters the waiting list, according to its type (see visual logic codes in appendices 3.2.2 (Demand Action Logic) and 3.2.3 (Surgery Route-In After Logic)).

- *'Priority dist aphakic conditioned'*: The same distribution as *'Priority dist Aphakic'*, but truncated at *'Cut priority score 2'*. This distribution is used when simulating the priority score for second-eye surgery correlated to the score of the first-eye in the same patient.
- *'Private Entries'*: Exponential distribution with parameter equal to the inverse of *'Monthly Private Sector cases'* (see global data items). This is the timing distribution of the work center *'Private'* (for the event 'Demand private sector').
- *'Prob Aphakic WL'*: Bernouilli distribution, defined using a probability profile distribution. The event is that a patient (in the waiting list backlog) is waiting for second-eye surgery. The value of the parameter is picked up from the spreadsheet *'Inputs'*.
- *'Prob Second'*: Bernouilli distribution, defined using a probability profile distribution. The event is that a patient that has had first-eye surgery goes back to the waiting list to wait for second-eye surgery (event 'Demand 2nd surgery'). The value of the parameter is picked up from the spreadsheet *'Inputs'*.
- *'Sex dist'*: Bernouilli distribution, defined using a probability profile distribution. The event is 'woman'. The parameter is picked up from the spreadsheet *'Input distributions'*. It is used when a new case is generated, at initialization, or at *'Incident cases'*.
- *'Surgery rate'*: Exponential distribution with parameter equal to the inverse of *'Supply'* (see global data items). This is the timing distribution of the work center *'Surgery'*.
- *'Time to Death distr'*: These probability profile distribution is created by applying the parameters of the Gompertz function (*'Alfa Male', 'Beta Male', 'Alfa Female', 'Beta Female'*) according to *'Age0'* and *'Sex'* of the current patient, when a new case is generated (at initialization, or at *'Incident cases'*). See appendices 3.3.2 and 3.2.1 for visual logic codes.

2.3.2.6: Information store

Global data items

Main

- *'Alfa Male', 'Alfa Female', 'Beta Male', 'Beta Female'*: These values are read from the spreadsheet *'Inputs'* and correspond to the parameter values of table 2.6 for equation 2.3, according to sex.
- *'Cut priority score 2'*: This value is used to truncate the distribution *'Priority dist Aphakic'* to obtain the distribution *'Priority dist aphakic conditioned'*. This distribution is used when

simulating the priority score for second-eye surgery correlated to the score of the first-eye in the same patient.

- *'Increase in priority'*: Score that has to be added to the priority score when it should be updated. It is picked up on reset from the spreadsheet *'Inputs'*.
- *'Increase in priority on off'*: This variable keeps the option that is set in the menu *Utilities>Increase in priority score* (see additional menus in section 4.2.6.3).
- *'Monthly cases entering the WL'*: This variable stores the mean number of cases entering the waiting list each month. Its initial value is picked up on reset from the spreadsheet *'Inputs'* and it's updated at time checks of one month using the visual logic codes in appendices 3.4 and 3.4.1.
- *'Monthly Incident cases'*: Stores the mean number of incident cases that should be generated monthly. Its value is picked up from the spreadsheet *'Inputs'*.
- *'Monthly Private Sector cases'*: Stores the mean number of cases that should be operated monthly in the private sector. Its value is picked up from the spreadsheet *'Inputs'*.
- *'Need 1st Backlog initial'*/*'Need 2nd Backlog initial'*: Store the initial number of backlog cases in *'Need 1st'* and *'Need 2nd'*. Its value is picked up from the spreadsheet *'Inputs'*.
- *'Number of run'*: Stores the number of the run currently running, or the last that has been run. At the end of the trial, it coincides with the total number of runs.
- *'Proportion'*: Stores the proportion that should be applied to the input numbers in order to reescalate them proportionally, when appropriate. Its value is picked up from the spreadsheet *'Inputs'*.
- *'r priorities'*: Stores the correlation coefficient, picked up from the spreadsheet *'Input distributions'* that will be used to correlate the priority scores of the first and the second surgery of the same patient.
- *'Random set'*: Stores the random stream number for creating the initial state of the simulation. Its value is asked to the user through the menu 'Create initial state' (see section 4.2.2).
- *'Reset for saving initial state'*: This variable is set to 1 through the menu 'Create initial state'. Its function is to activate the visual logic piece to initialize the system (see section 4.2.2). It is changed to zero after saving the initial state. The value of zero activates the reset visual logic for the execution of the simulation (see section 4.2.2).
- *'Supply'*: This variable stores the mean number of cases to be operated under the public sector (work center *'Surgery'*) each month. Its initial value is picked up before reset from the spreadsheet *'Inputs'* and it's updated at time checks of one month using the visual logic codes in appendices 3.4 and 3.4.1.
- *'Time to review'*: Time interval at which the priority score is increased in *'Increase in priority'* units. It is picked up before reset from the spreadsheet *'Inputs'*.
- *'Top threshold for WL contents'*: Maximum number of patients permitted in the waiting list. It is calculated before reset through values obtained from the spreadsheet *'Inputs'*.

- *'Total surgeries'*: Stores the cumulated number of surgeries in the public sector. That is, the number of completed jobs of the work center *'Surgery'*.
- *'Validation yes_no'*: This variable keeps the option that is set in the menu *Utilities>Validation run* (see menus, section 4.2.6.3).
- *'Waiting List Backlog initial'*: Stores the initial number of backlog cases in *'Waiting List'*. Its value is picked up from the spreadsheet *'Inputs'*.

Auxiliary

- *'Condition', 'i', 'j', 'k', 'N', 'Which one'*: Variables used in loops or conditional statements.
- *'Mu demand'*: Inverse of *'Monthly cases entering the WL'.*
- *'Mu incidence'*: Inverse of *'Monthly Incident cases'*.
- *'Mu private'*: Inverse of *'Monthly Private Sector cases'*.
- *'Mu supply'*: Inverse of *'Supply'*.
- *'N dead'*: Collects the number of cases that circulate through *'Dying'* (total number of dead people in the model).
- *'N private'*: Collects the number of cases that circulate through *'Private'* (total number of people who have surgery under the private sector in the model).
- *'Route Private'*: Variable used to sample the distribution *'Access Private'* in order to choose the queue (*'Need 1st'* or *'Waiting list'*) to collect the next case to be operated in the private sector (see visual logic code in appendix 3.2.4).
- *'Sum aux', 'Sum crossprod', 'Sum PS', 'Sum PS surg', 'Sum WT', 'Sum WTPS', 'Sum WTPS surg'*: They are used in several loops to calculate means, standard deviations and correlations of waiting times, priority scores and waiting times weighted by priority score.

Spreadsheets

For collecting inputs

- *'Input distributions'*: Collects, before reset, the contents of the sheet called *'Distributions'* of the excel file *'DATA.XLS'*.
- *'Inputs'*: Collects, before reset, the contents of the sheet called *'MainInputs'* of the excel file *'DATA.XLS'*.
- *'Warranty Times SS'*: Contains the warranty times, entered by the user (see section 4.2.6.3) to calculate the minimum priority to be operated in less than these times.

For collecting results

- *'Correlation between WT and PS'*: Includes, for each run, the value of the correlation between waiting time and priority score (at entry to the waiting list).

- *'Max priority score by waiting time'*: Includes, for each run and warranty time, the mean minimum priority to be operated in less than the warranty times entered by the user.
- *'Mean PS through time'*: Includes, for each run and from 1 to 60 months, the mean priority score of the patients currently included in the waiting list. The mean and standard deviation by months of all the runs is also included (see visual logic codes in appendices 3.4 and 3.4.2).
- *'Mean PS'*: Includes, for each run, the mean priority score, at entry to the waiting list, of the cases that have been in the waiting list. That is, operated cases (1st and 2nd surgeries), cases still waiting (for 1st and 2nd eye), cases that switched to private from the waiting list and cases who died while waiting.
- *'Mean PS surg'*: Equivalent to *'Mean PS'*, but with the priority score at exit of the waiting list.
- *'Mean WT'*: Includes, for each run, the mean waiting time of the cases that have been in the waiting list. That is, operated cases (1st and 2nd surgeries), cases still waiting (for 1st and 2nd eye), cases that switched to private from the waiting list and cases who died while waiting.
- *'Percent second surgeries'*: Includes, for each run, and from 1 to 60 months, the proportion of patients waiting for second-eye surgery of the patients currently included in the waiting list. The mean by month of all the runs is also included (see visual logic codes in appendices 3.4 and 3.4.3).
- *'Percentiles of WT'*: Collects, for each run, the percentiles of waiting time of the operated cases (1st and 2nd surgeries). See appendix 3.5 for visual logic code on calculus of percentiles.
- *'Results Summary SS'*: Collects results from Results Summary. See appendix 3.5 for visual logic code on end run.
- *'Stdev PS'*: Standard deviations for the mean priority scores of *'Mean PS'*.
- *'Stdev PS surg'*: Standard deviations for the mean priority scores of *'Mean PS surg'*.
- *'Stdev WT'*: Standard deviations for the mean priority scores of *'Mean WT'*.
- *'Sum WTPS SS'*: Contains, for each run, the sum of waiting time multiplied by the priority score (at entry to the waiting list and at exit, that is, taking into account the priority score increase through time) for operated cases (overall, 1st and 2nd surgeries), cases still waiting (overall, for 1st eye and for 2nd eye surgery), cases that switched to private from the waiting list and cases who died while waiting. See appendix 3.5 for visual logic code on end run.
- *'WT by PS'*: Contains, for each run and for each group of priority score (0-9, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89, 90-100 points) the number of operated cases, their mean waiting time and its standard deviation. See appendix 3.5 for calculations on end run.

Auxiliary

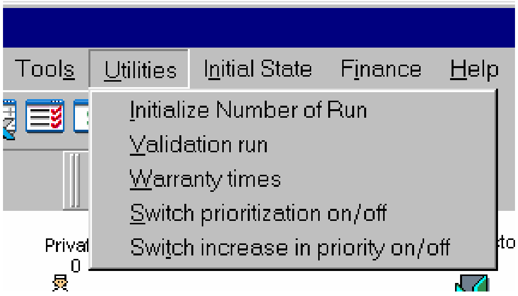
- *'Initial state Waiting List'*, *'Initial state Need 1st'* and *'Initial state Need 2nd'*: Contain the values of the labels of the *'Patients'* created to store the initial state. See section 4.2.2 on initialization of the system.

- *'Ordered WT'*: This spreadsheet is used to store the vector of ordered waiting times to calculate its percentiles. See appendix 3.5 for visual logic code on calculus of the percentiles.
- *'Waiting time and priority score'*: This spreadsheet stores, during the run of the simulation, several values of the cases that enter the waiting list (operated cases columns 21 to 29, cases still waiting columns 30 to 37, cases operated in the private sector columns 41 to 48, cases who died columns 51 to 59). The values stored are, in this order: waiting time, priority score at entry to the waiting list, 'type' of the patient, whether the case was contained in the backlog of the waiting list, priority score at exit of the waiting list, product of waiting time by priority score at entry and by the priority score at each time, category of priority score at entry and at exit (only operated cases), whether the case was contained in the backlog of *'Need 1st'* (only cases of the private sector and those who died) and whether the case was contained in the backlog of the *'Need 2nd'* (only cases who died). This spreadsheet is used in most of the calculations. See appendices 3.2.3 and 3.5 for visual logic codes.

Additional menus

A customized menu called 'Utilities' was created for several purposes (figure 2.27).

Figure 2.27: Contents of menu 'Utilities'.



- *'Initialize Number of Run'*: Initializes the variable *'Number of Run'* with a value of 0, as the number of run is increased in one unit on reset. See appendix 3.3.2 for visual logic code on reset and appendix 3.7.

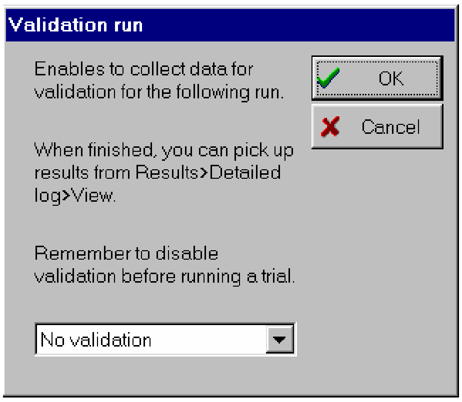
Figure 2.28: Dialog for 'Initialize Number of Run'.


Initialize Number of run

Sets Number of run=0

- *'Validation run'*: Another way of collecting results from a single run is through the SIMUL8 option Results>Detailed log. However, some options should be changed (see appendix 3.4). If the user wants to access the results of the detailed log, he or she should first select the option 'Validation' in this dialog, run a single simulation and, in the end, look up the detailed log for results. It is very important to disable this option (choose 'No validation') before running a trial, otherwise, no results will be exported to the excel file.

Figure 2.29: Dialog for 'Validation run'.



Validation run

Enables to collect data for validation for the following run.

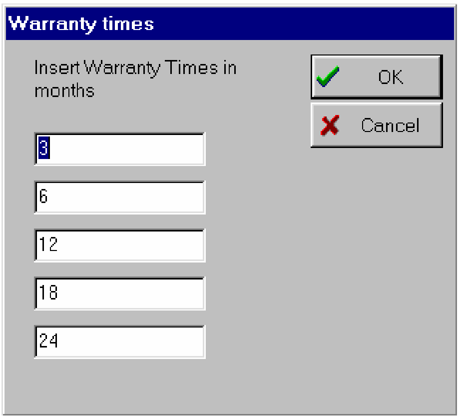
When finished, you can pick up results from Results>Detailed log>View.

Remember to disable validation before running a trial.

No validation

- *'Warranty times'*: This dialog allows the user to introduce, before executing the simulation, the warranty times for which the priority threshold will be calculated. Then, at the end of each execution, the priority threshold for each warranty time is set to 0 and modified when a bigger score is found with a waiting time higher than the warranty time. Thus, the parameter obtained is the maximum priority score of patients operated in more than the warranty time. Being the maximum, it means that 100% of the patients with higher priority scores were operated in less time.

Figure 2.30: Dialog for 'Warranty times'.



Warranty times

Insert Warranty Times in months

3

6

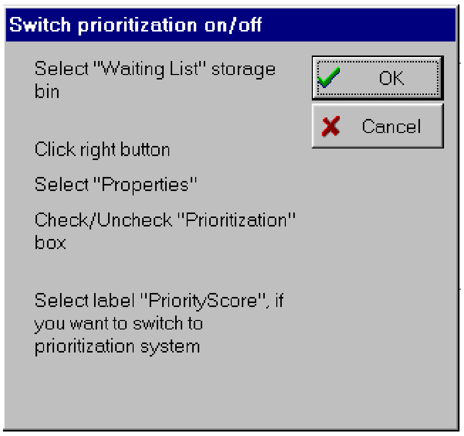
12

18

24

- *'Switch prioritization on/off'*: This wizard gives information about how to change the discipline of the waiting list.

Figure 2.31: Dialog for 'Switch prioritization on/off'.



Switch prioritization on/off

Select "Waiting List" storage bin

Click right button

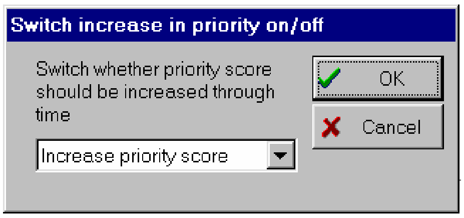
Select "Properties"

Check/Uncheck "Prioritization" box

Select label "PriorityScore", if you want to switch to prioritization system

- *'Switch increase in priority on/off'*: The option of increasing or not the priority score of the patients waiting can be changed through this dialog. The options are 'Increase priority score' and 'Do not increase priority score'.

Figure 2.32: Dialog for 'Switch increase in priority on/off'.



Switch increase in priority on/off

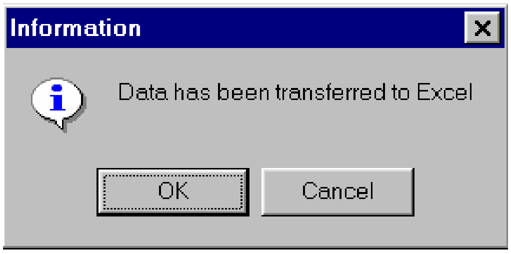
Switch whether priority score should be increased through time

Increase priority score

2.3.2.7: Results collection and analysis

Results are calculated through several visual logic pieces, especially with those at the end of run and at the end of trial (see appendices 3.5 and 3.6). The results are gathered in spreadsheets of the SIMUL8 file and are exported to the Excel file at the end of trial (see appendix 3.6). There's a description of the results gathered in the Excel file in section 2.3.2.1. The end of calculations is notified through the message box in figure 2.33.

Figure 2.33: Message box to notify the end of the trial.



Information

Data has been transferred to Excel

One of the objectives was to compare waiting list management alternatives. Because the impact of the time waited depended on the level of need, we considered that the waiting time weighted by priority score was the appropriate measure to use. This measure allowed waiting times to be compared between alternatives by taking into account how those times were assigned according to each patient's priority score. In order to weight waiting time by priority score the following formula was used:

$$wt_{ps} = \frac{\sum_i wt_i \, ps_i}{\sum_i ps_i} \tag{2.22}$$

In equation 2.22 wt_i represents waiting time and ps_i priority score for the i^{th} eye, that is, the mean weighted waiting time was calculated for all the patients (eyes) that entered the waiting list during the simulation horizon (those operated on in the public sector, those still waiting at the end of the simulation, those who switched to the private sector from the waiting list, and those who died while waiting); the weight was calculated as the priority score of each patient divided by the sum of the priority scores of all patients that entered the waiting list. Thus, the difference between the two alternatives can be interpreted as the time, weighted by need, saved or lost with one alternative versus the other (i.e., the prioritization system versus the FIFO discipline). This comparison allows the benefit associated with the prioritization system to be quantified in terms of need-adjusted lifetime, giving greater importance to the time waited by patients with greater need, while lower weighted waiting times mean that patients with higher need waited for less time.

Early executions of the model showed that the system was not stationary. Therefore, it was analyzed as a terminating simulation. We made n independent replications, each one beginning with the same initial conditions[60]. A trial is a block of n independent replications. In order to compare trials, the same streams of random numbers and seeds were used for each run within a trial, thus, the comparisons of means were paired by random stream. Although it is not the method of common random numbers, as the random numbers were not properly synchronized, it allowed comparing results paired by run and, consequently, variance for these comparisons was reduced.

In order to calculate the sample size n, some early replications were run to obtain the variance of the difference in waiting time weighted by priority score between the FIFO and the prioritization system disciplines. Then, the following formula was applied to obtain the sample size needed to achieve a certain precision (β)[60].

$$n_a^*(\beta) = min\left\{ i \geq n : t_{i-1,1-\alpha/2}\sqrt{\frac{S^2(n)}{i}} \leq \beta \right\} \tag{2.23}$$

A two-way sensitivity analysis was performed by forcing different waiting time scenarios (by changing the number of patients on the initial waiting list backlog) crossed with waiting list discipline. The different mean waiting times for patients undergoing surgery under the FIFO discipline were used to identify scenarios for comparison. Sensitivity analyses were based not only on the waiting time weighted by priority score, but also on calculating thresholds of priority score according to eventual warranty times. These thresholds meant that all patients with higher priority scores underwent surgery in less than the warranty time.

2.4: Verification and Validation

Validation of the model should be checked, when possible, by quantitative statistical comparisons between the results of the model and real results obtained from observation of the system. However, healthcare systems may be too complex to allow a reliable calculation of the result of interest and sometimes calculation may be even impossible. Additionally, even if we obtained a sample of real-world data, it would be autocorrelated, precluding the use of classical statistical techniques. In these cases, other types of validation, applying qualitative comparisons based on expert opinion, can be used to assess validity understood as usefulness of the model to achieve the established objectives.

Briefly, quantitative comparisons between the simulation outputs and real-world data may be performed through the inspection approach (comparing summary statistics without a formal statistical procedure), the correlated inspection approach (executing the model including historical input data of the system), the confidence interval approach (when a large amount of data can be collected from both the model and the system, then a confidence interval for the difference between the average result value from the model and the average result value for the system is calculated), and time-series approaches (spectral analysis and parametric time-series models). However, the choice of one or another depends on the availability of data and the conclusion will be ‘how close the results of the model resemble the expected output of the system’.[60]

The validation methodology applied to our model was problem-oriented, that is, validation was carried out according to the model’s intended purpose[71]. Validation of the conceptual model and the input values was integrated into the model-building process. Results were evaluated to see if they were consistent with the real system, as we don’t have appropriate real data to check validity through statistical quantitative tests. The face validation approach[72], which is widespread in simulation, was used. Results were presented in a systematic way to a panel of experts, including the research team, ophthalmologists and experts in simulation, and specific questions were asked. Results of the scenario relative to the real system (FIFO) were evaluated compared to historical knowledge. Results of new scenarios (prioritization system) were also evaluated. The face validation approach is included among the informal validation techniques, which are the most commonly used.

2.4.1: Sensitivity analysis on the variability of the estimated parameters

In order to assess how the uncertainty associated with the parameters estimation affects the results of the simulation model, design of experiments was used to perform sensitivity analysis. The lower and upper values for the factors will take into account the variability of their estimations (95% Confidence Intervals) and, in case of the discipline of the waiting list, the prioritization system will be compared with the FIFO discipline. Definitions of factors and response variables are shown in tables 2.15 and 2.16.

Table 2.15: Definition of factors for sensitivity analysis

Factor	Parameter
	Related to initial state
A	Non Expressed Need 1st Surgery Backlog
B	Non Expressed Need 2nd Surgery Backlog
C	Waiting List Backlog
D	Proportion of patients waiting for 2nd eye surgery
	Static parameters
E	Incident cases
F	Number of cases operated in the private sector
G	Proportion of cases of the waiting list who switch to the private sector
H	Top limit for waiting list contents (self-regulation)
J	Increase in priority score
K	Time between revisions of priority score
L	Mortality rate (Gompertz function)
	Male
	Female
	Dynamic parameters
M	Number of surgeries per month = $a + b \ln(60+t)$
	a
	b
N	Probability of second eye surgery = $p + c \ln(27+t)$
	p
	c
O	Mean number of new cases entering the waiting list per month
	Management policy
P	FIFO vs Prioritisation System

Table 2.16: Definition of response variables for sensitivity analysis

Outcomes
Operated cases
Waiting time of operated cases
Priority score of operated cases (at operation)
Number of cases operated in the public sector
Percent of second eyes operated in the public sector
Number of cases operated in the private sector
Number of cases who switched to private from the waiting list
Main outcome variable
Waiting time weighted by priority score
Waiting list cases
Number of entries in the waiting list
Mean volume of the waiting list
Percent of cases who died while waiting
Mean priority score of patients who died while waiting
Mean waiting time of patients who died while waiting
Non Expressed Need
Incidence
Number of patients in Non Expressed Need 1st Surgery at the end of the simulation
Number of patients in Non Expressed Need 2nd Surgery at the end of the simulatior

We focused our interest in estimating main effects and two-level interactions. The design used was a 2_{IV}^{15-10} fraction (with 32 runs) with generators:

F=ABC
G=ABD
H=ABE
J=ACD
K=ACE
L=ADE
M=BCD
N=BCE
O=BDE
P=CDE

This design allowed estimating all main effects and two-factor interactions; however, all two-factor interactions were confounded among them. The assignment of factors to variables is shown in table 2.15.

The design matrix for the 32 experiments combining the 15 factors is shown in table 2.17.

Table 2.17: Design matrix for sensitivity analysis.

Number of Experiment	FACTORS													
	A	B	C	D	E	F	G	H	J	K	L	M	N	O
1	1	-1	-1	1	1	1	-1	-1	-1	-1	1	1	1	-1
2	-1	-1	-1	1	-1	-1	1	-1	1	-1	1	1	-1	1
3	-1	1	-1	1	1	1	-1	-1	1	1	-1	-1	-1	1
4	-1	1	1	1	1	-1	-1	-1	-1	-1	-1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	-1	-1	-1	-1	1	-1	-1	1	-1	1	1	-1	1	1
7	-1	1	-1	-1	-1	1	1	1	-1	-1	-1	1	1	1
8	-1	-1	1	-1	1	1	-1	1	1	-1	1	1	-1	1
9	1	1	1	-1	-1	1	-1	-1	-1	-1	1	-1	-1	1
10	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1
11	1	-1	-1	-1	1	1	1	-1	1	-1	-1	-1	1	1
12	1	-1	1	-1	-1	-1	1	1	-1	-1	1	1	1	-1
13	1	1	-1	-1	1	-1	-1	1	1	-1	-1	1	-1	-1
14	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1
15	-1	1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1
16	1	1	1	1	-1	1	1	-1	1	-1	-1	1	-1	-1
17	-1	-1	-1	1	1	-1	1	1	1	1	-1	1	1	-1
18	-1	1	1	-1	-1	-1	1	1	1	1	-1	-1	-1	1
19	1	-1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
20	1	-1	1	1	1	-1	-1	-1	1	1	1	-1	-1	-1
21	-1	1	1	1	-1	-1	-1	1	-1	1	1	1	-1	-1
22	1	-1	1	1	-1	-1	-1	1	1	-1	-1	-1	1	1
23	1	1	-1	1	-1	-1	1	-1	-1	1	-1	-1	1	-1
24	-1	-1	1	1	-1	1	1	-1	-1	1	1	-1	1	1
25	1	1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1
26	1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1
27	-1	1	-1	-1	1	1	1	-1	-1	1	1	1	-1	-1
28	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
29	-1	-1	1	-1	-1	1	-1	-1	1	1	-1	1	1	-1
30	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1	1	-1
31	1	1	1	-1	1	1	-1	1	-1	1	-1	-1	1	-1
32	1	1	-1	1	1	-1	1	1	-1	-1	1	-1	-1	1

Table 2.18 shows the central values estimated for the factors and the lower and upper levels proposed for the factorial analysis. The upper and lower levels were calculated through different approaches, specified in column ‘Method’. For simple parameters, some use the definition of a 95% confidence interval and others opportunistic values. Complex parameters, defined through a statistical model, combine the upper and lower levels of the 95% confidence intervals of the coefficients of the model. The management policy is a qualitative factor with two levels: FIFO and prioritization system.

Figures 2.34, 2.35 and 2.36 show the values taken by the levels of the mortality hazard, the number of surgeries and the probability of second-eye surgery with respect to the central value of the parameter. Because the number of entries to the waiting list depends on the number of surgeries, the number of entries to the waiting list and the delay of the effect of changes in the number of surgeries, figure 2.35 shows the values taken by crossing the levels of these 3 parameters. Changes in the parameter lag caused little differences in the number of entries to the waiting list, thus, only the number of entries to the waiting list was varied to obtain the levels for the parameter.

Table 2.18: Levels for sensitivity analysis.

Factor	Parameter	Central value	Level		Method
			-	+	
	Related to initial state				
A	Non Expressed Need 1st Surgery Backlog	318752	317622.8375	319881.1625	$\hat{\lambda} \pm z_{\alpha/2}\sqrt{\hat{\lambda}}$
B	Non Expressed Need 2nd Surgery Backlog	81585	81013.73824	82156.26176	$\hat{\lambda} \pm z_{\alpha/2}\sqrt{\hat{\lambda}}$
C	Waiting List Backlog	19586	19306.10002	19865.89998	$\hat{\lambda} \pm z_{\alpha/2}\sqrt{\hat{\lambda}}$
D	Proportion of patients waiting for 2nd eye surgery	0.209	0.1822	0.2358	$p \pm z_{\alpha/2}\sqrt{p(1-p)/n}$
	Static parameters				
E	Incident cases	5695.043302	4610.342321	6293.1234	Lower-upper 95%CI of prevalence function
F	Number of cases operated in the private sector	383.47	341.41	425.54	$\bar{x} \pm z_{\alpha/2}\, s_x/\sqrt{n}$
G	Proportion of cases of the waiting list who switch to the private sectc	0.0613	0.0458	0.0768	$p \pm z_{\alpha/2}\sqrt{p(1-p)/n}$
H	Top limit for waiting list contents (self-regulation)	0.15	0.05	0.25	Oportunistic
J	Increase in priority score	17.39	13.86556364	20.91443636	$\bar{x} \pm z_{\alpha/2}\, s_x/\sqrt{n}$
K	Time between revisions of priority score	7	3	9	Oportunistic
L	Mortality rate (Gompertz function)				Lower-upper 95%CI of coefficients
	Male	$0.000018286\ e^{0.102374095\ age}$	$0.000015234\ e^{0.100424715\ age}$	$0.000021338\ e^{0.104323475\ age}$	
	Female	$0.00000124309\ e^{0.129010243\ age}$	$0.000000852883\ e^{0.125513332\ age}$	$0.00000163329\ e^{0.132507153\ age}$	
	Dynamic parameters				
M	Number of surgeries per month = $a + b\ \ln(60+t)$	$2350 + 380\ \ln(60+t)$	$2548.1 + 300\ \ln(60+t)$	$1970.8 + 500\ \ln(60+t)$	$\hat{\lambda} \pm z_{\alpha/2}\sqrt{\hat{\lambda}}$
	a	2350	2548.06552	1970.81356	
	b	380	300	500	
N	Probability of second eye surgery = $p + c\ \ln(27+t)$	$0.2805 + 0.0645725\ \ln(27+t)$	$0.2341751 + 0.0462534\ \ln(27+t)$	$0.32685194 + 0.0828916\ \ln(27+t)$	Lower-upper 95%CI of coefficients
	p	0.2805	0.2341751	0.32685194	
	c	0.0645725	0.0462534	0.0828916	
O	Mean number of new cases entering the waiting list per month	3872	3750.038222	3993.961778	$\hat{\lambda} \pm z_{\alpha/2}\sqrt{\hat{\lambda}}$
	Management policy				
P	FIFO vs Prioritisation System		FIFO	Prioritization system	

Figure 2.34: Central value and 95% confidence interval for mortality hazard by sex.

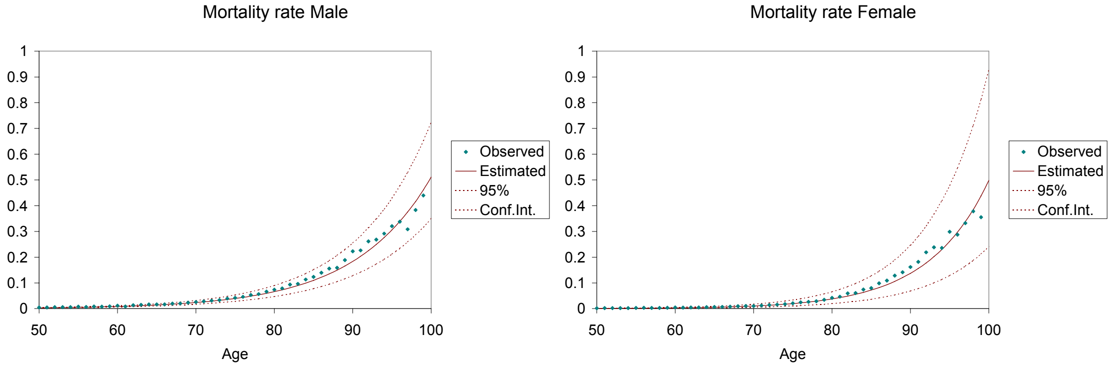


Figure 2.35: Central value and 95% confidence interval for the number of surgeries through the simulation horizon.

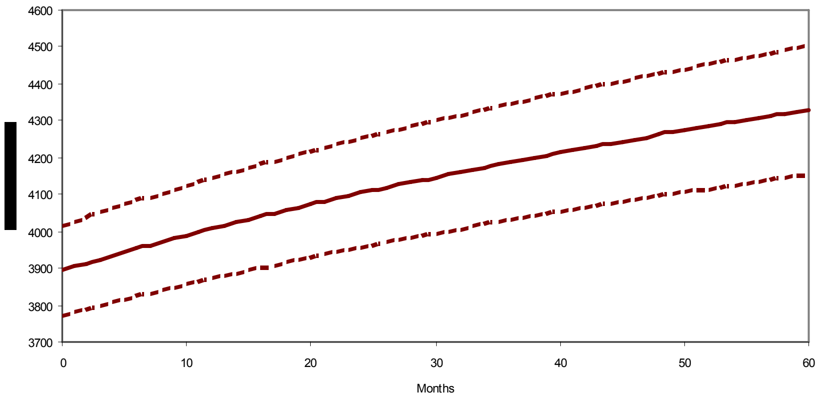


Figure 2.36: Central value and 95% confidence interval for the probability of second-eye surgery through the simulation horizon.

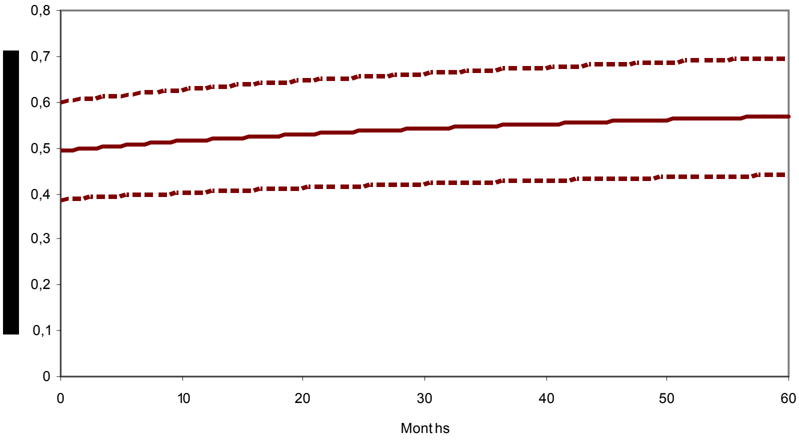
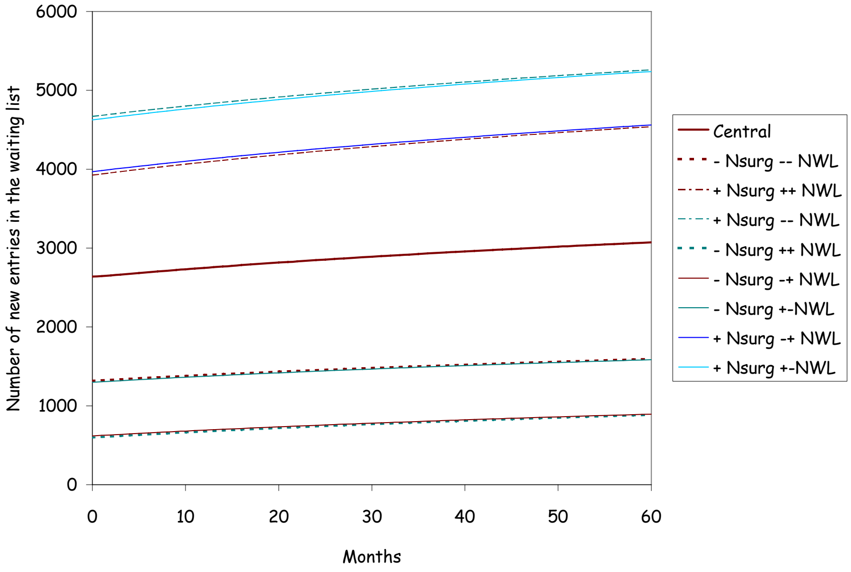


Figure 2.37: Central value and 95% confidence interval for the number of entries to the waiting list through the simulation horizon.



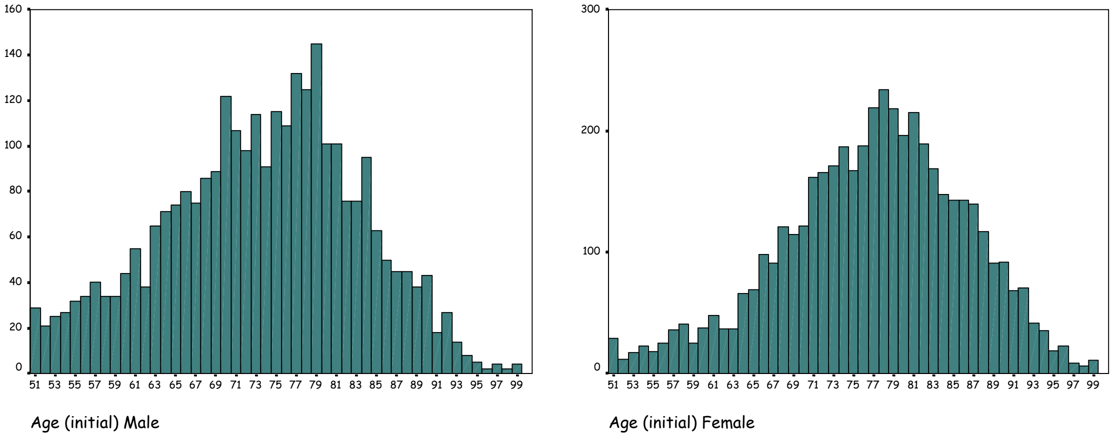
Chapter 3: Results

3.1: Verification and Validation

3.1.1: Verification of inputs

The simulation model was verified during its implementation through pilot runs. In order to verify the labels assigned at the individual level, the results of a single simulation were analyzed. The number of patients simulated was 7,638. A 61.7% (4,707 cases) were women. The mean age was 75.13 years overall with a standard deviation of 9.60 (73.02 (9.76) for men and 76.44 (9.27) for women).

Figure 3.1: Distribution of age by sex, results per patient of a 5-year simulation.



The proportion of women should be compared with the 61.9% shown in table 2.4 and the distributions of age by sex with those of figure 2.8.

Simulated priority scores shown in figure 3.2 should be compared to those in figure 2.20. The mean priority scores were 35.79 (standard deviation of 23.53) for the 1,849 cases of first-eye surgery and 26.84 (19.36) for the 871 cases of second-eye surgery (see table 2.14 for comparisons). The minimum priority score was 0 in all cases.

Figure 3.2: Priority scores (at entry to the waiting list) for 1st and 2nd eye surgery. Five-year simulation results per eye of individuals entered to the waiting list.

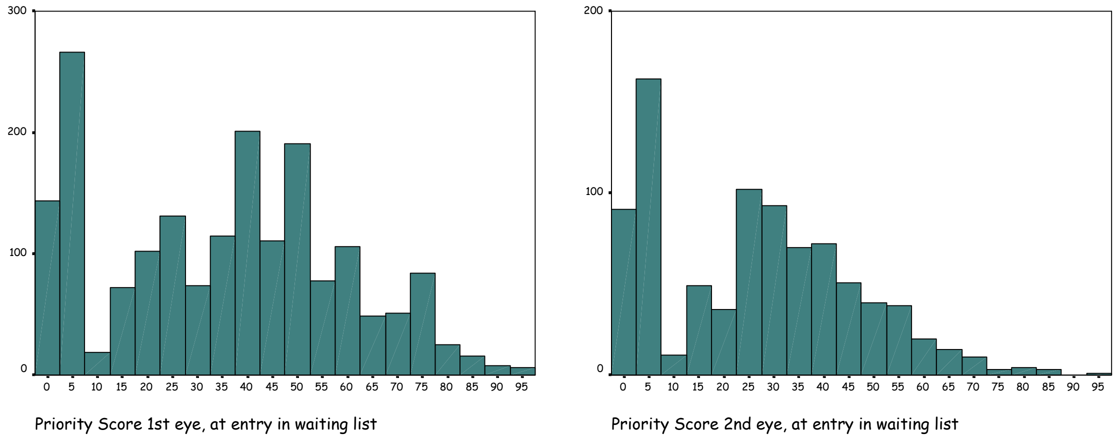
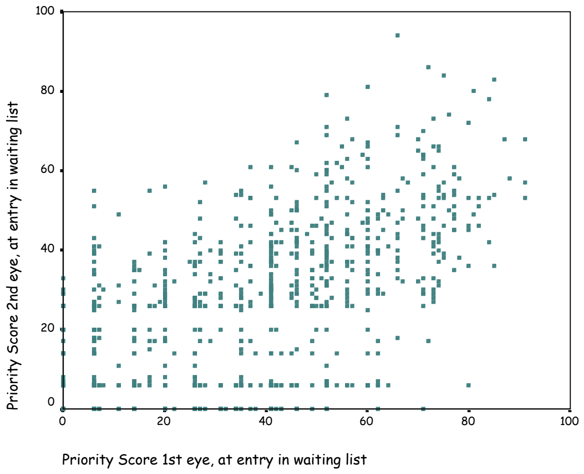


Figure 3.3: Relationship between the priority scores (at entry to the waiting list) for 1st and 2nd eye surgery within patient. Five-year simulation results paired by patient.



The relationship between the priority score of the 1st and the 2nd eye of patients who entered the waiting list for both surgeries is shown in figure 3.3. The Spearman correlation was 0.561 (the input value was 0.55, see section 2.2.2.3).

3.1.2: Validity of outputs

Results were validated not only by comparing the FIFO system with the available knowledge on the real system, but also by changing the waiting list discipline to the prioritization system to assess the impact of the prioritization system on the behavior of the system. Two single simulations of a five-year horizon were performed in order to validate the model. The FIFO and the prioritization system disciplines for the waiting list were simulated using the same stream of random numbers. The resulting differences were in the expected direction.

Because patients may have two cataract surgeries, results are presented per individual for those not operated at the end of simulation and per surgery for those operated in the public sector during the simulation.

3.1.2.1: Results per individual

The results of table 3.1 are person-based. The final state of the system showed an increase in prevalence of need, as the volume of all types of patients increased. As the priority score for second-eye surgery has a lower mean than that for first-eye surgery, a higher proportion of patients waiting for second-eye surgery was observed when applying the prioritization system (46.5% of the patients in waiting list while 32.5% under FIFO).

As the surgery rate in the private sector and the mortality rate were independent of the waiting list discipline, the number of exits of the system for these reasons was similar, and similarly distributed among categories of patients.

Table 3.1: Distribution of patients at the end of the simulation and origin of patients that left the system not by surgery in the public sector.

	FIFO		Prioritization System	
	n	%	n	%
Patients in the system at the end of simulation in:	4858		4888	
Non Expressed Need 1st Surgery	3459	71.20	3464	70.87
Non Expressed Need 2nd Surgery	1190	24.50	1224	25.04
Waiting List for 1st Surgery	141	2.90	107	2.19
Waiting List for 2nd Surgery	68	1.40	93	1.90
Patients gone to the private sector from:	221		221	
Non Expressed Need 1st Surgery	202	91.40	202	91.40
Waiting List for 1st Surgery	11	4.98	12	5.43
Waiting List for 2nd Surgery	8	3.62	7	3.17
Patients gone to the 'Death' state from:	1750		1750	
Non Expressed Need 1st Surgery	1309	74.80	1309	74.80
Non Expressed Need 2nd Surgery	375	21.43	378	21.60
Waiting List for 1st Surgery	40	2.29	38	2.17
Waiting List for 2nd Surgery	26	1.49	25	1.43

3.1.2.2: Results per surgery

The following results are surgery-based (or operated eye-based), they include information on all surgeries performed in the public sector, except those that were included in the waiting list backlog.

Table 3.2: Number of surgeries performed during the 5-year simulation.

	FIFO		Prioritization System	
	n	%	n	%
Number of surgeries*	2248		2251	
First eye surgeries	1476	65.66%	1508	66.99%
Second eye surgeries	772	34.34%	743	33.01%

* excludes surgeries from the waiting list backlog

Around one third of surgeries were performed in second eyes. The proportion of first-eye surgeries was slightly higher under the prioritization system.

Table 3.3: Descriptives of waiting time, by waiting list discipline.

	FIFO		Prioritization System	
Waiting time of operated cases				
Overall				
Mean - SD	4.49	0.55	3.40	6.92
Minimum - Maximum	3.56	5.88	0.00001	28.02
First surgeries				
Mean - SD	4.50	0.56	3.05	6.58
Minimum - Maximum	3.56	5.84	0.00001	28.02
Second surgeries				
Mean - SD	4.48	0.53	4.13	7.51
Minimum - Maximum	3.57	5.88	0.001	27.66

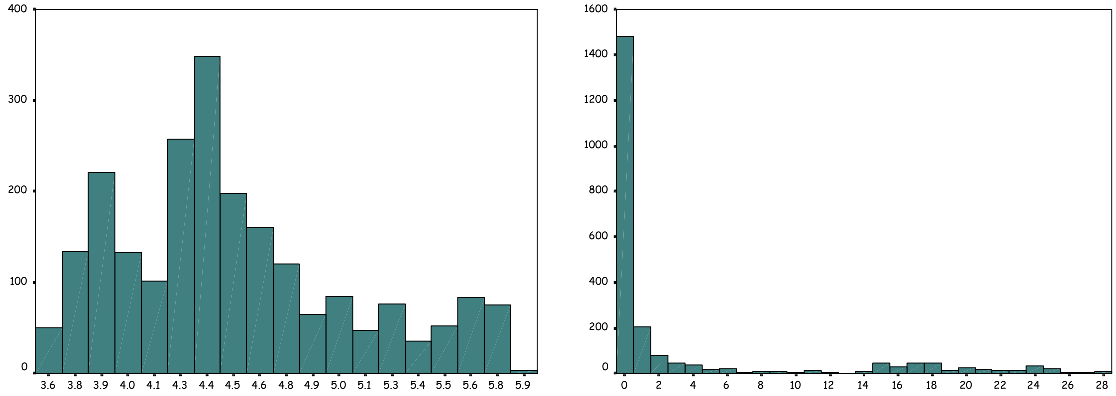
The mean waiting time under the FIFO discipline was 4.5 months with a standard deviation of 0.55 months. It was similar for first and second surgeries. For the prioritization system the mean waiting time was lower (3.4 months), but with a higher standard deviation (7 months). This was due to the distribution of waiting times, which was positively skewed, as shown in table 3.4 and figure 3.3. The waiting time was higher for second surgeries, as they had a lower priority score.

Table 3.4: Percentiles of the waiting time distribution, by waiting list discipline.

	Percentiles of waiting time (months)								
	Minimum	**5**	**10**	**25**	**50**	**75**	**90**	**95**	**Maximum**
FIFO	3.56	3.77	3.84	4.09	4.39	4.76	5.36	5.64	5.88
Prioritization system	0.00001	0.004	0.009	0.03	0.10	1.55	17.06	20.51	28.02

The percentile distribution in table 3.4 shows that 75% of the patients under the prioritization system discipline had a waiting time lower than one month and a half. Only a 10% of patients waited for more than 17 months.

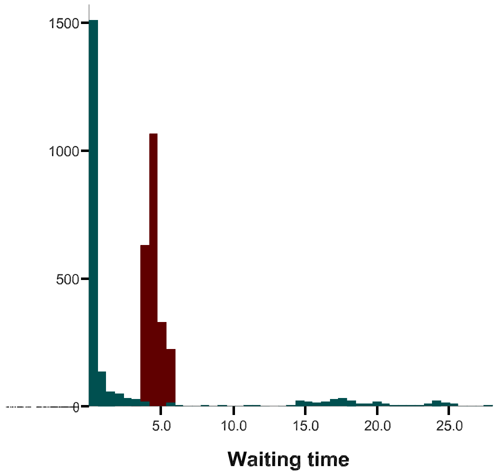
Figure 3.4: Waiting time distributions, by waiting list discipline.



Waiting time operated cases (FIFO discipline)

Waiting time operated cases (Prioritization System)

Figure 3.5: Comparison between waiting time distributions by waiting list discipline.



The mean priority score at entry to the waiting list of cases that were operated in each simulation are shown in table 3.5. The priority was slightly higher for cases operated under the prioritization system discipline.

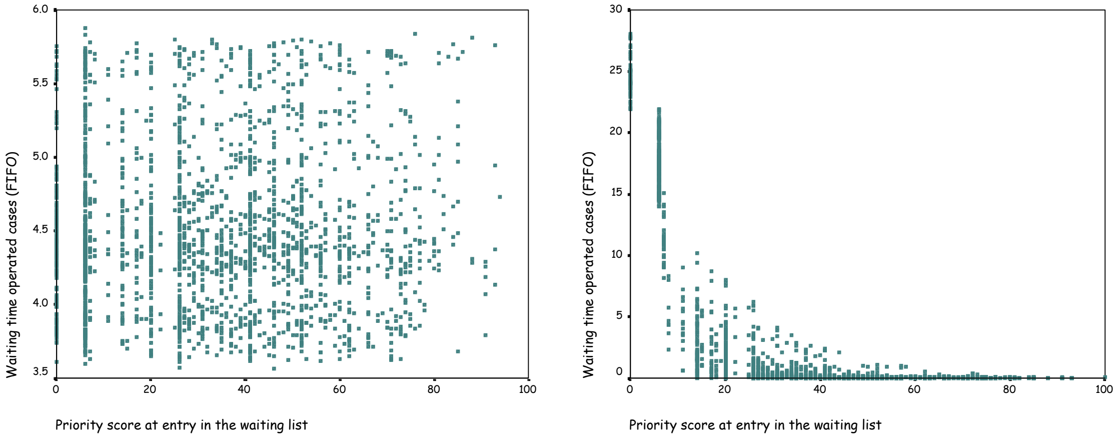
Table 3.5: Descriptives of the priority score (at entry to the waiting list) of cases operated under both waiting list disciplines.

	FIFO		Prioritization System	
Priority score for all operated cases				
Mean - SD	33.55	22.60	36.50	21.54
Minimum - Maximum	0	94	0	100
Priority score for 1st surgeries				
Mean - SD	36.59	23.29	39.12	22.15
Minimum - Maximum	0	93	0	93
Priority score for 2nd surgeries				
Mean - SD	27.45	19.81	30.92	19.04
Minimum - Maximum	0	94	0	100

* SD: Standard Deviation

Figure 3.6 shows no relationship between waiting time and priority score for cases operated under the FIFO system and a negative relationship for those operated under the prioritization system. Although it is not a linear relationship, the Spearman's correlation coefficient was – 0.793 for the prioritization system and almost null (0.020) for the FIFO system. Figure 3.7 overlays the graphics of figure 3.6.

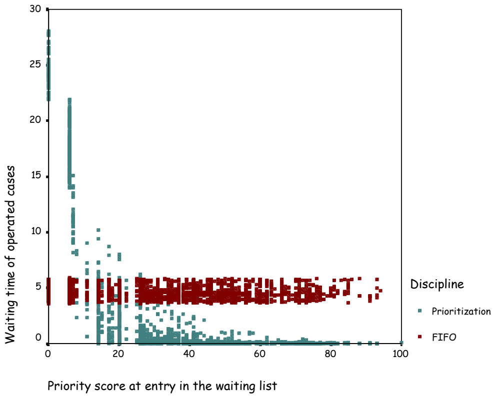
Figure 3.6: Relationship between priority score and waiting time, by waiting list discipline.



Correlation (Spearman's rho): 0.020

Correlation (Spearman's rho): -0.793

Figure 3.7: Comparison of the relationship between priority score and waiting time, by waiting list discipline.



When the computer model is considered as valid, experiments are designed according to the study's objectives to analyze results (e.g., the alternatives or scenarios to be compared).

3.1.2.3: Sensitivity analysis on the variability of the estimated parameters

Table 3.6 shows the p_values resulting from the sensitivity analysis. The waiting time of the operated cases was no sensitive to the variability of the estimations of the input parameters, as any p_value was significant. The mean priority score of the operated cases was sensitive to the waiting list discipline in the sense that, with the prioritization system, operated patients presented a priority score 2.73 points higher (table 3.6) than with the FIFO system. One interaction was significant, with the following confusion profile: A*G + B*D + C*M + E*O + F*J + H*L + N*P. Giving the main effects results, we conclude that the significant interaction was that between the probability of second-eye surgery and the waiting list discipline (N*P), meaning that the mean priority score of operated cases was 0.92 points higher when the probability of second-eye surgery was at the lower level in the FIFO discipline. This makes sense because the priority score of second-eye patients is lower than that of first-eye patients.

The number of surgeries in the public sector performed during the 5-year horizon was sensitive to the variability of the input value of the number of monthly surgeries in the public sector only (table 3.6). The same happened with the percentage of second eyes operated in the public sector, which was sensitive to the parameter of the probability of second-eye surgery only; and the number of patients operated in the private sector, which was sensitive to the number of monthly surgeries in the private sector only. No significant effects were found for the number of patients who switched to private from the waiting list.

Several parameters were statistically significant for the number of entries to the waiting list: the top limit for waiting list contents, the number of monthly surgeries, the probability of second-eye surgery, the number of new cases entering the waiting list and their two-level interactions. Their significance was expected since they are the parameters mostly related to the process of entries to the waiting list. The significance of parameters such as volume of "Non Expressed Need 1st Surgery", incidence, or waiting list discipline was not expected. For the mean volume of patients in the waiting list, the significant factors were the number of monthly surgeries and the probability of second-eye surgery, both with a positive coefficient, as higher values cause more entries to the waiting list.

For the proportion of patients who died while waiting, a small effect of the probability of second-eye surgery was found because, when the probability of second surgery is higher, the patient has a higher probability of being included in a waiting list and, thus, of dying while included in the waiting list. The mean priority score of patients who died while waiting was only significantly influenced by the time between revisions of priority score, giving that the mean priority score of patients who died while waiting was 11.6 points lower when the time between revisions changed from 3 to 9 months. As expected, the only factor influencing the mean waiting time of the patients who died while waiting was the waiting list discipline: those who died under the prioritization system waited for 5 months more.

Incidence and number of patients in “Non Expressed Need 1st Surgery” at the end of simulation weren’t sensitive to the variability of the estimations of the input parameters. The number of patients in “Non Expressed Need 2nd Surgery” at the end of the simulation was influenced by the probability of second-eye surgery (higher probability implied less volume of non expressed need) and the mortality rate (a higher rate implied also less volume of “Non Expressed Need 2nd Surgery”).

The main outcome of the model was the waiting time weighted by priority score, which showed to be no sensitive to the variability of the input factors.

Table 3.6: Results of the sensitivity analysis (p_values and confounding structure for 2-factor interactions).

Factor	Parameter	Waiting time of operated patients	Priority score of operated cases (at operation)	N operated in the public sector	% of second eyes operated in the public sector	N operated in the private sector	N who switched to private from the waiting list	Waiting time weighted by priority score	Number of entries in the waiting list	Mean volume of the waiting list	% of cases who died while waiting	Mean priority score of patients who died while waiting	Mean waiting time of patients who died while waiting	Incidence	N in Non Expressed Need 1st Surgery at the end of the simulation	N in Non Expressed Need 2nd Surgery at the end of the simulation
	Related to initial state															
A	Non Expressed Need 1st Surgery Backlog	0.981	0.332	0.326	0.956	0.500	0.692	0.873	**0.041**	0.361	0.604	0.424	0.495	0.757	0.841	0.326
B	Non Expressed Need 2nd Surgery Backlog	0.628	0.677	0.675	0.607	0.500	0.951	0.931	0.924	0.408	0.315	0.871	0.801	0.757	0.797	0.273
C	Waiting List Backlog	0.816	0.120	0.228	0.277	0.500	0.683	0.873	0.054	0.221	0.800	0.612	0.356	0.757	0.826	0.582
D	Proportion of patients waiting for 2nd eye surgery	0.938	0.310	0.407	0.423	0.500	0.951	0.875	0.058	0.806	0.824	0.705	0.893	0.571	0.541	0.292
	Static parameters															
E	Incident cases	0.938	0.194	0.452	0.354	0.500	0.701	0.955	**0.047**	0.600	0.165	0.610	0.386	0.164	0.158	0.423
F	Number of cases operated in the private sector	0.845	0.141	0.526	0.657	**0.011**	0.291	0.880	0.100	0.686	0.321	0.566	0.269	0.571	0.608	0.311
G	Proportion of cases of the waiting list who switch to the private secto	0.886	0.144	0.303	0.216	0.500	0.075	0.974	0.104	0.211	0.923	0.515	0.617	0.757	0.802	0.507
H	Top limit for waiting list contents (self-regulation)	0.313	0.050	0.339	0.296	0.500	0.379	0.603	**0.041**	0.540	0.160	0.265	0.185	0.875	0.885	0.519
J	Increase in priority score	0.771	0.393	0.394	0.319	0.500	0.806	0.980	0.055	0.649	0.712	0.165	0.844	0.757	0.771	0.445
K	Time between revisions of priority score	0.452	0.086	0.475	0.835	0.500	0.464	0.727	0.093	0.678	0.500	**0.049**	0.075	0.875	0.867	0.326
L	Mortality rate (Gompertz function)	0.309	0.088	0.328	0.256	0.500	0.785	0.617	0.066	0.388	0.464	0.597	0.210	0.875	0.136	**0.017**
	Dynamic parameters															
M	Number of surgeries per month = $a + b\ \ln(60+t)$	0.195	0.056	**0.029**	0.119	0.500	0.585	0.414	**0.008**	**0.044**	0.111	0.256	0.149	0.757	0.570	0.102
N	Probability of second eye surgery = $p + c\ \ln(27+t)$	0.091	0.089	0.882	**0.013**	0.500	0.494	0.211	**0.006**	**0.012**	**0.037**	0.118	0.072	0.875	0.550	**0.013**
O	Mean number of new cases entering the waiting list per month	0.299	0.058	0.308	0.103	0.500	0.648	0.620	**0.010**	0.631	0.143	0.359	0.160	0.875	0.978	0.106
	Management policy															
P	FIFO vs Prioritisation System	0.135	**0.008**	0.358	0.209	0.500	0.362	0.163	**0.037**	0.509	0.282	0.057 *	**0.020**	0.875	0.801	0.262
Interaction terms																
A*B + C*F + D*G + E*H + J*M + K*N + L*O		0.849	0.565	0.339	0.201	0.500	0.811	0.978	0.339	0.181	0.974	0.187	0.464	0.757	0.789	0.520
A*C + B*F + D*J + E*K + G*M + H*N + L*P		0.353	0.147	0.469	0.488	0.500	0.871	0.512	0.225	0.273	0.518	0.630	0.693	0.757	0.790	0.282
A*D + B*G + C*J + E*L + F*M + H*O + K*P		0.563	0.104	0.293	0.888	0.500	0.624	0.290	**0.033**	0.304	0.496	0.074 *	0.073	0.757	0.985	0.393
A*E + B*H + C*K + D*L + F*N + G*O + J*P		0.697	0.754	0.274	0.291	0.500	0.916	0.621	0.055	0.168	0.464	0.197	0.681	0.875	0.763	0.530
A*F + B*C + D*M + E*N + G*J + H*K + O*P		0.526	0.088	0.299	0.531	0.500	0.701	0.858	0.099	0.280	0.452	0.649	0.286	0.757	0.760	0.309
A*G + B*D + C*M + E*O + F*J + H*L + N*P		0.550	**0.023**	0.514	0.469	0.500	0.997	0.984	0.111	0.424	0.873	0.233	0.135	0.757	0.778	0.427
A*H + B*E + C*N + D*O + F*K + G*L + M*P		0.478	0.063	0.450	0.740	0.500	0.648	0.806	0.356	0.608	0.300	0.802	0.310	0.875	0.843	0.333
A*J + B*M + C*D + E*P + F*G + K*L + N*O		0.392	0.103	0.477	0.382	0.500	0.754	0.671	**0.03**	0.876	0.192	0.682	0.310	0.757	0.746	0.700
A*K + B*N + C*E + D*P + F*H + J*L + M*O		0.845	0.774	0.250	0.809	0.500	0.754	0.907	**0.03**	0.261	0.412	0.773	0.811	0.875	0.789	0.367
A*L + B*O + C*P + D*E + G*H + J*K + M*N		0.383	0.149	0.890	0.262	0.500	0.527	0.661	0.099	0.119	0.257	0.795	0.305	0.500	0.516	0.142
A*M + B*J + C*G + D*F + H*P + K*O + L*N		0.823	0.051	0.600	0.642	0.500	0.871	0.739	**0.034**	0.368	0.175	0.737	0.220	0.571	0.489	0.643
A*N + B*K + C*H + E*F + G*P + J*O + L*M		0.554	0.565	0.419	0.509	0.500	0.464	0.771	0.166	0.688	0.412	0.486	0.420	0.500	0.489	0.437
A*O + B*L + D*H + E*G + F*P + J*N + K*M		0.946	0.122	0.340	0.459	0.500	0.849	0.958	0.173	0.344	0.808	0.465	0.247	0.875	0.833	0.318
A*P + C*L + D*K + E*J + F*O + G*N + H*M		0.908	0.594	0.477	0.748	0.500	0.521	0.945	0.082	0.542	0.800	0.663	0.422	0.875	0.860	0.301
B*P + C*O + D*N + E*M + F*L + G*K + H*J		0.923	0.203	0.339	0.246	0.500	0.391	0.995	0.342	0.192	0.588	0.964	0.806	0.875	0.797	0.477

N: number of individuals

Table 3.7: Magnitude of the effects (statistically significant effects in bold).

Factor	Parameter	Waiting time of operated patients	Priority score of operated cases (at operation)	N operated in the public sector	% of second eyes operated in the public sector	N operated in the private sector	N who switched to private from the waiting list	Waiting time weighted by priority score	Number of entries in the waiting list	Mean volume of the waiting list	% of cases who died while waiting	Mean priority score of patients who died while waiting	Mean waiting time of patients who died while waiting	Incidence	N in Non Expressed Need 1st Surgery at the end of the simulation	N in Non Expressed Need 2nd Surgery at the end of the simulation
	Related to initial state															
A	Non Expressed Need 1st Surgery Backlog	-0.0063	-0.0588	-13.72	-0.01	-85.300	-0.3594	-0.0831	**-1356**	-672.8	-0.0662	-1.139	-0.1575	-8348	-4297	1208
B	Non Expressed Need 2nd Surgery Backlog	-0.1362	-0.0187	4.31	-0.1019	-85.300	0.0531	-0.0444	11	-572.8	-0.1712	-0.184	0.05	-8348	-5572	1485
C	Waiting List Backlog	0.0612	0.178	-20.61	-0.3099	-85.300	-0.3719	-0.0831	-1038	-1185.3	-0.030	-0.624	0.2475	-8348	-4736	524
D	Proportion of patients waiting for 2nd eye surgery	-0.02	0.064	10.36	-0.1837	-85.300	0.0531	-0.0819	959	134.7	-0.0262	0.446	-0.0262	16629	14832	1373
	Static parameters															
E	Incident cases	-0.02	-0.1075	8.97	-0.2312	-85.300	-0.3469	0.0294	**1203**	-310.300	-0.3487	-0.629	-0.2238	79073	66772	868
F	Number of cases operated in the private sector	-0.0512	-0.15	7.1	0.0861	**4834.7**	1.3906	0.078	-557.000	229.7	-0.1675	-0.726	-0.345	16629	11937	1277
G	Proportion of cases of the waiting list who switch to the private sect	-0.0375	0.1462	-14.97	-0.4072	-85.300	5.8156	0.0169	533	-1245.3	-0.0112	0.854	0.1062	-8348	-5428	665
H	Top limit for waiting list contents (self-regulation)	0.385	0.425	-13.09	-0.287	-85.300	-1.0094	0.2956	**1354**	377.200	0.361	2.024	0.5188	4140	3097	640
J	Increase in priority score	-0.0775	0.0475	10.82	-0.2622	-85.300	0.2156	0.013	1019	-262.8	-0.045	3.374	0.0387	-8348	-6347	807
K	Time between revisions of priority score	-0.24	0.2487	8.34	-0.0381	-85.300	0.7656	-0.1881	601	237.2	-0.093	**-11.629**	1.3162	4140	3591	1209
L	Mortality rate (Gompertz function)	-0.3913	0.2425	-13.64	-0.3373	-85.300	0.2406	-0.2819	853	-612.8	0.1038	0.656	-0.453	4140	-77882	**-24977**
	Dynamic parameters															
M	Number of surgeries per month = $a + b \ln(60+t)$	-0.6525	-0.3825	**170.01**	0.758	-85.300	-0.5219	-0.5406	**7123**	**6162.2**	-0.5275	-2.101	-0.6487	-8348	-13524	4184
N	Probability of second eye surgery = $p + c \ln(27+t)$	1.4375	0.2387	-1.45	**7.2488**	-85.300	-0.6969	1.1956	**-9788**	**22869.7**	**1.575**	4.781	1.3737	4140	14433	**-33768**
O	Mean number of new cases entering the waiting list per month	0.4062	0.3725	14.68	-0.8788	-85.300	-0.4219	0.279	**5597**	-280.3	0.4037	1.411	0.605	4140	-572	4045
	Management policy															
P	FIFO vs Prioritisation System	-0.9613	**2.7313**	-12.22	-0.4223	-85.300	-1.0719	-1.5644	**-1527**	-415.3	-0.195	-9.931	**5.053**	4140	5467	1557
Interaction terms																
A*B + C*F + D*G + E*H + J*M + K*N + L*O		-0.05	0.0275	13.1	0.4404	85.300	0.2094	0.0144	149	1460.3	-0.0037	-2.955	0.1738	8348	5826	-638
A*C + B*F + D*J + E*K + G*M + H*N + L*P		0.3325	0.1438	-8.5	0.1493	85.300	-0.1406	0.3956	-239	935.3	0.0875	0.588	-0.0813	8348	5787	-1429
A*D + B*G + C*J + E*L + F*M + H*O + K*P		-0.1688	0.205	15.58	-0.0255	85.300	0.4594	-0.838	**1713**	825.3	0.0937	-7.642	1.34	8348	-396	-955
A*E + B*H + C*K + D*L + F*N + G*O + J*P		0.1063	-0.0137	16.81	0.292	85.300	-0.0906	0.2781	1027	1585.3	0.1038	2.8	0.085	-4140	-6601	-618
A*F + B*C + D*M + E*N + G*J + H*K + O*P		-0.19	0.2412	15.19	0.1304	85.300	0.3469	-0.0931	564	910.300	-0.1075	0.55	0.3213	8348	6677	-1289
A*G + B*D + C*M + E*O + F*J + H*L + N*P		-0.176	**0.9225**	-7.39	0.1587	85.300	-0.0031	0.0106	-501	545.3	-0.0188	2.335	0.7225	8348	6152	-855
A*H + B*E + C*N + D*O + F*K + G*L + M*P		0.2213	-0.3413	-9.030	-0.062	85.300	0.4219	0.1294	141	-302.2	0.181	-0.288	-0.293	-4140	-4238	-1178
A*J + B*M + C*D + E*P + F*G + K*L + N*O		-0.2912	-0.2063	8.29	0.2101	85.300	-0.2781	-0.2331	**-1854**	-84.7	-0.2975	-0.487	-0.293	8348	7133	346
A*K + B*N + C*E + D*P + F*H + J*L + M*O		0.0513	0.0125	18.630	0.0445	85.300	-0.2781	0.0606	**1872**	985.3	0.1225	-0.332	-0.0475	-4140	-5809	-1044
A*L + B*O + C*P + D*E + G*H + J*K + M*N		0.3	0.1413	-1.350	0.3289	85.300	-0.6281	0.2419	564	2260.3	0.2162	-0.298	0.2987	20837	16053	-3000
A*M + B*J + C*G + D*F + H*P + K*O + L*N		0.0588	0.4238	-5.600	-0.0907	85.300	-0.1406	0.1781	**1647**	655.3	0.3275	0.392	0.430	-16629	-17472	426
A*N + B*K + C*H + E*F + G*P + J*O + L*M		0.1738	0.0275	-9.99	0.1397	85.300	-0.7656	0.1544	-329	227.8	0.1225	0.933	0.200	20837	17506	-829
A*O + B*L + D*H + E*G + F*P + J*N + K*M		-0.0175	-0.1737	13.040	0.1637	85.300	-0.1656	-0.0269	316	712.8	0.0287	0.998	-0.3788	-4140	-4524	-1245
A*P + C*L + D*K + E*J + F*O + G*N + H*M		-0.03	-0.025	-8.29	0.0601	85.300	-0.6406	-0.0356	-683	-374.7	-0.030	-0.522	-0.1987	-4140	-3766	-1329
B*P + C*O + D*N + E*M + F*L + G*K + H*J		-0.025	-0.1025	13.07	0.3535	85.300	0.9719	0.0031	148	1377.8	0.07	0.05	0.0487	-4140	-5586	-729

N: number of individuals

3.2: Analysis of the prioritization system

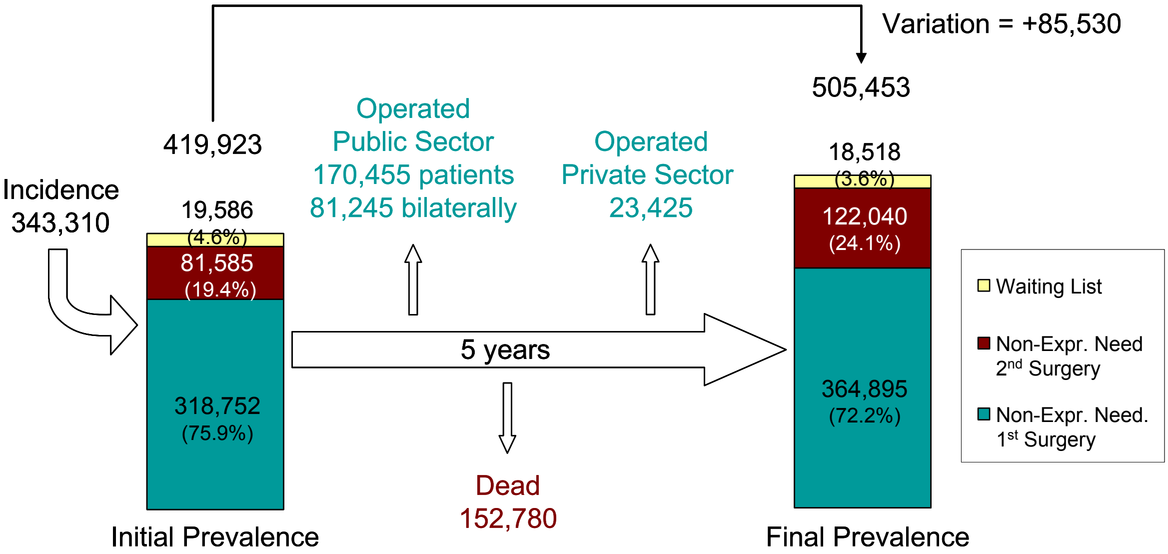
Appendix 2.3 contains a manuscript accepted for publication in the journal *Value in Health* with a summary of the methodology and the results of this section.

3.2.1: Current scenario

After concluding that the model gives valid and credible results, several outcome variables were compared between the FIFO system and the prioritization system using trials composed of several runs. The sample size of runs for these trials was calculated upon the results of a first simulation of 10 runs. The paired differences between the means of each run of the variable waiting time weighted by priority score had a mean of 2.3 months with a standard deviation of 0.21 months. Then, applying formula (4.2), a sample size of 20 trials was needed to achieve a precision of 0.11 months to estimate the 95% confidence interval for the difference in mean waiting time weighted by priority score.

Each run processed around 7,630 individuals, representing 1% of the simulated population. Figure 3.8 shows the evolution of the number of individuals in the model. Regardless of the waiting list discipline, the number of patients in “Non-Expressed Need” and the overall number of patients with need for surgery (also including patients on the waiting list) increased across the time horizon (results under the FIFO discipline are shown). “Non-expressed Need for First-Eye Surgery” represented 75.9% of overall initial need, “Non-Expressed Need for Second-Eye Surgery” represented 19.4% and the “Waiting List” represented 4.7%. After 5 years, overall need increased by 85,530 patients (a 20% increase): “Non-Expressed Need for First- and Second-Eye Surgery” increased by 14% and 50%, respectively. The number of patients on the waiting list was stable throughout the 5-year period, as expected due to the regulation mechanism. Of the 152,780 patients who died during the 5-year period, 6,020 (3.9%) did so while waiting for surgery. Of the 23,425 patients who underwent surgery in the private sector, 1,340 (5.7%) switched from the public waiting list.

Figure 3.8: Five-year evolution of the population with need for cataract surgery.



*: Results shown for the FIFO discipline only, as they were similar between disciplines.

For the comparison between FIFO and the prioritization system, simulation of the current scenario of the waiting list for cataract surgery (data from 2003-2004) showed that the mean raw waiting time for patients undergoing surgery in the public sector with no prioritization was 4.5 months (95% CI from 4.2 to 4.7). This mean waiting time was considered similar to the value of 4.38 months obtained from the health authority (CatSalut, Barcelona, October 2004) for the mean waiting time for cataract surgery in Catalonia, June 2004. When applying the prioritization system, the waiting time of operated patients was reduced to 3.8 months (95% CI from 3.6 to 4.0) (table 3.8).

Taking a look at raw waiting times, eyes operated under the prioritization system had lower waiting times (an overall mean of 0.65 months less, 95%CI from 0.55 to 0.74). However, as second eyes have lower priority scores than first eyes, the waiting time for second eyes was higher under the prioritization system. On the other hand, patients still waiting at the end of the simulation under the prioritization system had a mean waiting time of 5.75 months (95% CI from 5.39 to 6.12), which was 3.54 months longer than that for the FIFO system (95% CI from 3.24 to 3.84). Under the prioritization system, the waiting time of patients who died while waiting was 3.22 months longer (95% CI from 2.90 to 3.55) than that for the FIFO system (table 3.8), while the cases who switched to the private sector had similar waiting times between disciplines.

From table 3.8 one can calculate that, approximately, 34.5% of the operated cases and 34.2% of cases still waiting were second eyes. However, with the prioritization system, 33.8% of operated cases and 42.2% of cases still waiting were second eyes. The paired comparisons of the number of first and second surgeries show that, for the prioritization system, the number of second eyes operated was significantly lower and the number of second eyes still waiting was significantly higher.

Table 3.8: Waiting times for comparison between waiting list disciplines, results of 20-run trials.

	FIFO			Prioritization System			Paired differences		
	Mean	SD	95% CI	Mean	SD	95% CI	Mean	SD	95% CI
Waiting time weighted by priority score	**3.76**	**0.41**	**[3.58; 3.94]**	**2.22**	**0.32**	**[2.08; 2.36]**	**1.55**	**0.13**	**[1.47; 1.62]**
Raw waiting times									
Operated cases									
Overall									
N	2246.70	46.32	[2226.4; 2267]	2255.00	45.66	[2235; 2275]	-8.30	1.84	[-9.30; -7.30]
Mean	4.48	0.57	[4.23; 4.73]	3.84	0.45	[3.64; 4.03]	0.65	0.18	[0.55; 0.74]
SD	0.57	0.27	[0.45; 0.69]	5.36	0.44	[5.17; 5.56]			
1st surgery									
N	1470.70	31.16	[1457; 1484.4]	1491.80	32.85	[1477.4; 1506.2]	-21.10	6.54	[-24.66; -17.54]
Mean	4.48	0.57	[4.23; 4.73]	3.43	0.41	[3.25; 3.61]	1.05	0.23	[0.93; 1.17]
SD	0.57	0.28	[0.45; 0.69]	5.20	0.43	[5.01; 5.39]			
2nd surgery									
N	776.00	25.01	[765; 787]	763.20	26.55	[751.6; 774.8]	12.80	7.13	[8.92; 16.68]
Mean	4.49	0.57	[4.24; 4.74]	4.63	0.57	[4.38; 4.88]	-0.15	0.22	[-0.27; -0.03]
SD	0.57	0.27	[0.45; 0.69]	5.57	0.46	[5.37; 5.77]			
Cases still waiting									
Overall									
N	186.25	38.17	[169.5; 203]	188.10	34.63	[172.9; 203.3]	-1.85	11.69	[-8.21; 4.51]
Mean	2.21	0.47	[2.01; 2.42]	5.75	0.82	[5.39; 6.12]	-3.54	0.56	[-3.84; -3.24]
SD	1.24	0.25	[1.13; 1.35]	4.08	0.51	[3.86; 4.31]			
1st surgery									
N	122.55	24.69	[111.7; 133.4]	108.65	20.69	[99.6; 117.7]	13.90	10.17	[8.37; 19.43]
Mean	2.20	0.49	[1.99; 2.42]	5.72	0.87	[5.34; 6.1]	-3.52	0.52	[-3.80; -3.23]
SD	1.24	0.25	[1.13; 1.35]	4.04	0.56	[3.8; 4.29]			
2nd surgery									
N	63.70	15.21	[57; 70.4]	79.45	16.64	[72.2; 86.7]	-15.75	7.15	[-19.64; -11.86]
Mean	2.24	0.47	[2.04; 2.45]	5.81	0.94	[5.39; 6.22]	-3.57	0.76	[-3.98; -3.15]
SD	1.22	0.26	[1.11; 1.34]	4.12	0.48	[3.92; 4.33]			
Cases that switched to private from waiting list									
N	13.40	3.03	[12.1; 14.7]	13.45	3.25	[12; 14.9]	-0.05	1.28	[-0.74; 0.64]
Mean	4.71	0.51	[4.49; 4.93]	4.19	1.24	[3.64; 4.73]	0.52	1.34	[-0.21; 1.25]
SD	0.62	0.29	[0.49; 0.74]	5.40	1.14	[4.9; 5.9]			
Cases who died while waiting									
N	60.20	6.33	[57.4; 63]	53.30	10.70	[48.6; 58]	6.90	7.75	[2.69; 11.11]
Mean	2.19	0.28	[2.07; 2.31]	5.41	0.71	[5.1; 5.72]	-3.22	0.60	[-3.55; -2.90]
SD	1.35	0.14	[1.29; 1.41]	4.26	0.47	[4.06; 4.47]			

SD: Standard Deviation
95% CI: 95% Confidence Interval

The percentiles of the waiting time distribution show that, while all cases under the FIFO discipline waited between 3 and 6 months, a 50% of patients under the prioritization system waited for less than 3 days and 25% waited for more than 6 months. Under the prioritization system, 5% waited for more than 15 months, with a maximum of 18 months.

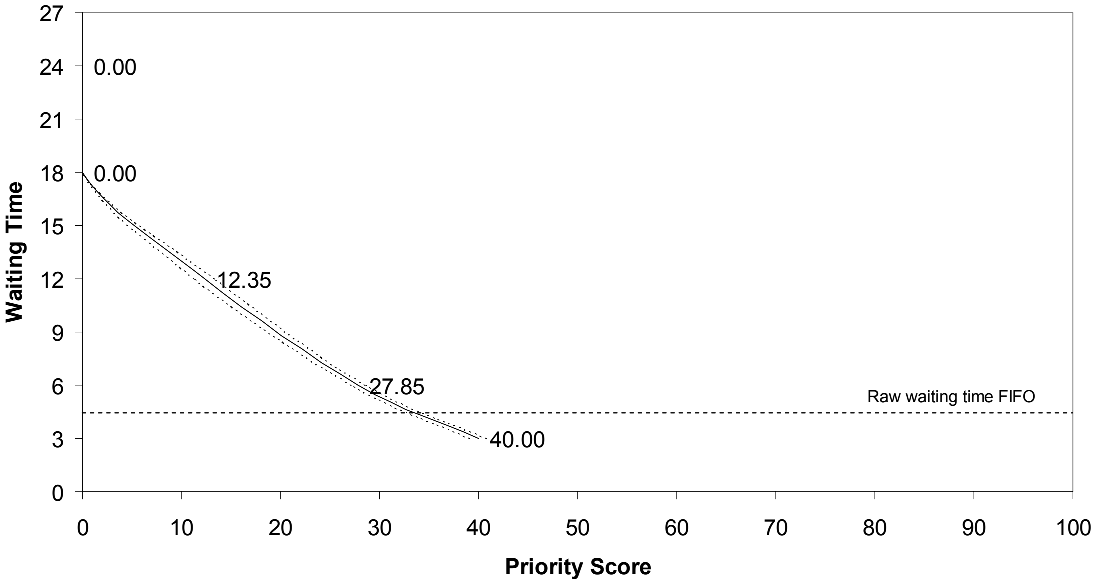
Table 3.9: Percentiles of the waiting time distribution, by waiting list discipline.

	Percentiles of waiting time (months)								
	Minimum	0.05	0.1	0.25	0.5	0.75	0.9	0.95	Maximum
FIFO	3.36	3.63	3.76	4.03	4.45	4.90	5.28	5.45	5.76
Prioritization System	0.00004	0.005	0.01	0.03	0.33	6.49	13.45	15.03	18.77

Figure 3.9 shows the minimum priority score needed to undergo surgery under an eventual warranty time. That is, patients with a priority score (at entry to the waiting list) higher than 40.0 points underwent surgery in less than 3 months. Conversely, patients with less than 12.4 points underwent surgery after 12 months. Figure 3.9 also shows which patients benefited from the prioritization system and which patients were penalized. Patients with priority scores higher than

27.9 points (56.8% of patients, according to the priority score distribution) had a waiting time of less than 6 months, and patients with priority scores higher than 35 points (48.0% of patients, according to the priority score distribution) had lower waiting times than the reference waiting time for the FIFO system.

Figure 3.9: Priority score thresholds, and 95% confidence interval, to achieve several warranty times (prioritization system).



The dynamic outputs about the evolution of the system through the five-year simulation horizon show that the mean priority score of patients on the waiting list decreased through time when the prioritization system was applied. However, after one year, a stationary level of priority around 10 points was achieved (figure 3.10). With regard to the proportion of patients waiting for second-eye surgery (figure 3.11), the proportion increased through time under the prioritization system, although it also stabilized after one year and a half. The first months with the FIFO system show a transitory stage, as the proportion stabilized after one year around 33%. This suggests that the input value for the initial proportion of second eyes in the waiting list (20.9% in table 2.13) may be biased. In fact, the value around 33% corresponds to the proportion of second-eye surgeries found in the Minimum Data Set.

Figure 3.10: Evolution through the time horizon of the priority score of the patients currently included in the waiting list, by waiting list discipline.

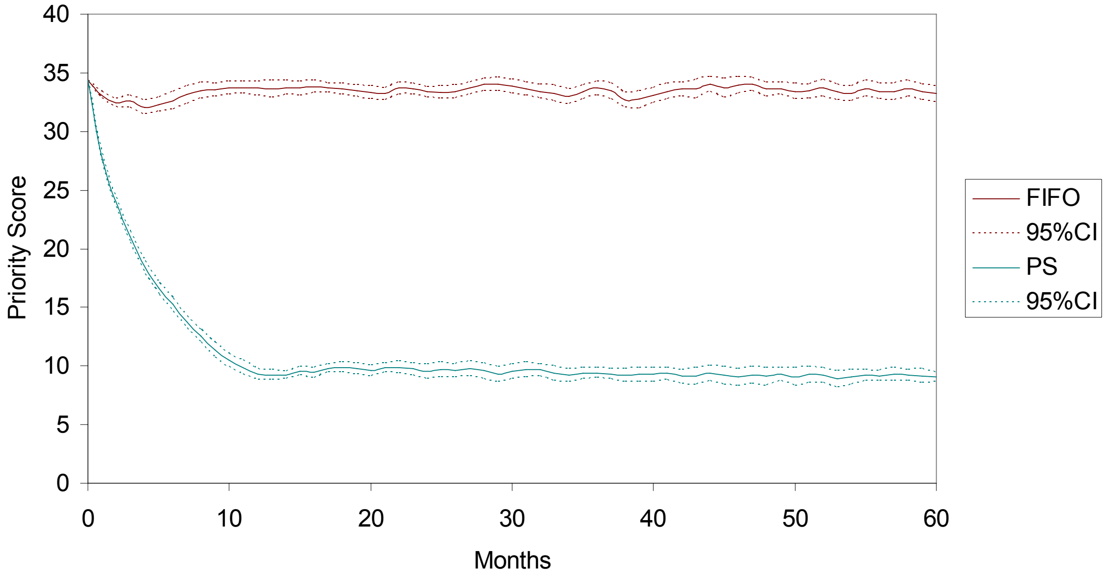
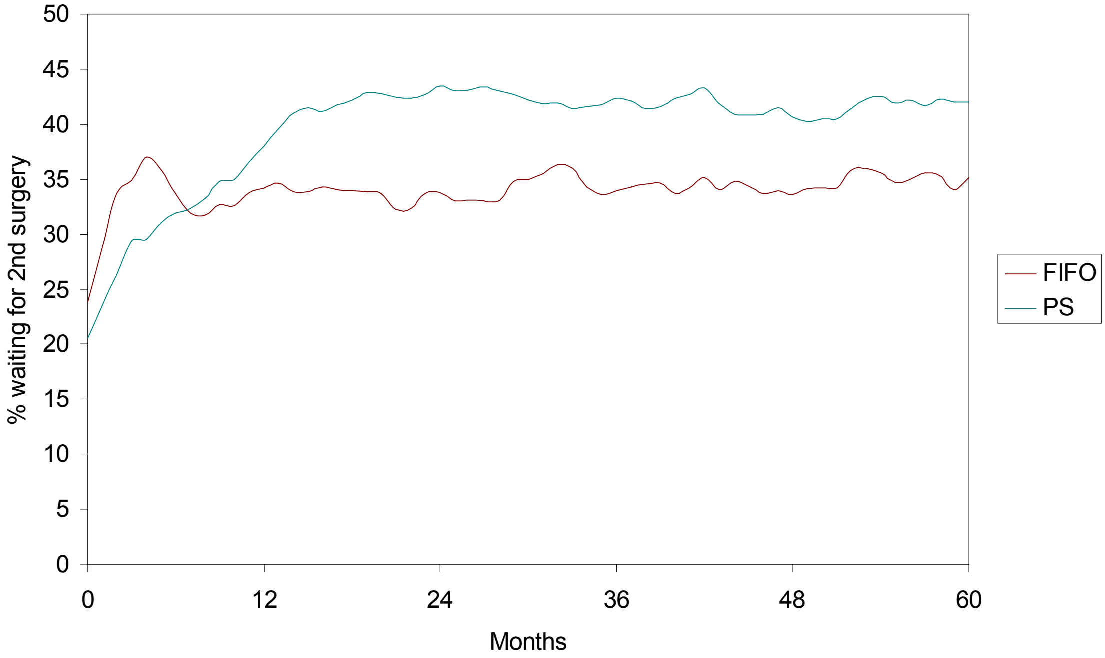


Figure 3.11: Evolution through the time horizon of the proportion of patients waiting for second-eye surgery currently included in the waiting list, by waiting list discipline.



3.2.2: Sensitivity analysis on waiting time

A two-way sensitivity analysis was performed by forcing different waiting time scenarios (by changing the number of patients on the initial waiting list backlog) crossed with waiting list discipline. The different mean waiting times for patients undergoing surgery under the FIFO discipline were used to identify scenarios for comparison.

Waiting times of operated patients were always higher under the FIFO system than under the prioritization system, the longer the raw waiting time, the greater the difference between disciplines (table 3.10). On the other hand, the waiting times of patients still waiting at the end of simulation were always higher under the prioritization system, although the differences between disciplines were similar among levels (table 3.10).

For all scenarios of waiting time for surgical patients under the FIFO discipline, the waiting time weighted by priority score under the prioritization system was lower (table 3.10). The waiting time weighted by priority score saved with the prioritization system was around 2 months. Moreover, the longer the raw waiting time, the greater the benefit (table 3.10). Figure 3.12 shows the benefit of applying the prioritization system for scenarios shown in table 3.10 and other scenarios. Figure 3.12 also shows that, the higher the raw waiting time, the higher the benefit of applying the prioritization system.

Table 3.10: Sensitivity analysis of raw and weighted waiting times by waiting list discipline and scenarios of raw waiting time of operated cases and paired differences between disciplines.

Mean raw waiting time										Paired differences in waiting time	
Operated patients		Patients still waiting		Patients who switched to the private sector		Patients who died while waiting		Mean waiting time weighted by priority score		Waiting time weighted by priority score	
FIFO	Prioritization System	FIFO	Prioritization System	FIFO	Prioritization System	FIFO	Prioritization System	FIFO	Prioritization System	Mean	95% CI
4.48	3.84	2.21	5.75	4.71	4.19	2.19	5.41	3.76	2.22	1.55	[2.17; 2.38]
6.96	5.80	3.28	6.98	7.22	6.02	3.26	6.21	5.43	3.71	1.72	[1.50; 1.97]
11.31	8.96	5.15	8.85	11.60	10.51	5.00	8.16	8.00	6.07	1.94	[2.23; 2.56]
15.53	12.04	6.99	10.37	15.83	13.00	6.84	9.28	10.27	8.12	2.15	[2.87; 3.26]
19.70	14.99	8.70	11.90	20.01	14.36	9.14	10.42	12.36	9.91	2.45	[4.47; 4.88]

FIFO: First-in, first-out. 95% CI: 95% Confidence Interval

Figure 3.12: Benefit of introducing the Prioritization System by raw time of operated patients under the FIFO (first-in, first-out) system.

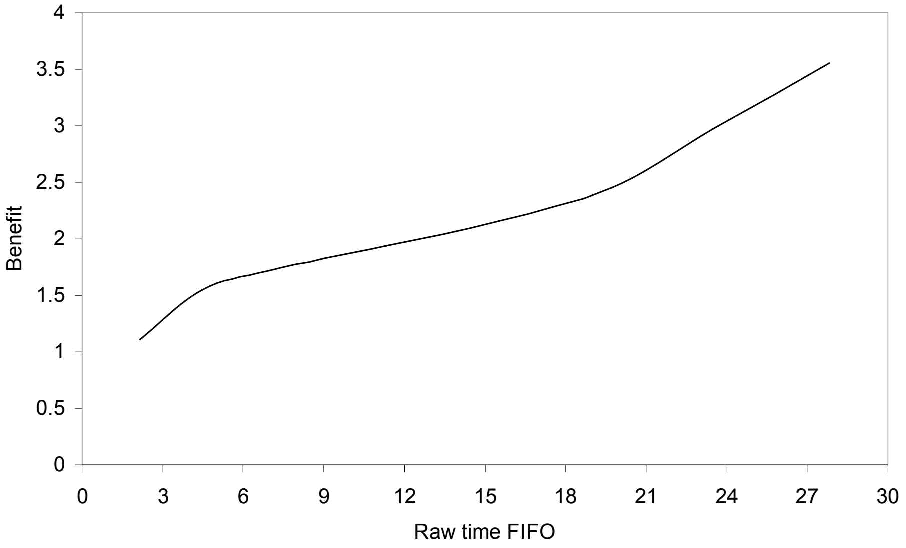
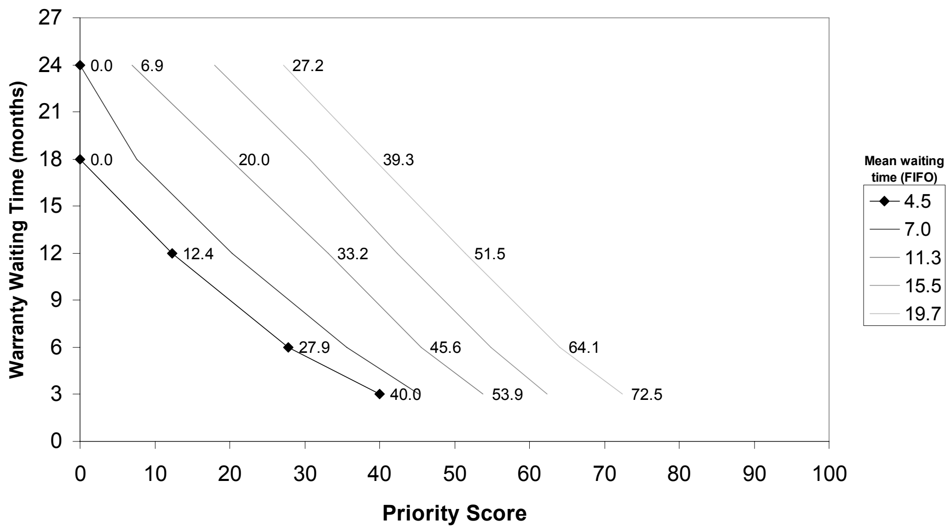


Figure 3.13 shows the minimum priority score needed to undergo surgery under an eventual warranty time for the scenarios in table 3.10. For scenarios with raw waiting times higher than the current scenario, the profile was similar, but the threshold of priority indicating the highest waiting times increased. For example, for a warranty time of 6 months, the minimum priority score increased from 27.9 points for the current scenario (4.5 months of raw waiting time) to 72.5 points for the scenario with 19.7 months of raw waiting time (figure 3.13). In all scenarios, patients with priority scores higher than 40 points (37.1%) had lower waiting times than the reference waiting time for the FIFO system.

Figure 3.13: Minimum priority score (x-axis) to achieve an eventual warranty time (y-axis).



*: Diamonds represent the results of the model in the scenario with current data. FIFO: First-in, first-out.

3.3: Needs assessment

Appendix 2.4 contains a manuscript under second review in the journal *British Journal of Ophthalmology* with a summary of the results of this section.

Another application of the model was to analyze the volume of unmet needs for cataract surgery. In this case, information on the demand in the public health system of Spain was included. Input data was obtained from five regions of Spain (Andalusia, Aragon, the Basque Country, the Canary Islands and Catalonia), which account for 18.68 million people (45.7% of the Spanish population).

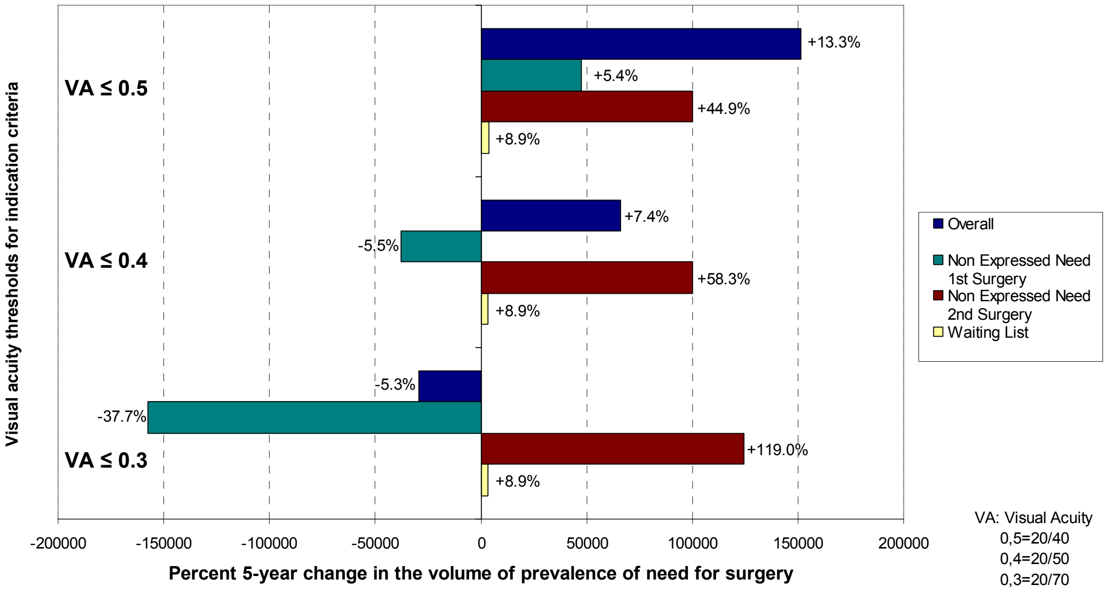
The model was replicated applying three different indication criteria based on any lens opacity under a given threshold for worse eye visual acuity: 0.3, 0.4 and 0.5 on the decimal scale were used. The least restrictive threshold was chosen to be 0.5 because, in most countries, it is the minimum legal visual acuity required for a driving license.[73]

Data from the NLES were used to analyze the distribution of worse eye visual acuity in people with prevalence of need. The distribution was calculated separately for people with bilateral cataracts and those who had already undergone surgery on one eye.

A sensitivity analysis of the surgery rate was performed to determine the extent to which the surgery rate would need to be increased to prevent the cataract backlog from increasing in the following 5 years.

The regions included in this study accounted for almost 6 million people aged 50 years old or older (32% of the overall population). The waiting lists accounted for 39,701 patients, representing 7.1%, 4.5% and 3.5% of the prevalence of need for surgery for visual acuity thresholds of 0.3, 0.4 and 0.5, respectively. Simulation started with a surgery rate of 16,626 surgeries per million inhabitants aged 50 years old or older. According to the tendency observed in previous years, the surgery rate increased during the 5-year simulation horizon, reaching an increase of 6.7% by the end of the period. The model predicted an overall volume of need for the year 2008 of almost 1.3 million people (a 13.3% increase), and almost 1 million (a 7.4% increase) for the 0.5 and 0.4 threshold scenarios, respectively (figure 3.14). When a visual acuity threshold of 0.3 was applied, a 5.26% decrease in the prevalence of need for surgery was observed after 5 years.

Figure 3.14: Five-year evolution of prevalence of need for surgery, divided by category and by different visual acuity thresholds for indication criteria.



The category of the model showing the greatest increase in all scenarios was "Non-Expressed Need for Second-eye Surgery", doubling its volume in 5 years when the 0.3 threshold was used (figure 3.14). Otherwise, "Non-Expressed Need for First-eye Surgery" decreased by 37.69% and 5.53% for the 0.3 and 0.4 visual acuity scenarios.

The increment in cataract surgery rate needed to prevent the cataract backlog from increasing was 60% for indication criteria including a 0.5 visual acuity threshold, and 50% for a 0.4 threshold.

The worse eye visual acuity distribution of the population with unmet need for surgery of the NLES[10] database according to indication criteria is shown in table 3.11. For bilateral cataract, the most frequent level of visual acuity was between 0.3 and 0.4 when the threshold was 0.5 or 0.4. However, when the threshold was 0.3, the distribution among the levels of visual acuity (0.1 or less, between 0.1 and 0.2, and between 0.2 and 0.3) was more balanced. The worse eye visual acuity distribution of aphakic cases showed the opposite pattern: the most frequent category was a visual acuity of 0.1 or less regardless of the indication criteria, while better levels of visual acuity (over 0.2) presented the lowest percentages (table 3.11).

Table 3.11: Visual acuity distribution among population with prevalence of need defined according to different criteria for visual acuity. Data source: North London Eye Study (n=1,425).

	Bilateral cataracts				Aphakia (one eye operated)			
		Thresholds				Thresholds		
	N	VA≤0.5	VA≤0.4	VA≤0.3	N	VA≤0.5	VA≤0.4	VA≤0.3
VA≤0.1	58	12.2%	15.0%	26.6%	17	32.7%	34.0%	44.7%
0.1<VA≤0.2	87	18.4%	22.5%	39.9%	15	28.8%	30.0%	39.5%
0.2<VA≤0.3	73	15.4%	18.9%	33.5%	6	11.5%	12.0%	15.8%
0.3<VA≤0.4	168	35.4%	43.5%		12	23.1%	24.0%	
0.4<VA≤0.5	88	18.6%			2	3.8%		

VA: Visual acuity of the worse eye. Percent columns add up to 100%.

3.4: Transferability of the methodology

3.4.1: Analysis of the variations among Spanish Regions

Appendix 2.5 contains a manuscript accepted for publication in the journal *BMC Health Services Research* with a summary of the results of this section.

The information needed to estimate the model's parameters was compiled for each region studied (Andalusia, Aragon, Basque Country, Canary Islands and Catalonia). The Hospital Discharge Minimum Data Set of at least three consecutive years was obtained for each of the five regions. Prevalence estimates were projected onto the population of each of the five regions studied and incidence was also obtained. The number of inhabitants in each region, as well as the number of deaths by age and sex, in 2001 was obtained from the Spanish National Statistics Institute (INE).

The number of monthly entries to the waiting list in 2003 and the number of patients waiting were obtained from the waiting lists register of each region's health system. The pilot study to assess the introduction of the prioritization system in clinical practice with data from Andalusia and Aragon[27] was used to calculate the distributions of priority score at entry to the waiting list, as well as the proportions of patients with bilateral cataract or aphakia (those who had already undergone surgery in one eye) for Andalusia and Aragon. Different empirical distributions were used for bilateral and aphakic patients because statistically different scores were found for first- and second-eye surgery. In the absence of priority data for the Canary Islands and the Basque Country, in these two regions we used a pooled priority distribution of the three regions for which priority data was available (Andalusia, Aragon and Catalonia).

Geographical variation was measured through rates (number of occurrences per 100,000 inhabitants), high/low ratio for rates, and coefficient of variation, defined as the ratio of the standard deviation relative to the mean.

Different patterns of aging were found among regions: Aragon, Catalonia and the Basque Country showed the greatest ageing, with more than 34% of their populations being over 50 years of age. In Andalusia and the Canary Islands, less than 30% of the population was over 50 years old. The estimated percentage of the population with need for cataract surgery was between one-fifth and one-fourth of the population over 50 years of age in all the regions studied (table 3.12).

Table 3.12: Descriptive information on senile cataracts in the autonomous regions studied.

	Regions				
	Andalusia	**Aragon**	**Basque Country**	**Canary Islands**	**Catalonia**
Population	7,357,558	1,204,215	2,082,587	1,694,477	6,343,110
Population over 50 years	2,142,202	457,631	744,419	449,819	2,164,467
% Population over 50 years	29%	38%	36%	27%	34%
Prevalence					
% Prevalence in people over 50 years	22.40%	25.80%	22.80%	20.40%	23.50%
Surgery rate*					
Yearly rate	405	529	607	440	685
Surgery rate in people over 50 years	1,391	1,392	1,724	1,650	2,156
Waiting List	9,205	2,826	2,313	5,771	19,586
% of prevalent population	1.90%	2.40%	1.40%	6.30%	3.80%
Waiting List entry rate (2003)*	612	755	656	602	733
Mean priority (at entry to the waiting list)					
First surgery (SD)	47.1 (19.9)	28.3 (22.4)	39.3 (22.7) †	39.3 (22.7) †	36.5 (22.8)
Second surgery (SD)	36.8 (22.3)	13.7 (11.7)	28.8 (22.6)†	28.8 (22.6)†	26.1 (22.2)

* N° of ocurrences/ 100,000 inhabitants

† A pooled Distribution was used in the absence of empirical data

SD: Standard Deviation.

A coefficient of variation (COV) of 0.24 was found in surgery rates among the regions studied. In particular, the surgery rates found in Catalonia were greater than those in the Canary Islands and Andalusia (high/low ratio 1.76 and 1.69 respectively). The rates of entries to the waiting list were more homogeneous among regions than the surgery rates (COV: 0.1). The percentage of the prevalent population included on a waiting list was less than 6.5% in all regions. This percentage varied among the regions studied (COV: 0.62), table 3.12. The results of the pilot study[26,27] showed significant differences in the mean priority score at entry to the waiting list among the three regions for which data were available (Andalusia, Aragon, Catalonia). Priority scores showed a dispersion that covered the entire range of possible values. The 25th and 75th percentiles of the assigned priority scores were 34 and 62 points, respectively, for first-eye surgery and 20 and 53 points for second-eye surgery in Andalusia, 7 and 46 for first-eye surgery and 6 and 21 for second-eye surgery in Aragon, and 20 and 52 for first-eye surgery and 6 and 41 for second-eye in Catalonia.

Simulation of the current waiting list scenario (FIFO) showed that the raw mean waiting time of patients who underwent surgery in the public sector varied from 1.97 months (95% CI 1.85; 2.09) in the Basque Country to 10.01 months (95% CI 9.90; 10.11) in the Canary Islands, table 3.13. When the prioritization system was applied, the mean waiting time was reduced to 0.88 months weighted by priority score (95% CI 0.82; 0.93) in the Basque Country (lowest value) and 5.42 months (95% CI 5.36; 5.48) in the Canary Islands (highest value), table 3.13. However, patients still waiting at the end of the simulation period had longer waiting times with the prioritization system than with the FIFO discipline. Differences of 3.74 months (95% CI 3.33; 4.15) in Andalusia, 2.35 months (95% CI 2.13; 2.57) in Aragon, 3.39 months (95% CI 3.06; 3.72) in the Basque Country, 3.79 months (95% CI 3.56; 4.02) in the Canary Islands and 3.54 months (95% CI 3.24; 3.84) in Catalonia were found. Patients who died while on the waiting list also had longer mean waiting times with the prioritization system than with the FIFO discipline, with waiting times increased by 3.03 months (95% CI 2.69; 3.37) in Andalusia, 2.09 months (95% CI 1.81; 2.37) in Aragon, 2.86 months (95% CI 2.43; 3.30) in the Basque Country, 3.09 months (95% CI 2.80; 3.39) in the Canary Islands and 3.22 months (95% CI 2.90; 3.55) in Catalonia.

Table 3.13: Raw waiting times (FIFO) and times weighted by priority score (prioritization system).

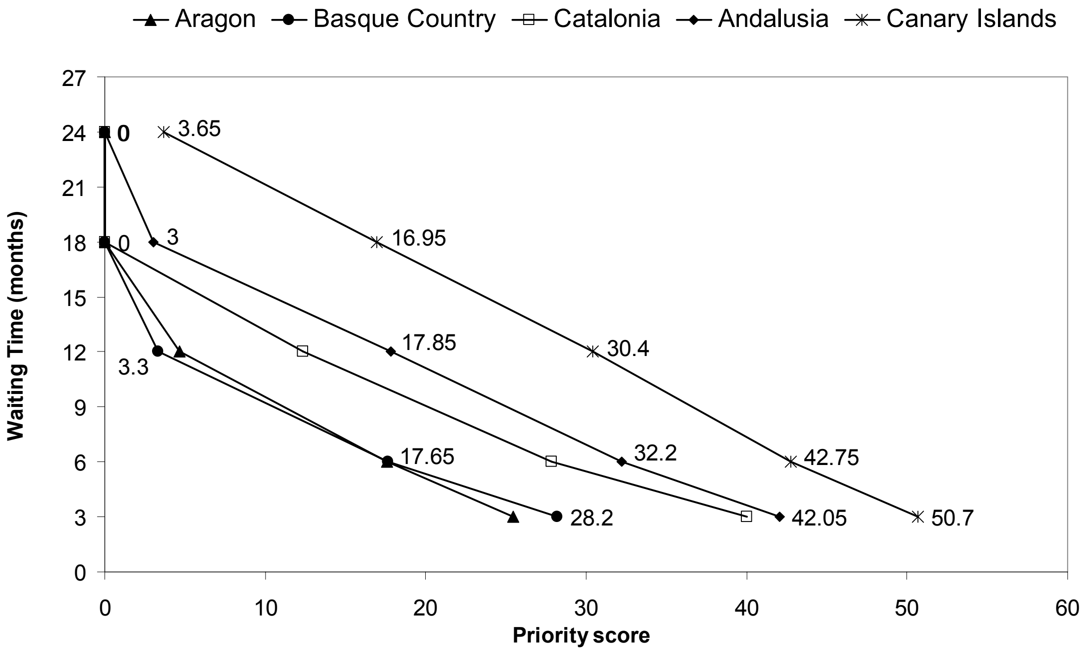
	Raw waiting times (FIFO)		Waiting times weighted by priority score			
			Prioritization system		Benefit of the priorization system	
	Mean	95%CI	Mean	95%CI	Mean	95%CI
Andalusia	2.91	[2.87; 2.95]	1.64	[1.61; 1.67]	0.98	[0.96; 1.00]
Aragon	5.19	[5.10; 5.28]	2.54	[2.48; 2.60]	1.56	[1.53; 1.59]
Basque Country	1.97	[1.85; 2.09]	0.88	[0.82; 0.93]	0.94	[0.88; 1.00]
Canary Islands	10.01	[9.90; 10.11]	5.42	[5.36; 5.48]	1.87	[1.83; 1.91]
Catalonia	4.48	[4.23; 4.73]	2.22	[2.08; 2.36]	1.55	[1.47; 1.62]

FIFO: First-in, first-out. 95%CI: 95% Confidence Interval

The overall mean waiting time weighted by priority score, that is, considering each patient who entered the waiting list (operated patients, patients still waiting at the end of the simulation period, patients who switched to the private sector and patients who died while on the waiting list), was reduced in all the regions when the prioritization system was applied. The waiting time weighted by priority score saved by the prioritization system was 0.98 months (95% CI 0.96; 1.00) in Andalusia, 1.56 months (95% CI 1.53; 1.59) in Aragon, 0.94 months (95% CI 0.88; 1.00) in the Basque Country, 1.87 months (95% CI 1.83; 1.91) in the Canary Islands and 1.55 months (95% CI 1.47; 1.62) in Catalonia, table 3.13.

Figure 3.15 shows the relationship between the priority score and the waiting time under the prioritization system, i.e., the minimum priority score required for a patient to undergo surgery under an eventual warranty time. Patients with a priority score at entry to the waiting list of 40 or more points waited for 3 months or less in Aragon, the Basque Country and Catalonia. However, in Andalusia and the Canary Islands, priority scores of 42 and 51 points were needed to undergo surgery in less than 3 months. Patients waiting for 12 months or more had priority scores of 3, 4, 12, 17 and 30 or less for Aragon, the Basque Country, Catalonia, Andalusia and the Canary Islands, respectively.

Figure 3.15: Minimum priority scores for warranty times.



3.4.2: Application to needs and demand for knee arthroplasty

3.4.2.1: Methodology

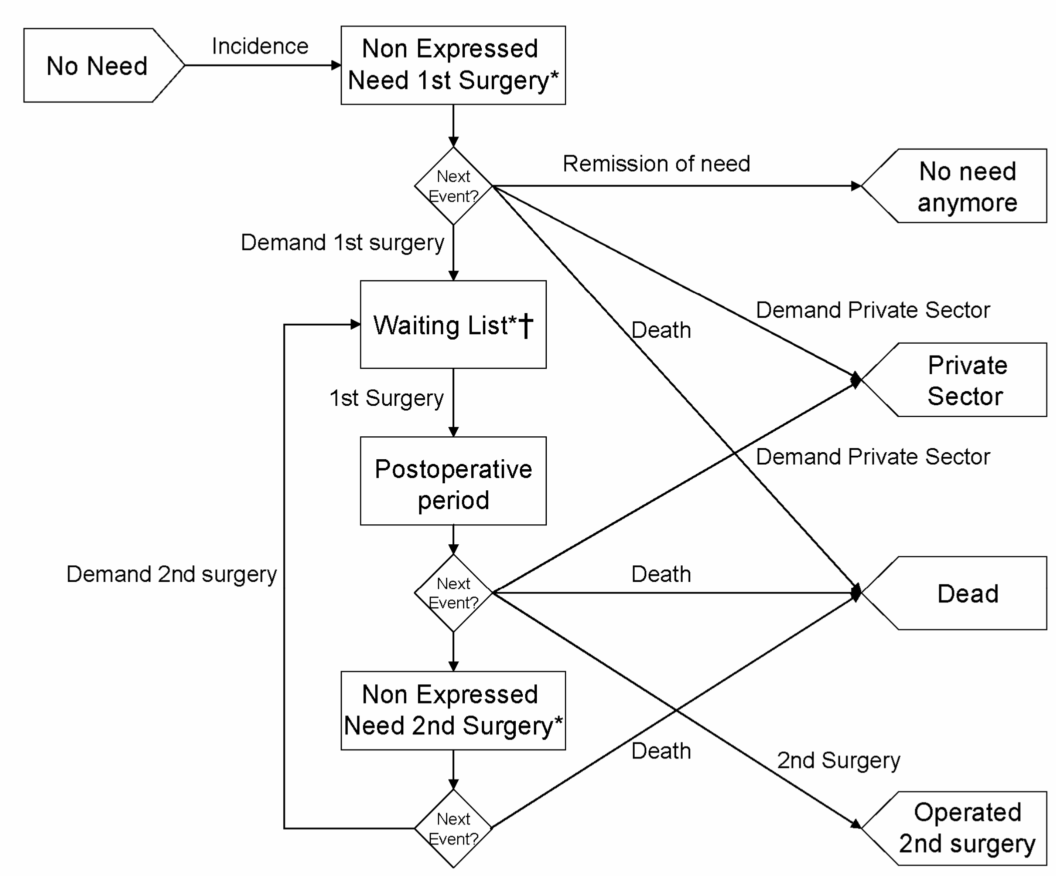
Conceptual model

The conceptual model was discussed and agreed on by a multidisciplinary panel of experts that included epidemiologists, statisticians, health economists, and traumatologists. The model referred to subjects from the general population, aged 50 years or older, at risk of need for knee replacement, and focused on demand in the health system of Spain, which provides universal coverage. Information was obtained from four regions of Spain (Andalusia, Aragon, Canary

Islands and Catalonia), which account for 16.6 million people (about 40% of the population of Spain).

The need for knee arthroplasty was defined as the prevalence of need for surgery according to indication criteria. Criteria for surgical indication were defined as presenting symptoms of knee osteoarthritis (pain) confirmed through radiological examination. The conceptual model (figure 3.13) was similar to that of cataract surgery: like cataracts, knee osteoarthritis is an age-related pathology, mostly bilateral, and interventions are performed on one knee at a time. However, some additional elements were added to the model for knee arthroplasty. First, an event called 'Remission of need' was allowed from 'Non-Expressed Need 1st Surgery' to a new exit point called 'No need anymore' because data analysis showed that, as age increased, the volume of need for surgery decreased, even though knee osteoarthritis is a chronic disease. This was possibly due to the competing risks that may contraindicate surgery. Second, a 'Postoperative Period' was included in the model because the decision on operating the second knee cannot be taken before a postoperative period of about 6 months after the first surgery.

Figure 3.16: Conceptual model for need and demand for knee arthroplasty.



*: Prevalence of need is divided among these 3 categories.
†: Cases in the waiting list have the priority score as an additional attribute.

The model included the following assumptions: 1) incident cases presented bilateral knee osteoarthritis (because osteoarthritis is an age-related disease); 2) surgery indication is always appropriate; 3) there was no return from the private sector to the public sector waiting list; 4) demand depended on supply capacity; 5) the level of need cannot improve through time; 6) the simulation horizon was small enough to consider that evolution of the population (in age and gender) and incidence remained constant through the time horizon; 7) patients are operated on one knee at a time.

Parameter estimation

The methodology developed for cataract surgery was used to estimate the parameters for the knee arthroplasty model. A summary of results is included in table 3.14

Information on prevalence of need of knee arthroplasty by age and sex was obtained from a population-based study on the prevalence of knee osteoarthritis in the Basque Country (in the north of Spain).

Table 3.14: Summary of estimated parameters for the knee arthroplasty model.

Parameter	Value	
Related to initial state		
Non Expressed Need 1st Surgery Backlog	490,054	
Non Expressed Need 2nd Surgery Backlog	864,480	
Waiting List Backlog (December 2004)	15,005	
Proportion of patients waiting for 2nd surgery (per one)	0.15	
Static parameters		
Incident cases per month	N_I = 1,577	
Number of cases operated in the private sector per month	N_P = 225	
Postoperative time distribution	*Normal* (6, 0.2)	
Proportion of cases of the waiting list who switch to the private sector (per one)	0.14	
Top limit for waiting list contents (self-regulation)	0.15	
Increase in priority score (points)	0.67	
Time between revisions of priority score (months)	1	
Mortality hazard (Gompertz function)		
Male	$0.000032\ e^{0.0972155\ \mathrm{age}}$	
Female	$0.000004\ e^{0.1175802\ \mathrm{age}}$	
Dynamic parameters		
Number of surgeries per month	$N_S(t) = 855 + 105\ ln(36+t)$	*
Probability of second eye surgery	$p(t) = 0.1047 + 0.0315\ ln(16+t)$	**
Number of bilateral cases entering the waiting list per month	$N_E(t) = N_S(t\text{-}1) + 256.14$	†

*: from 1,231.27 at t=0 to 1,334.26 at t=60

**: from 0.192 at t=0 to 0.241 at t=60

†: from 1,484.45 at t=0 to 1,589.30 at t=60

Simulation and analysis of results

We calculated, through the fixed-sample-size procedure[60] the number of replicates needed to obtain a prespecified precision of 0.13 months in estimating the difference in waiting time weighted by priority score between the FIFO and the prioritization system disciplines. First, we ran 10 replicates of the model and a standard deviation of 0.2 months was obtained. This value was used to calculate the sample size with a 95% confidence level and resulted in 20 replications.

Values of 6, 12, 24, 36 and 48 months were used to calculate the thresholds of priority score according to eventual warranty times.

3.4.2.2: Results

The mean waiting time of 12.55 months (95% confidence interval [CI] from 12.33 to 12.76, table 3.15) under the FIFO discipline was considered representative of the actual situation. The results were also validated by changing the waiting list discipline from FIFO to the prioritization system to assess its impact on the behavior of the system, and the resulting differences were in the expected direction.

For the comparison between FIFO and the prioritization system, simulation showed that the mean raw waiting time for patients undergoing surgery in the public sector was reduced to 6.7 months (95% CI from 6.6 to 6.9) (table 3.15). However, patients still waiting at the end of the simulation under the prioritization system had a mean waiting time of 17.5 months (95% CI from 16.9 to 18.0), which was 11.3 months longer than that for the FIFO system (95% CI from 10.7 to 11.9). Under the prioritization system, the waiting time of patients who died while waiting was 5.6 months longer (95% CI from 4.4 to 6.7) than that for the FIFO system (table 3.15).

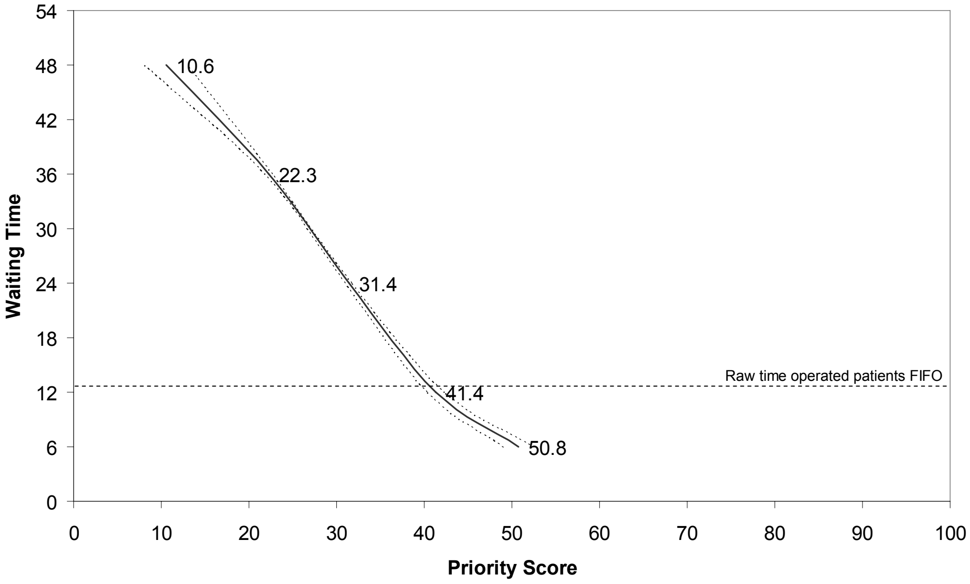
Table 3.15: Raw and weighted waiting times of patients included in the waiting list stratified by their way out. Comparison between waiting list disciplines.

	FIFO		Prioritization system		Benefit	
	Mean	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
Raw waiting times						
Operated patients	12.55	[12.33 ; 12.76]	6.74	[6.58 ; 6.89]	5.81	[5.53 ; 6.08]
Patients still waiting	6.13	[5.91 ; 6.35]	17.45	[16.93 ; 17.97]	-11.32	[-11.91 ; -10.72]
Patients who switched to private from waiting list	12.96	[12.72 ; 13.20]	7.25	[6.08 ; 8.42]	5.71	[4.30 ; 7.11]
Patients who died while waiting	6.54	[6.32 ; 6.77]	12.11	[11.19 ; 13.02]	-5.56	[-6.73 ; -4.40]
Waiting time weighted by priority score	10.39	[10.24 ; 10.54]	5.90	[5.79 ; 6.01]	4.49	[4.39 ; 4.59]

FIFO: First-in, first-out. 95% CI: 95% Confidence Interval. Benefit: difference in waiting time paired by run.

Figure 3.17 shows the relationship between the priority score and the waiting time. The x-axis indicates the minimum priority score needed to undergo surgery under an eventual warranty time (y-axis). That is, patients with a priority score (at entry to the waiting list) higher than 50.8 points (95% CI from 49.0 to 52.6) underwent surgery in less than 6 months. Conversely, patients with less than 22.3 points (95% CI from 21.9 to 22.7) underwent surgery after 36 months. Figure 3.17 also shows which patients benefited from the prioritization system and which patients were penalized. Patients with priority scores higher than 41 points presented waiting times lower than the reference waiting time for the FIFO system and patients with priority scores lower than 38 presented higher waiting times.

Figure 3.17: Minimum priority score (x-axis) to achieve an eventual warranty time (y-axis).



*: Dashed lines indicate the 95% confidence interval for the priority score.

Chapter 4: Discussion

4.1: Methodological contribution

The present thesis has contributed to establish a methodology to solve a type of problem in the context of health services research that, although it has been studied before, any of the published studies used a methodological approach like the one presented here. The thesis has shown the steps to apply the discrete-event simulation technique, which is widely used in other disciplines, to the analysis of needs and demand for cataract surgery. A computerised model, which has been shown to be useful and transferable to other sets of input data or other types of elective surgeries, has been obtained.

Virtual experimentation is specially interesting in health services research because it is difficult to experiment with health services. They are complex: an important amount of unknown or unmeasurable variables intervene in health services and there are no specific studies gathering data on all variables and their relationships. Although the model has been simplified to obtain more reliable results (which may limit validity), our model is more complex than previous models used for similar purposes. It integrates a relevant amount of variables and the technique used allows doing sensitivity analyses to modify the value of a variable for which the estimation is uncertain.

Approaching healthcare systems through mathematical models is difficult because of the inherent complexity of such systems. Several attempts to simulate specific health services have been published in the medical literature. Waiting lists fit the requirements to be modeled as queues and have been analyzed as such in several studies[17,56,57]. In the context of transplants, for example, waiting lists reflect the actual need for the surgical procedure. However, in the context of elective surgery, if the objective is estimating population's volume of need for surgery, waiting lists represent a management artifact only and a model with a wider perspective should be built. This means several challenges. First, the system to be observed to gather knowledge about the problem is not only the healthcare system, but also the population not in contact with the healthcare system who may or may not need the health service of the study. This implies that information should be gathered from different sources with different levels of quality and availability. Second, there is no data on the real-world scenario to be compared quantitatively, using statistical tests, with the results of the model for validation purposes. Validation should be carried out by presenting the results of the model to a panel of experts who should evaluate the credibility, robustness and usefulness of the model.

A main methodological contribution of this thesis is the systematization of the processes to collect input data in order to integrate them in the model, not only with the perspective of solving the problem, but also with the objective of making the model transferable. The ideal situation is when data can be collected directly from the system in a way that the desired information is obtained. However, in the context of health services research this can be overwhelming and available data, mostly from administrative records or research studies, should be used. The characteristics of the technique and the knowledge of the system to be represented should be taken into account in the process of obtaining the parameter estimations from the available data. In fact, as the model is stochastic, dynamic and the event probabilities change through time, neither analytical solution, nor Poisson-type queues can be used. Then, special attention should be paid to identifying and modeling the uncertainty related to the input parameters.

In order to assess robustness and validity of the model, the design of experiments technique was used to evaluate the impact of controlled variations in the input values on the output of the model. The range of variation of the inputs, according to the variability of their estimations, was used to define scenarios to execute the model. As the outputs obtained were bounded and stable, the model was considered as robust and with predictive capacity.

The model was analyzed as a terminating simulation. This type of analysis was appropriate for two reasons. On one hand, we were interested in analyzing the behavior of the system in the mid-term. Being a healthcare related system, it is not plausible to assume that the current parameter estimation would be correct in the long-term, thus, it is not reasonable to expect the model to reach a steady state. On the other hand, the model results show an increasing tendency of the number of individuals with need for surgery, confirming the lack of stationarity of the system.

The model initial conditions reproduced the current distribution of the population with need for surgery, thus, a warm-up period was not needed to provide an initial state to the model. In fact, the subjects of the initial state were included in all the analyses except for the analysis of waiting times, in which the patients on the waiting list at the beginning of the simulation were removed because their waiting times were left-truncated.

4.2: Interpretation of results

The model described allows several factors that are commonly used separately by decision-makers to be integrated into a complex but easy to understand decision model. The model allowed assessing the benefit of applying a prioritization system and its variations by waiting time and by geographical areas. The model was also useful to predict the future prevalence of need for cataract surgery related to trends in the population and in surgery supply. Moreover, the methodology was easily adapted to obtain a model for another elective surgery such as knee replacement.

4.2.1: Prioritization system

Our findings show the benefit of a prioritization system based on need for surgery as opposed to the routinely used FIFO system, based on waiting time, in terms of minimizing the impact of waiting in patients with surgical indication because surgeries are assigned according to the level of need for the patients. When assessing geographical variations, we found that the benefit of applying the prioritization system varied substantially, depending on the specific characteristics of each region's local health system. Previous experiences of using discrete-event simulation to assess the impact of needs-based waiting list management strategies on waiting time for cataract surgery concluded that assigning surgery by priority criteria was more beneficial than assigning surgery by waiting time[16,17,56].

The model shows that the prioritization system was more beneficial than allocating surgery by waiting time only. Given the same number of surgeries, the prioritization system distributes waiting time according to priority; thus, patients with greater need wait less time. The mean benefit was 1.54 months less waiting time, weighted by priority. Moreover, the benefit of the prioritization system was greater for scenarios with longer waiting times. Currently, in Catalonia, as in other countries such as the United Kingdom, Canada or Sweden, a waiting-time guarantee of 6 months has been established and waiting times have been reduced. This reduction was reflected in our model. However, or results were useful to show the benefit of prioritization for longer waiting times and that waiting lists are an artifact because a substantial volume of unmet needs remain in the population in addition to waiting lists, even though cataract surgery is a highly cost-effective procedure. The guarantee time of 6 months was complied with in 56.8% of patients in our model (those with priority scores higher than 27).

Although the prioritization system was more beneficial, patients with lower priority scores had excessive waiting times. For example, patients with less than 12 points (23.6% of patients) would wait for 12 months or longer. Unless supply is increased, an excess waiting time of 1 year would exclude these patients from the system. That is, given a level of supply, the model allows knowing which patients can receive the intervention under a waiting time 'socially reasonable'. Moreover, in our model, if the priority score had not been increased to take into account worsening of clinical criteria over time, these patients would never undergo surgery.

Several studies have observed geographical variations in clinical practice worldwide[74]. Most of the results found in other countries can be extrapolated to Spain, which offers universal coverage. In agreement with previous studies[75,76], the variation in clinical practice found among regions is notable. The results obtained suggest that prioritization systems reduce geographical variations in waiting time in patients with higher levels of need, that is, they improve the system's equity despite differences in supply.

Although based on individual data, waiting time weighted by priority score can be considered an overall measure of benefit since it took into account the priority scores of all patients who had been assigned a priority score. The impact of waiting time on each individual depends on his/her level of priority and the benefit in terms of social efficiency would depend on several factors. First, on the mean waiting time under the FIFO discipline because the longer the waiting time, the greater the benefit. However, other factors should be taken into account, such as variability of priority levels and waiting list volume. For an extreme scenario in which all patients on the waiting list had the same priority score, prioritization would have no impact. At the opposite end of the spectrum, wide variations in priority score would imply a greater social impact, penalizing low priority patients, but making prioritization systems more necessary to ensure equity. To prevent indefinite waits in patients with low priority scores, the priority score of each patient was linearly increased during the waiting period by taking into account worsening of clinical criteria over time. Other authors have included time in the prioritization system or on waiting list management. Everett [56] included time as an explicit criterion in a priority score based on urgency, waiting time and expected operating hours and bed days. Fantini et al.[17] added a function of waiting time to a priority score based on visual acuity and limitation. Tuft et al.[16] took into account a maximum acceptable waiting time. All concluded that assigning surgeries according to priority criteria was more beneficial than by waiting time only, although patients with low priority scores had long waiting times.

The variables that appeared to have the greatest influence on the benefit obtained from the prioritization system and its impact in the waiting time were the variability in the priority scores at entry to the waiting list, the surgery rate and the waiting list volume. It is expected that the greater the waiting list and the lower the surgery rate within each region, the greater the benefit of introducing the prioritization system. Moreover, the higher the variability within each region in the priority scores assigned to patients, the higher the impact that can be expected from the prioritization system. If all patients had the same priority score, prioritization would have no impact.

4.2.2: Needs assessment

Our model anticipated an increase in the number of people with need for surgery in a 5-year time horizon, indicating that the increase in the older population played a greater role than that in the number of surgeries. To our knowledge, this is the first study that uses discrete-event simulation to assess population needs for elective surgery, specifically cataract surgery. Minassian et al.[5] used the systems dynamics methodology to predict the need for cataract surgery in England and Wales and tested some actions to prevent an increase in the cataract surgery backlog. Congdon et al.[77] pooled the results of several population-based studies and projected prevalence estimates to the US population of the year 2020. In view of the results of these studies, the increase found for the overall need for surgery was expected.

The model was also used to calculate which increment in the surgery rate would be needed to prevent the cataract backlog from growing, resulting in increments of 60% and 50% for visual acuity thresholds of 0.5 and 0.4, respectively. This would result in cataract surgery rates of 8,364.8 and 7,842 per million inhabitants, which are similar to the cataract surgery rates in other countries. In fact, the current cataract surgery rate in Spain is low compared with other developed countries.

The most important increase involved patients with need for second-eye surgery, which was (obviously) a consequence of previously performed first-eye surgeries. Thus, these patients represent people whose disease has been partially treated and who could benefit from second-eye surgery[78,79]; moreover, these individuals are more conscious of their need and have greater knowledge of how to access treatment. Results on visual acuity for aphakic cases show important visual impairment in the worse eye, as the most frequent categories were those under a visual acuity of 0.2, regardless of the indication threshold. Despite most ophthalmologists would not prioritize aphakic patients with good visual acuity in the operated eye, it is expected that they would have a good result from surgery in their cataractous eye.

Cataract surgery is an elective, highly cost-effective procedure[19]. However, a substantial volume of need for cataract surgery remains in the population, in addition to waiting lists. Waiting lists cannot be used as an indicator of unmet needs, as they represent a small proportion of the overall need, that is, waiting lists only include people who have accessed the health services and, thus, would substantially underestimate the volume of unmet needs. It is important to know the level of need for the population meeting indication criteria, as there is evidence of absence of prioritization of people with unmet needs. Data on the level of a priority score at entry to a waiting list in Spain show wide variability[26].

The visual acuity distributions of people with prevalence of need showed a wide variability covering the entire range of visual acuities under the indication threshold. Thus, when the current supply cannot be increased to meet overall need, prioritisation should be applied prior to the entry to the waiting list, that is, at indication of surgery, in order to increase the system's efficiency by operating in a first place those who would derive a higher benefit. However, the threshold would need to be determined.

Moreover, the waiting list volume remained stable in the model because a self-regulation mechanism was forced. The model has shown that, for those patients expressing need, the public health system can offer a reasonable waiting time over a certain level of priority.

4.2.3: Decision-making recommendations

In the present study, the variability among regions found in surgery rates was not related to demand or to the level of need of the population on the waiting list. This lack of association indicates the need to improve the effectiveness of some management policies. Less than 6.5% of the population with need for surgery is included on a waiting list and there is wide variability in the priority scores assigned. Waiting lists do not represent unmet needs, but rather an auto-regulation mechanism of the health system. If the surgery supply is insufficient to cover unmet needs, it seems reasonable to introduce prioritization systems, which involve modifying the indication thresholds in accordance with the resources available in the system. The effectiveness of prioritization systems would increase substantially if prioritization was applied at surgery indication instead of assigning priorities only to patients entering the waiting list. Giving a warranty time to each patient related to his/her level of need would further increase equity, since levels of need in patients on the waiting list differ widely. Thus, the introduction of a prioritization system should entail an analysis of the unmet needs in each region, or at least involve a reduction in the variations in the surgery rates among regions.

The increase in unmet need may increase the pressure on demand, partly due to the increase in the need for second-eye surgery. This pressure causes the necessity to increase surgery supply. Knowing that patients waiting for second-eye surgery present a level of need lower than that of patients with bilateral cataracts, the model results may indicate that a restriction in indication criteria conditioned by the level of need is advisable to avoid excessive waiting times for patients with less need. However, not only need for surgery, but also the timeliness of care should play a role in indication for surgery. Although longer waiting times in patients with less need may seem acceptable, this waiting time may reduce the benefit from surgery due to the progression of the disease and the shorter lifetime in which to enjoy the benefits of surgery.

4.3: Limitations

Simulation models have several limitations. One of them relates to the complexity of the model: a compromise should be found between complexity and manageability of the model. A very complex model may represent reality more comprehensively, but be of little usefulness due to the lack of available data or to computational requirements. Moreover, the results of a simulation model are only estimations that depend on the input values used and, thus, on their quality. Then, the principle of ‘garbage in-garbage out’ applies. In our model, the sensitivity of the outputs to the variability of the estimations was tested and results were in the expected direction. Importantly, the main outcome variable for the assessment of the prioritization system, which is the waiting time weighted by priority score, was insensitive to the uncertainty of the parameter estimations.

Related to the estimation of the parameters of the model, there are few published studies about prevalence or incidence of these diseases, explaining the factors related to demand of these services, explaining geographical differences among surgery rates, or explaining the relationships among the parameters of the model. Then, several assumptions had to be made.

All incident cases of senile cataract that meet indication criteria were considered as bilateral. According to data from the North London Study, the proportion of unilateral cases is small and may be due to lack of symmetry, that is, one eye may have a faster evolution (loss of visual acuity) than the other eye, although both are affected by cataracts. The same reasoning applies to knee osteoarthritis, as both are pathologies related to aging. However, the asymmetrical worsening of the eyes (or knees) may lead to an overestimation of the need for second surgery.

The level of priority was not allowed to decrease through time. This may not be true for social criteria. However, the most weighted criteria of the prioritization systems for cataract surgery and knee arthroplasty were clinical and functional criteria which, being an age-related pathology, are expected to worsen through time. According to this, the study of patients in the waiting list of Hospital de l’Esperança showed a global increase in priority, although no clear relationship with time was found, probably due to the sample size and the range of time observed, which may be too small.

The relationships among some parameters of the cataract model were difficult to assess, and several mathematical functions were defined to approximate their behavior within the system. These functions were used to simulate parameter relationships, such as the relationship between surgery and demand, and self-regulation of the waiting list. These relationships were not based on real data because the information needed to estimate them comes from sources with different levels of robustness and data must be compared through time. The results of estimating the parameters and the proposed relationships among them were also validated by a panel of experts and were considered as reasonable. Moreover, we checked through the multivariate sensitivity analysis that variations in these two parameters had little effect on the outputs of the model.

The exponential distribution for the number of surgeries and the number of entries to the waiting list was chosen because of its mathematical properties (lack of memory). It was impossible to estimate a true distribution for these parameters, as the exact time of each event was unavailable.

All parameters were estimated without taking into account calendar effects. That is, no stationalities due to holidays, or weekends were considered, as this was beyond the scope of the study.

Patients who are assigned to have surgery in their second eye are immediately returned to the waiting list, and patients who are not, go to ‘Non Expressed Need 2nd Surgery’. The model does not allow patients to return to the waiting list after spending some time in ‘Non Expressed Need 2nd Surgery’. However, given the current waiting lists, it is usual that patients re-enter the waiting list after first-eye surgery if they want to have their second eye operated.

Chapter 5: Conclusions

The present thesis has established a methodology to approach a type of problems that, in the context of health services research, are difficult to assess because of the complexity of the healthcare systems.

The methodology can be summed up as follows: the health system is observed in order to gather knowledge to build a conceptual model. After that, the parameters of the model are estimated according to the characteristics of the technique to be used to translate the conceptual model into a computational model. A compromise should be found between complexity of the model and approximation to the real process. Input data may be difficult to get and specific methods would be needed for each parameter. The last step before getting the intended results is verifying and validating the computational model to ensure its credibility, validity and usefulness. Finally, results should be collected and analyzed in an appropriate manner to apply the classical statistical tests.

Our study demonstrates that discrete-event simulation is a valid and robust tool to represent the flow of patients between need, waiting lists and surgery, considering that elective surgery is a scarce resource for which patients compete. Moreover, it can be used as a tool for shared decision making as patients can be presented with the expected waiting time according to their priority score and they may decide whether they are willing to accept this waiting time. On the other hand, healthcare managers can test different scenarios or interventions without experimenting with the real system.

Introducing a prioritization system of waiting lists was more beneficial than allocating surgery by waiting time only and the proportion of patients penalized with excessive waiting times was small and with low priority. However, prioritizing waiting lists had little impact on the global volume of need, thus suggesting that prioritizing patients at indication, for example by the family practitioner, would be more beneficial due to the time spent between first contact with the health system and inclusion on a waiting list.

The model also allowed evaluating the benefit of the prioritization system across regions which present variations in clinical practice. Results suggest that introducing the prioritization system reduces the variations among regions and improves the system’s equity and effectiveness, specially for patients with greater need.

In view of current data on waiting lists, testing the prioritization system through the simulation model allows a (justifiable) level of need over which the public health system can meet demand with a “socially reasonable” waiting time to be defined. This alternative would make waiting list management transparent, would ensure that the waiting time of the most disabled patients is extremely reduced, and may be a less costly and more maintainable option than shock plans.

Given current incidence, surgery rates and life expectancy, a substantial increase in the need for surgery is expected in the next 5 years. This increase is mainly due to the increase in the need for second-eye surgery. Since cataract surgery is not simultaneous, different attention should be paid to patients depending on whether they have been already operated on in one eye, as their level of need is conceptually different: patients with bilateral cataract, although they have better visual acuity in the worse eye, will get a higher benefit from surgery in the first-eye. Aphakic patients would also get an important benefit because their cataractous eye presents a relevant visual impairment. The lower level of worse eye visual acuity found in aphakic patients with unmet needs, raises the question on whether indication criteria should take into account the visual acuity of the better eye, as it is closer to the actual need for the patient.

The methodology developed for the cataract surgery model was easily adapted to a model for needs and demand for knee replacement. Future applications of this methodology may include other elective surgeries with important waiting lists, such as bariatric surgery, or other types of health services, such as cancer screening programs.

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Chapter 7: Publications derived from the thesis

7.1: Articles in international journals

Hoffmeister L, Román R, **Comas M**, Cots F, Bernal-Delgado E, Castells X. Time-trend and variations in the proportion of second-eye cataract surgery. *BMC Health Services Research.* 2007;7:53. (See appendix 2.1).

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Comas M, Castells X, Hoffmeister L, Román R, Cots F, Mar J, Gutiérrez-Moreno S, Espallargues M. Discrete-event simulation applied to analysis of waiting lists. Evaluation of a prioritization system for cataract surgery. *Value in Health*. (in press). (See appendix 2.3).

Comas M, Román R, Cots F, Quintana JM, Mar J, Reidy A, Minassian D, Castells X and the IRYSS Modeling Group. Unmet needs for cataract surgery in Spain according to indication criteria. Evaluation through a simulation model. *British Journal of Ophthalmology.* (under review). (See appendix 2.4).

Román R, **Comas M**, Mar J, Bernal E, Jiménez-Puente A, Gutiérrez-Moreno S, Castells X and the IRYSS Network Modelling Group Geographical variations in the benefit of applying a prioritization system for cataract surgery in different regions of Spain. *BMC Health Services Research.* 2008;8:32. (See appendix 2.5).

7.2: Articles in national journals

Acosta ER, Hoffmeister L, Román R, **Comas M**, Castilla M, Castells X. Revisión sistemática de estudios poblacionales de prevalencia de catarata. *Archivos de la Sociedad Española de Oftalmología*. 2006; 81:509-516.

7.3: Oral communications in international conferences

Comas M, Castells X, Román R, Hoffmeister L, Cots F, Mar J, Gutiérrez-Moreno S, Espallargues M, Allepuz A, Pinto JL. Assessment of a prioritization system for waiting lists for knee replacement through a simulation model. *European Congress of Epidemiology*. Utrecht (The Netherlands), 28th-31st June 2006. *Eur J Epidemiol.* 2006:21(Suppl 13);54.

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Comas M, Castells X, Román R, Cots F, Hoffmeister L, Mar J, Quintana JM, Barceló J. Discrete-event simulation applied to health services research: analysis of demand and waiting time for knee arthroplasty. *28th Annual Conference of the International Society for Clinical Biostatistics.* Alexandropoulis (Greece), 29th July-2nd August 2007.

7.4: Oral communications in national conferences

Comas M, Castells X, Acosta R. Estimación de la prevalencia de cataratas según edad y sexo a través de una encuesta de salud poblacional. Comparación con resultados según criterios clínicos. *X Congreso de la Sociedad Española de Salud Pública y Administración Sanitaria*. Santander, 28th-30th May 2003. *Gac Sanit*. 2003;17(Supl 1):21.

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Hoffmeister L, Román R, **Comas M**, Castells X. Probabilidad de cirugía de cataratas de segundo ojo en el sistema público de cataluña y variaciones geográficas entre regiones sanitarias. *XXIII Reunión Científica de la Sociedad Española de Epidemiología*. Gran Canaria, 1st-5th November 2005. *Gac Sanit.* 2005;19(Supl 1):81.

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Román R, **Comas M**, Castells X, Hoffmeister L, Mar J, Gutiérrez-Moreno S, Espallargues M, Jiménez A, Bernal E. Variaciones en el beneficio de aplicar un sistema de priorización para cirugía de cataratas en diferentes comunidades autónomas. *XXIV Reunión Científica de la Sociedad Española de Epidemiología*. Logroño, 3rd-6th October 2006. *Gac Sanit.* 2006;20(Espec Congr):83.

Román R, **Comas M**, Castells X. Discrete Event Simulation as a tool to study Geographical Variations: Application to the benefits of introducing a prioritization system for cataract surgery in different regions of Spain. *XI Conferencia Española y I Encuentro Iberoamericano de Biometría.* Salamanca, 20th-22nd June 2007.

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7.5: Poster presentations in international conferences

Comas M, Castells X, Román R, Cots F, Hoffmeister L, Mar J, Gutiérrez S. Discrete-event simulation model to analyze demand and waiting time for cataract surgery. Assessment of a prioritization system for waiting lists. *27th Annual Meeting of the Society for Medical Decision Making*. San Francisco (USA), 21st-24th October 2005.

Hoffmeister L, **Comas M**, Román R, Castells X. Proportion of second-eye cataract surgery in the public health system in Catalonia (Spain). *European Congress of Epidemiology*. Utrecht (The Netherlands), 28th -31st June 2006. *Eur J Epidemiol.* 2006:21(Suppl 13);120-1.

Hoffmeister L, Román R, **Comas M**, Montserrat F, Cáceres E, Castells X. Change in priority score (need for surgery) of patients waiting for knee arthroplasty. *European Congress of Epidemiology*. Utrecht (The Netherlands), 28th -31st June 2006. *Eur J Epidemiol.* 2006:21(Suppl 13);120.

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7.6: Poster presentations in national conferences

Román R, **Comas M**, Castells X, Minassian D, Reidy A, Acosta R. Estimación de la prevalencia de necesidad de cirugía de cataratas en España a partir de los datos del North London Eye Study (NLES). *XXIII Reunión Científica de la Sociedad Española de Epidemiología*. Gran Canaria, 1st-5th November 2005. *Gac Sanit*. 2005;19(Supl 1):115.

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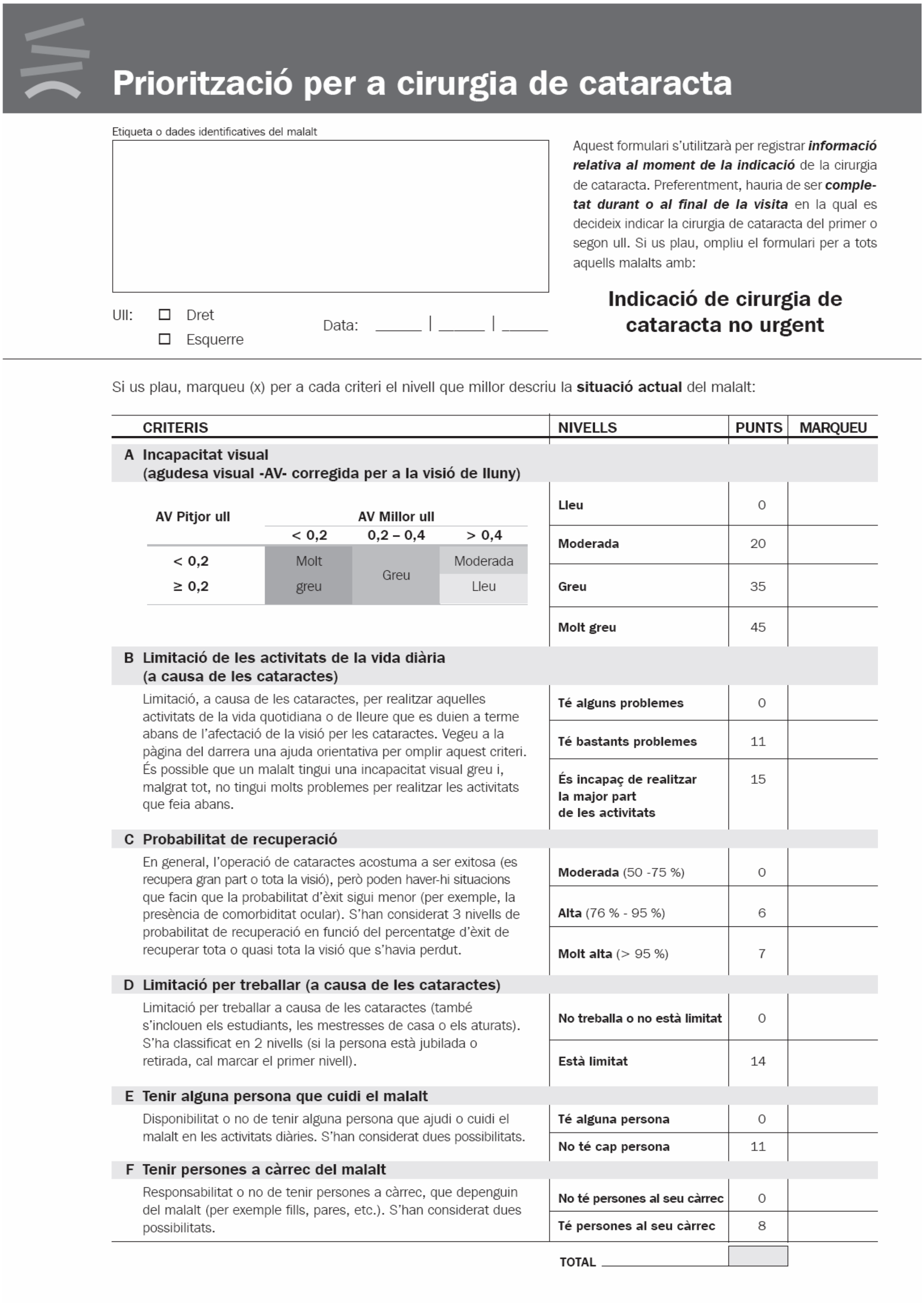
Hoffmeister L, Román R, **Comas M,** Castells X. Perfil de la prevalencia sintomática de artrosis y de la utilización de artroplastia de rodilla*. I Jornada Científica de la Red de Investigación en*

Resultados y Servicios de Salud (Red IRYSS) en España. Gran Canaria, 1st-5th November 2005. *Gac Sanit*. 2005;19(Supl 1):189.

Appendix 1: Prioritization forms

1.1: Prioritization form for cataract surgery



Priorització per a cirurgia de cataracta

Etiqueta o dades identificatives del malalt

Ull: ☐ Dret
☐ Esquerre

Data: ______ | ______ | ______

Aquest formulari s'utilitzarà per registrar ***informació relativa al moment de la indicació*** de la cirurgia de cataracta. Preferentment, hauria de ser ***completat durant o al final de la visita*** en la qual es decideix indicar la cirurgia de cataracta del primer o segon ull. Si us plau, ompliu el formulari per a tots aquells malalts amb:

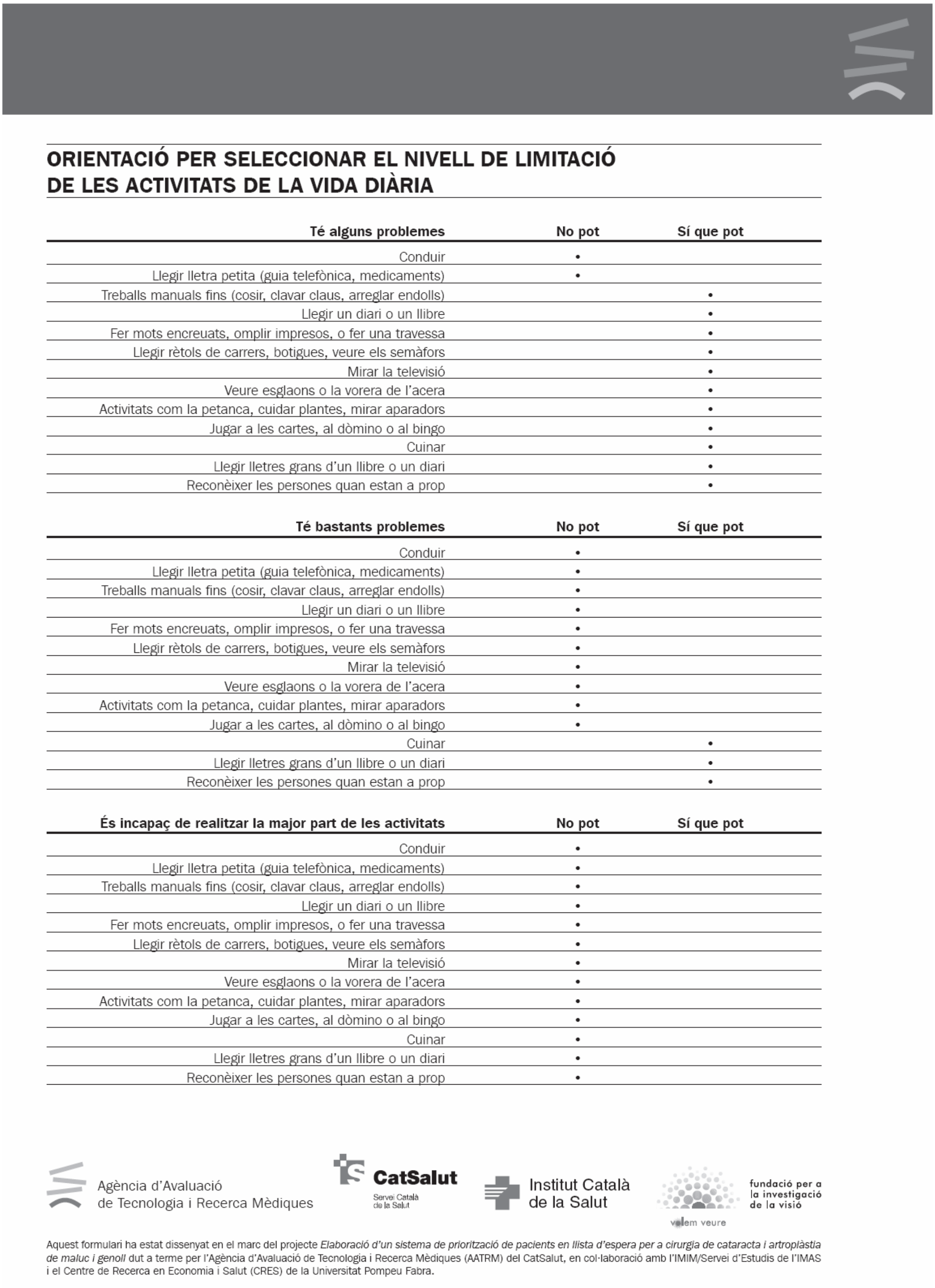
Indicació de cirurgia de cataracta no urgent

Si us plau, marqueu (x) per a cada criteri el nivell que millor descriu la **situació actual** del malalt:

CRITERIS	NIVELLS	PUNTS	MARQUEU
A Incapacitat visual (agudesa visual -AV- corregida per a la visió de lluny)			
	Lleu	0	
	Moderada	20	
	Greu	35	
	Molt greu	45	

AV Pitjor ull	**AV Millor ull** < 0,2	0,2 – 0,4	> 0,4
< 0,2	Molt greu	Greu	Moderada
≥ 0,2			Lleu

B Limitació de les activitats de la vida diària (a causa de les cataractes)			
Limitació, a causa de les cataractes, per realitzar aquelles activitats de la vida quotidiana o de lleure que es duien a terme abans de l'afectació de la visió per les cataractes. Vegeu a la pàgina del darrera una ajuda orientativa per omplir aquest criteri. És possible que un malalt tingui una incapacitat visual greu i, malgrat tot, no tingui molts problemes per realitzar les activitats que feia abans.	**Té alguns problemes**	0	
	Té bastants problemes	11	
	És incapaç de realitzar la major part de les activitats	15	
C Probabilitat de recuperació			
En general, l'operació de cataractes acostuma a ser exitosa (es recupera gran part o tota la visió), però poden haver-hi situacions que facin que la probabilitat d'èxit sigui menor (per exemple, la presència de comorbiditat ocular). S'han considerat 3 nivells de probabilitat de recuperació en funció del percentatge d'èxit de recuperar tota o quasi tota la visió que s'havia perdut.	**Moderada** (50 -75 %)	0	
	Alta (76 % - 95 %)	6	
	Molt alta (> 95 %)	7	
D Limitació per treballar (a causa de les cataractes)			
Limitació per treballar a causa de les cataractes (també s'inclouen els estudiants, les mestresses de casa o els aturats). S'ha classificat en 2 nivells (si la persona està jubilada o retirada, cal marcar el primer nivell).	**No treballa o no està limitat**	0	
	Està limitat	14	
E Tenir alguna persona que cuidi el malalt			
Disponibilitat o no de tenir alguna persona que ajudi o cuidi el malalt en les activitats diàries. S'han considerat dues possibilitats.	**Té alguna persona**	0	
	No té cap persona	11	
F Tenir persones a càrrec del malalt			
Responsabilitat o no de tenir persones a càrrec, que depenguin del malalt (per exemple fills, pares, etc.). S'han considerat dues possibilitats.	**No té persones al seu càrrec**	0	
	Té persones al seu càrrec	8	
	TOTAL		



ORIENTACIÓ PER SELECCIONAR EL NIVELL DE LIMITACIÓ DE LES ACTIVITATS DE LA VIDA DIÀRIA

Té alguns problemes	**No pot**	**Sí que pot**
Conduir	•	
Llegir lletra petita (guia telefònica, medicaments)	•	
Treballs manuals fins (cosir, clavar claus, arreglar endolls)		•
Llegir un diari o un llibre		•
Fer mots encreuats, omplir impresos, o fer una travessa		•
Llegir rètols de carrers, botigues, veure els semàfors		•
Mirar la televisió		•
Veure esglaons o la vorera de l'acera		•
Activitats com la petanca, cuidar plantes, mirar aparadors		•
Jugar a les cartes, al dòmino o al bingo		•
Cuinar		•
Llegir lletres grans d'un llibre o un diari		•
Reconèixer les persones quan estan a prop		•

Té bastants problemes	**No pot**	**Sí que pot**
Conduir	•	
Llegir lletra petita (guia telefònica, medicaments)	•	
Treballs manuals fins (cosir, clavar claus, arreglar endolls)	•	
Llegir un diari o un llibre	•	
Fer mots encreuats, omplir impresos, o fer una travessa	•	
Llegir rètols de carrers, botigues, veure els semàfors	•	
Mirar la televisió	•	
Veure esglaons o la vorera de l'acera	•	
Activitats com la petanca, cuidar plantes, mirar aparadors	•	
Jugar a les cartes, al dòmino o al bingo	•	
Cuinar		•
Llegir lletres grans d'un llibre o un diari		•
Reconèixer les persones quan estan a prop		•

És incapaç de realitzar la major part de les activitats	**No pot**	**Sí que pot**
Conduir	•	
Llegir lletra petita (guia telefònica, medicaments)	•	
Treballs manuals fins (cosir, clavar claus, arreglar endolls)	•	
Llegir un diari o un llibre	•	
Fer mots encreuats, omplir impresos, o fer una travessa	•	
Llegir rètols de carrers, botigues, veure els semàfors	•	
Mirar la televisió	•	
Veure esglaons o la vorera de l'acera	•	
Activitats com la petanca, cuidar plantes, mirar aparadors	•	
Jugar a les cartes, al dòmino o al bingo	•	
Cuinar	•	
Llegir lletres grans d'un llibre o un diari	•	
Reconèixer les persones quan estan a prop	•	

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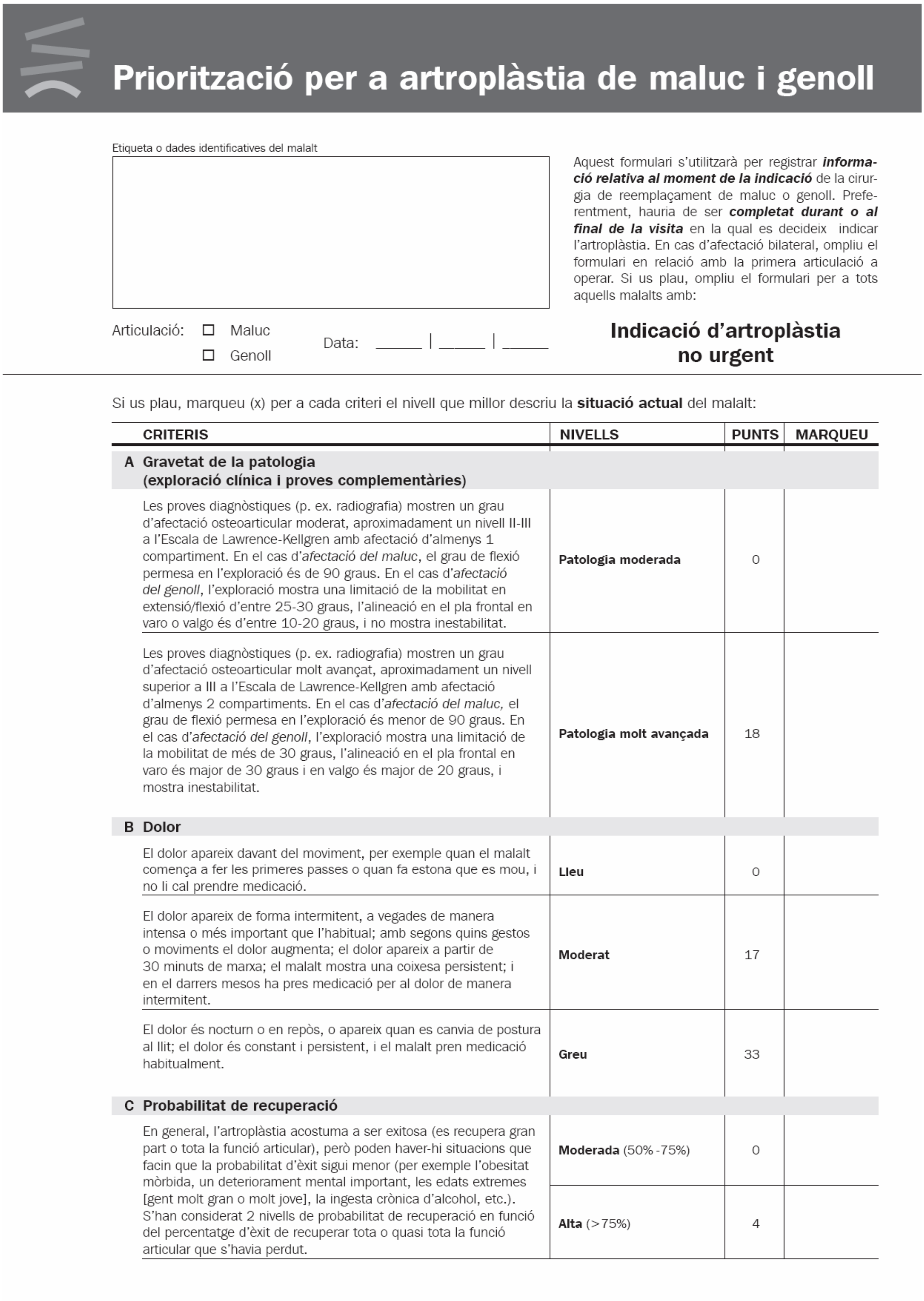
fundació per a
la investigació
de la visió
volem veure

Aquest formulari ha estat dissenyat en el marc del projecte *Elaboració d'un sistema de priorització de pacients en llista d'espera per a cirurgia de cataracta i artroplàstia de maluc i genoll* dut a terme per l'Agència d'Avaluació de Tecnologia i Recerca Mèdiques (AATRM) del CatSalut, en col·laboració amb l'IMIM/Servei d'Estudis de l'IMAS i el Centre de Recerca en Economia i Salut (CRES) de la Universitat Pompeu Fabra.

1.2: Prioritization form for knee and hip arthroplasty



Priorització per a artroplàstia de maluc i genoll

Etiqueta o dades identificatives del malalt

Aquest formulari s'utilitzarà per registrar ***informació relativa al moment de la indicació*** de la cirurgia de reemplaçament de maluc o genoll. Preferentment, hauria de ser ***completat durant o al final de la visita*** en la qual es decideix indicar l'artroplàstia. En cas d'afectació bilateral, ompliu el formulari en relació amb la primera articulació a operar. Si us plau, ompliu el formulari per a tots aquells malalts amb:

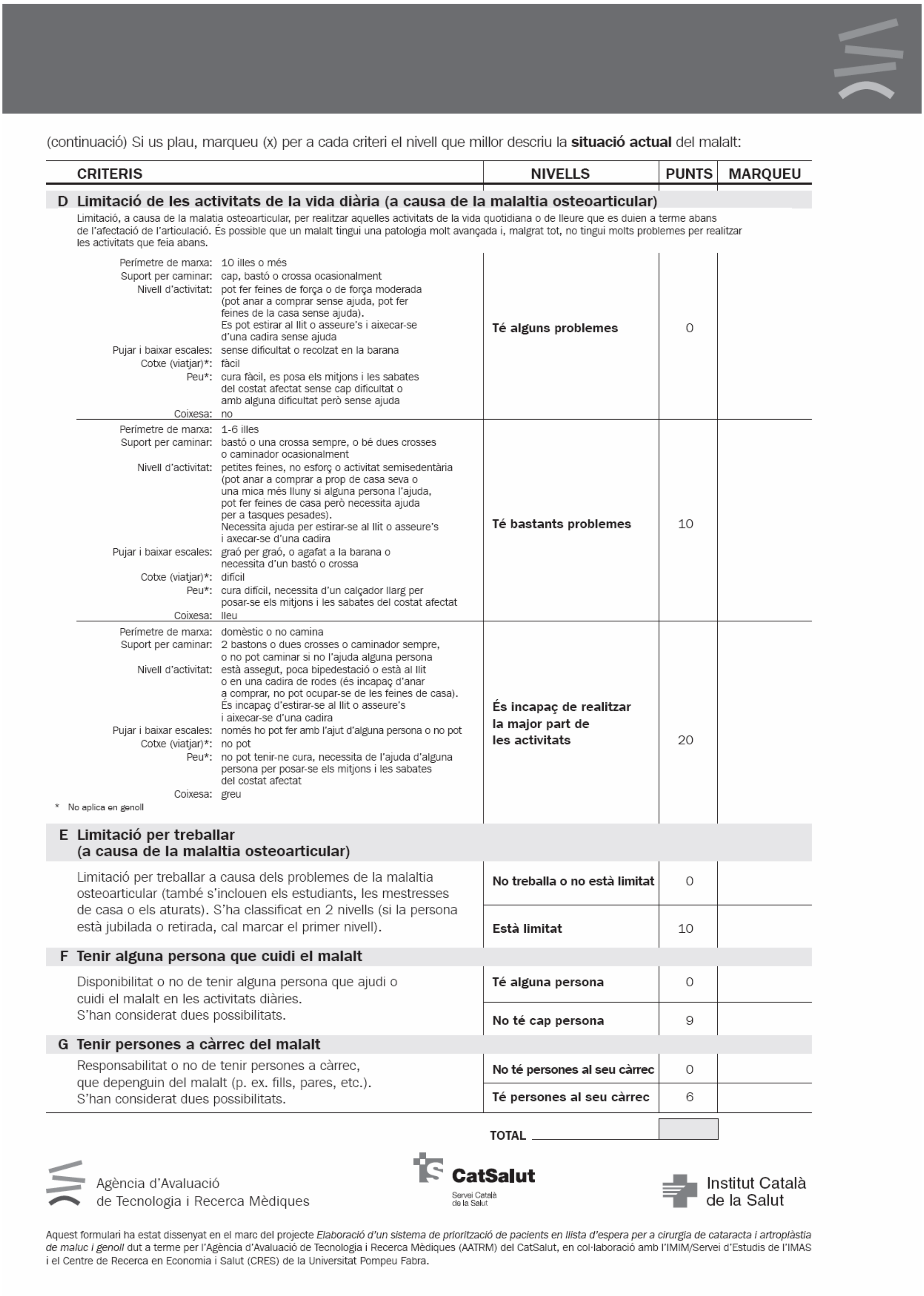
Articulació: ☐ Maluc
☐ Genoll

Data: ______ | ______ | ______

Indicació d'artroplàstia no urgent

Si us plau, marqueu (x) per a cada criteri el nivell que millor descriu la **situació actual** del malalt:

CRITERIS	NIVELLS	PUNTS	MARQUEU
A Gravetat de la patologia (exploració clínica i proves complementàries)			
Les proves diagnòstiques (p. ex. radiografia) mostren un grau d'afectació osteoarticular moderat, aproximadament un nivell II-III a l'Escala de Lawrence-Kellgren amb afectació d'almenys 1 compartiment. En el cas d'*afectació del maluc*, el grau de flexió permesa en l'exploració és de 90 graus. En el cas d'*afectació del genoll*, l'exploració mostra una limitació de la mobilitat en extensió/flexió d'entre 25-30 graus, l'alineació en el pla frontal en varo o valgo és d'entre 10-20 graus, i no mostra inestabilitat.	**Patologia moderada**	0	
Les proves diagnòstiques (p. ex. radiografia) mostren un grau d'afectació osteoarticular molt avançat, aproximadament un nivell superior a III a l'Escala de Lawrence-Kellgren amb afectació d'almenys 2 compartiments. En el cas d'*afectació del maluc,* el grau de flexió permesa en l'exploració és menor de 90 graus. En el cas d'*afectació del genoll*, l'exploració mostra una limitació de la mobilitat de més de 30 graus, l'alineació en el pla frontal en varo és major de 30 graus i en valgo és major de 20 graus, i mostra inestabilitat.	**Patologia molt avançada**	18	
B Dolor			
El dolor apareix davant del moviment, per exemple quan el malalt comença a fer les primeres passes o quan fa estona que es mou, i no li cal prendre medicació.	**Lleu**	0	
El dolor apareix de forma intermitent, a vegades de manera intensa o més important que l'habitual; amb segons quins gestos o moviments el dolor augmenta; el dolor apareix a partir de 30 minuts de marxa; el malalt mostra una coixesa persistent; i en el darrers mesos ha pres medicació per al dolor de manera intermitent.	**Moderat**	17	
El dolor és nocturn o en repòs, o apareix quan es canvia de postura al llit; el dolor és constant i persistent, i el malalt pren medicació habitualment.	**Greu**	33	
C Probabilitat de recuperació			
En general, l'artroplàstia acostuma a ser exitosa (es recupera gran part o tota la funció articular), però poden haver-hi situacions que facin que la probabilitat d'èxit sigui menor (per exemple l'obesitat mòrbida, un deteriorament mental important, les edats extremes [gent molt gran o molt jove], la ingesta crònica d'alcohol, etc.). S'han considerat 2 nivells de probabilitat de recuperació en funció del percentatge d'èxit de recuperar tota o quasi tota la funció articular que s'havia perdut.	**Moderada** (50% -75%)	0	
	Alta (>75%)	4	



(continuació) Si us plau, marqueu (x) per a cada criteri el nivell que millor descriu la **situació actual** del malalt:

CRITERIS	NIVELLS	PUNTS	MARQUEU
D Limitació de les activitats de la vida diària (a causa de la malaltia osteoarticular)			
Limitació, a causa de la malatia osteoarticular, per realitzar aquelles activitats de la vida quotidiana o de lleure que es duien a terme abans de l'afectació de l'articulació. És possible que un malalt tingui una patologia molt avançada i, malgrat tot, no tingui molts problemes per realitzar les activitats que feia abans.			
Perímetre de marxa: 10 illes o més Suport per caminar: cap, bastó o crossa ocasionalment Nivell d'activitat: pot fer feines de força o de força moderada (pot anar a comprar sense ajuda, pot fer feines de la casa sense ajuda). Es pot estirar al llit o asseure's i aixecar-se d'una cadira sense ajuda Pujar i baixar escales: sense dificultat o recolzat en la barana Cotxe (viatjar)*: fàcil Peu*: cura fàcil, es posa els mitjons i les sabates del costat afectat sense cap dificultat o amb alguna dificultat però sense ajuda Coixesa: no	**Té alguns problemes**	0	
Perímetre de marxa: 1-6 illes Suport per caminar: bastó o una crossa sempre, o bé dues crosses o caminador ocasionalment Nivell d'activitat: petites feines, no esforç o activitat semisedentària (pot anar a comprar a prop de casa seva o una mica més lluny si alguna persona l'ajuda, pot fer feines de casa però necessita ajuda per a tasques pesades). Necessita ajuda per estirar-se al llit o asseure's i axecar-se d'una cadira Pujar i baixar escales: graó per graó, o agafat a la barana o necessita d'un bastó o crossa Cotxe (viatjar)*: difícil Peu*: cura difícil, necessita d'un calçador llarg per posar-se els mitjons i les sabates del costat afectat Coixesa: lleu	**Té bastants problemes**	10	
Perímetre de marxa: domèstic o no camina Suport per caminar: 2 bastons o dues crosses o caminador sempre, o no pot caminar si no l'ajuda alguna persona Nivell d'activitat: està assegut, poca bipedestació o està al llit o en una cadira de rodes (és incapaç d'anar a comprar, no pot ocupar-se de les feines de casa). És incapaç d'estirar-se al llit o asseure's i aixecar-se d'una cadira Pujar i baixar escales: només ho pot fer amb l'ajut d'alguna persona o no pot Cotxe (viatjar)*: no pot Peu*: no pot tenir-ne cura, necessita de l'ajuda d'alguna persona per posar-se els mitjons i les sabates del costat afectat Coixesa: greu * No aplica en genoll	**És incapaç de realitzar la major part de les activitats**	20	
E Limitació per treballar (a causa de la malaltia osteoarticular)			
Limitació per treballar a causa dels problemes de la malaltia osteoarticular (també s'inclouen els estudiants, les mestresses de casa o els aturats). S'ha classificat en 2 nivells (si la persona està jubilada o retirada, cal marcar el primer nivell).	**No treballa o no està limitat**	0	
	Està limitat	10	
F Tenir alguna persona que cuidi el malalt			
Disponibilitat o no de tenir alguna persona que ajudi o cuidi el malalt en les activitats diàries. S'han considerat dues possibilitats.	**Té alguna persona**	0	
	No té cap persona	9	
G Tenir persones a càrrec del malalt			
Responsabilitat o no de tenir persones a càrrec, que depenguin del malalt (p. ex. fills, pares, etc.). S'han considerat dues possibilitats.	**No té persones al seu càrrec**	0	
	Té persones al seu càrrec	6	

TOTAL ______ ☐

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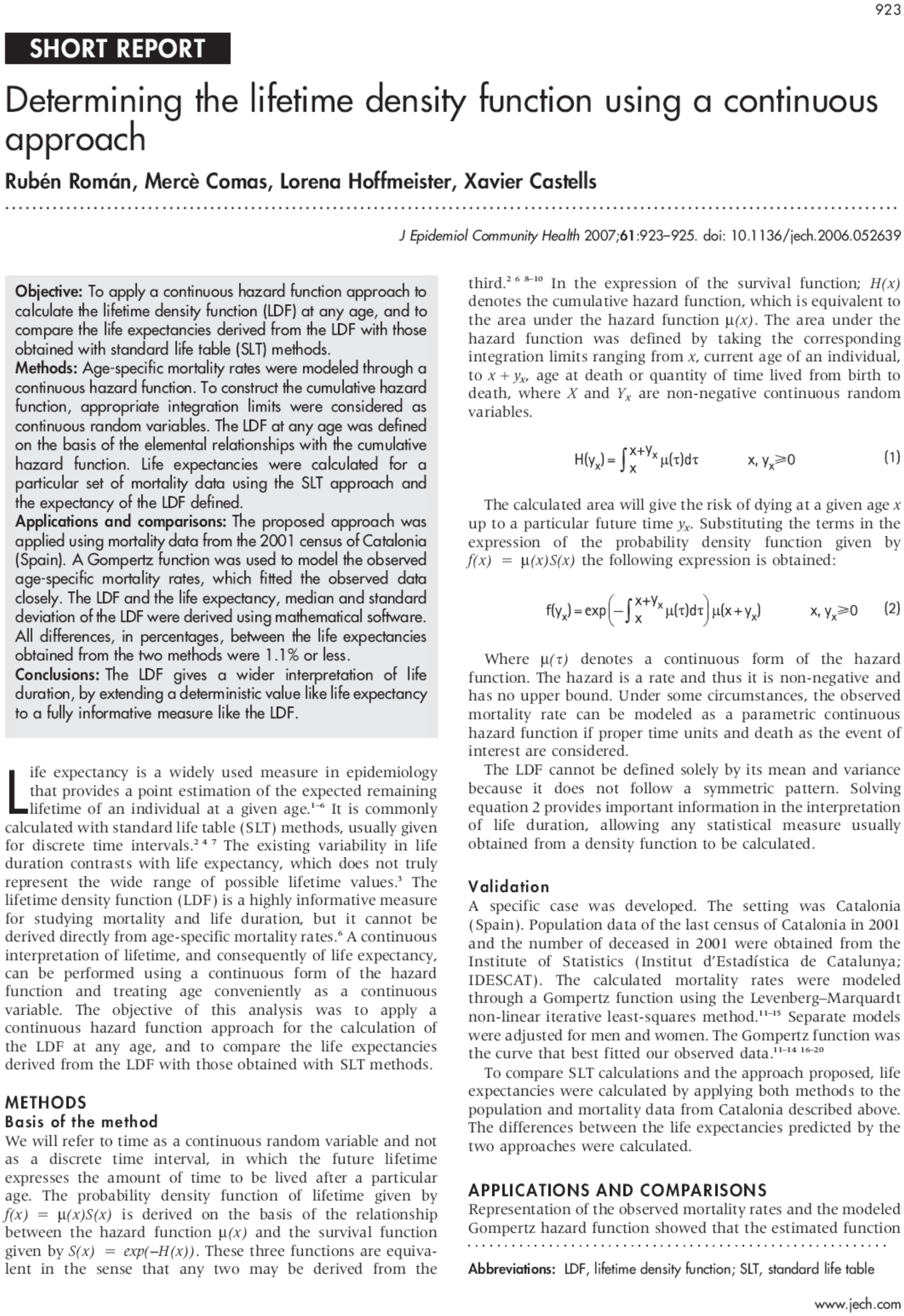
Aquest formulari ha estat dissenyat en el marc del projecte *Elaboració d'un sistema de priorització de pacients en llista d'espera per a cirurgia de cataracta i artroplàstia de maluc i genoll* dut a terme per l'Agència d'Avaluació de Tecnologia i Recerca Mèdiques (AATRM) del CatSalut, en col·laboració amb l'IMIM/Servei d'Estudis de l'IMAS i el Centre de Recerca en Economia i Salut (CRES) de la Universitat Pompeu Fabra.

Appendix 2: Articles derived from this thesis

2.1: Determining the lifetime density function using a continuous approach



SHORT REPORT

Determining the lifetime density function using a continuous approach

Rubén Román, Mercè Comas, Lorena Hoffmeister, Xavier Castells

J Epidemiol Community Health 2007;**61**:923–925. doi: 10.1136/jech.2006.052639

Objective: To apply a continuous hazard function approach to calculate the lifetime density function (LDF) at any age, and to compare the life expectancies derived from the LDF with those obtained with standard life table (SLT) methods.

Methods: Age-specific mortality rates were modeled through a continuous hazard function. To construct the cumulative hazard function, appropriate integration limits were considered as continuous random variables. The LDF at any age was defined on the basis of the elemental relationships with the cumulative hazard function. Life expectancies were calculated for a particular set of mortality data using the SLT approach and the expectancy of the LDF defined.

Applications and comparisons: The proposed approach was applied using mortality data from the 2001 census of Catalonia (Spain). A Gompertz function was used to model the observed age-specific mortality rates, which fitted the observed data closely. The LDF and the life expectancy, median and standard deviation of the LDF were derived using mathematical software. All differences, in percentages, between the life expectancies obtained from the two methods were 1.1% or less.

Conclusions: The LDF gives a wider interpretation of life duration, by extending a deterministic value like life expectancy to a fully informative measure like the LDF.

Life expectancy is a widely used measure in epidemiology that provides a point estimation of the expected remaining lifetime of an individual at a given age.[1–6] It is commonly calculated with standard life table (SLT) methods, usually given for discrete time intervals.[2,4,7] The existing variability in life duration contrasts with life expectancy, which does not truly represent the wide range of possible lifetime values.[3] The lifetime density function (LDF) is a highly informative measure for studying mortality and life duration, but it cannot be derived directly from age-specific mortality rates.[6] A continuous interpretation of lifetime, and consequently of life expectancy, can be performed using a continuous form of the hazard function and treating age conveniently as a continuous variable. The objective of this analysis was to apply a continuous hazard function approach for the calculation of the LDF at any age, and to compare the life expectancies derived from the LDF with those obtained with SLT methods.

METHODS

Basis of the method

We will refer to time as a continuous random variable and not as a discrete time interval, in which the future lifetime expresses the amount of time to be lived after a particular age. The probability density function of lifetime given by $f(x) = \mu(x)S(x)$ is derived on the basis of the relationship between the hazard function $\mu(x)$ and the survival function given by $S(x) = exp(-H(x))$. These three functions are equivalent in the sense that any two may be derived from the third.[2,6,8–10] In the expression of the survival function; $H(x)$ denotes the cumulative hazard function, which is equivalent to the area under the hazard function $\mu(x)$. The area under the hazard function was defined by taking the corresponding integration limits ranging from x, current age of an individual, to $x + y_x$, age at death or quantity of time lived from birth to death, where X and Y_x are non-negative continuous random variables.

$$H(y_x) = \int_x^{x+y_x} \mu(\tau)d\tau \qquad x, y_x \geqslant 0 \qquad (1)$$

The calculated area will give the risk of dying at a given age x up to a particular future time y_x. Substituting the terms in the expression of the probability density function given by $f(x) = \mu(x)S(x)$ the following expression is obtained:

$$f(y_x) = \exp\left(-\int_x^{x+y_x} \mu(\tau)d\tau\right)\mu(x+y_x) \qquad x, y_x \geqslant 0 \qquad (2)$$

Where $\mu(\tau)$ denotes a continuous form of the hazard function. The hazard is a rate and thus it is non-negative and has no upper bound. Under some circumstances, the observed mortality rate can be modeled as a parametric continuous hazard function if proper time units and death as the event of interest are considered.

The LDF cannot be defined solely by its mean and variance because it does not follow a symmetric pattern. Solving equation 2 provides important information in the interpretation of life duration, allowing any statistical measure usually obtained from a density function to be calculated.

Validation

A specific case was developed. The setting was Catalonia (Spain). Population data of the last census of Catalonia in 2001 and the number of deceased in 2001 were obtained from the Institute of Statistics (Institut d'Estadística de Catalunya; IDESCAT). The calculated mortality rates were modeled through a Gompertz function using the Levenberg–Marquardt non-linear iterative least-squares method.[11–15] Separate models were adjusted for men and women. The Gompertz function was the curve that best fitted our observed data.[11–14,16–20]

To compare SLT calculations and the approach proposed, life expectancies were calculated by applying both methods to the population and mortality data from Catalonia described above. The differences between the life expectancies predicted by the two approaches were calculated.

APPLICATIONS AND COMPARISONS

Representation of the observed mortality rates and the modeled Gompertz hazard function showed that the estimated function

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Abbreviations: LDF, lifetime density function; SLT, standard life table

Table 1 Life expectancy (age at death) from standard life table calculations

	Males					Females				
	Life table	Lifetime density function				Life table	Lifetime density function			
Age (years)	Life expectancy	Life expectancy	Median age at death	Lifetime SD	% Difference in life expectancy	Life expectancy	Life expectancy	Median age at death	Lifetime SD	% Difference in life expectancy
5	77.00	77.63	79.68	12.56	0.82	83.75	83.70	85.41	10.39	0.05
10	77.06	77.64	79.69	12.52	0.76	83.79	83.71	85.41	10.38	0.10
15	77.11	77.67	79.69	12.45	0.72	83.83	83.71	85.41	10.37	0.14
20	77.30	77.71	79.70	12.36	0.53	83.92	83.72	85.41	10.35	0.25
25	77.54	77.77	79.72	12.24	0.30	84.00	83.73	85.41	10.31	0.32
30	77.74	77.86	79.74	12.06	0.15	84.10	83.75	85.42	10.26	0.42
35	78.00	77.99	79.78	11.83	0.01	84.23	83.78	85.43	10.19	0.53
40	78.30	78.19	79.85	11.51	0.13	84.38	83.83	85.44	10.07	0.65
45	78.72	78.49	79.97	11.09	0.30	84.58	83.92	85.47	9.89	0.77
50	79.23	78.91	80.15	10.56	0.41	84.83	84.07	85.51	9.64	0.90
55	79.95	79.51	80.46	9.90	0.56	85.16	84.31	85.60	9.28	1.00
60	80.82	80.34	80.94	9.10	0.60	85.56	84.68	85.76	8.80	1.03
65	82.00	81.48	81.69	8.16	0.64	86.09	85.25	86.04	8.15	0.97
70	83.42	82.98	82.82	7.12	0.52	86.84	86.11	86.54	7.34	0.84
75	85.23	84.91	84.46	6.00	0.37	87.84	87.34	87.39	6.37	0.57
80	87.49	87.32	86.68	4.87	0.19	89.30	89.06	88.77	5.28	0.27
85	90.33	90.23	89.54	3.79	0.11	91.45	91.34	90.83	4.15	0.12
90	93.70	93.60	92.97	2.82	0.10	94.33	94.21	93.65	3.07	0.12
95	97.74	97.41	96.90	2.01	0.34	98.05	97.66	97.17	2.12	0.40

Life expectancy (age at death), median and standard deviation (SD) from the lifetime density function, and percentage difference in life expectancy between standard life table calculations and the continuous lifetime calculation proposed. Data from Catalonia, 2001.

almost overlaps with the observed mortality rates for both men and women (data not shown).

The lifetime probability density functions at any current age are represented in fig 1 and show a great asymmetry, being left skewed and with a flattened slope for ages under 50 years for men and 60 years for women. As age increases over these values, the density becomes more right skewed and leptokurtic.

Table 1 compares the life expectancies obtained with the approach proposed with those obtained from the SLT method. Life expectancies were calculated for all age values between one and 100 but, for reasons of space, only ages at five-year intervals are presented in the table; however, the results refer to all the data. All differences were 1.1% or less. For women, the largest difference was found in the middle-age range (approximately 55–65 years), in which a maximum difference of 0.90 (84.51 versus 85.41) more years for the age of 58 years was estimated with the SLT method. This difference diminished gradually as younger and older ages were considered. For males the largest differences were found in the youngest age groups (1–15 years of age) and in those approximately 60 years of age. A maximum difference of 0.70 (77.62 versus 76.92) more years was estimated by the proposed approach for infants aged one year, and a difference of 0.53 (81.47 versus 82.00) more years was estimated by the life tables for people aged 65 years.

As the present study concerns asymmetric forms of the density function, calculation of the median and standard deviation of the distribution was especially relevant and is included in table 1. Median values were higher than mean values for ages less than 60 years for men and under 75 years for women, reflecting the left skewness of the distribution for these ages. For ages over these values the opposite relationship was found but was less pronounced. Standard deviations were larger in males than in females for ages under 65 years, for ages

What this paper adds

The study of mortality is of great interest for epidemiologists, demographers and statisticians. Calculation of the lifetime distribution function at any age using a continuous approach gives useful information for the interpretation of mortality and life duration beyond the usual life expectancy calculated through standard life tables.

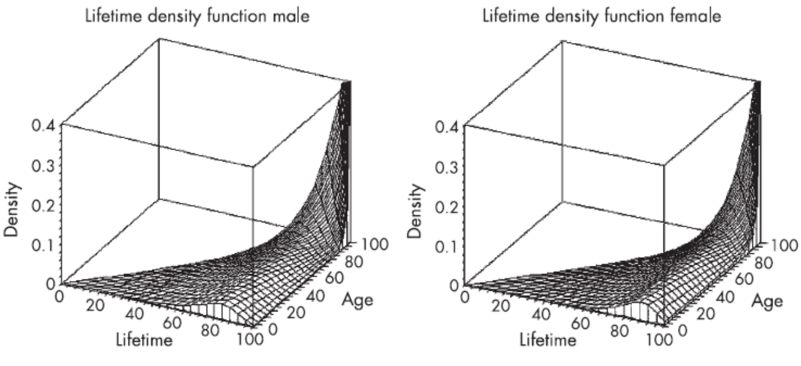

Figure 1 Density function of life duration for men and women. Mortality data from Catalunya 2001.

Policy implications

The applied procedure, which is based on age-specific mortality rates, gives the opportunity to study life duration more accurately, because all the information about the distribution of lifetime is contained in its density function. Obtaining density functions is essential in several statistical methods such as Bayesian analysis or simulation.

over 65 years women had larger standard deviations. The large standard deviations obtained show the great variability involved with human mortality and life duration.

DISCUSSION

Life expectancies obtained from the LDF were valid as they were similar to those calculated using SLT methods. The applied method allows the characterisation of the lifetime distribution, which seems essential on account of the level of uncertainty found in life expectancy.[6] The LDF was shown to be non-symmetric and to have different shapes depending on the current age considered. In addition to its utility in the interpretation of mortality, the LDF might be of great interest in situations in which a priori distributions are needed, such as Bayesian statistics or stochastic processes. A poorly estimated hazard function would, however, lead to biased estimations.[2 10 21]

In conclusion, the LDF provides a wider interpretation of life duration by extending a deterministic point estimation such as life expectancy to a totally informative measure like the density function of lifetime values.

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Competing interests: None.

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2.2: Time-trend and variations in the proportion of second-eye cataract surgery

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Time-trend and variations in the proportion of second-eye cataract surgery

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Abstract

Background: Despite recommendations for greater use of second-eye cataract surgery and the bilateral progression of the disease, there is a substantial proportion of unmet need for this treatment. Few studies have explored the factors associated with second-eye cataract surgery utilisation. The objective of our study was to estimate the proportion of second-eye cataract surgery, evaluate its time-trend, and explore differences in utilisation by patients' gender, age, and region of residence.

Methods: All senile cataract surgeries performed between 1999 and 2002 in the public health system of Catalonia (Spain) were obtained from the Minimum Data Set. The proportion of second-eye surgery from November 2000 to December 2002 was calculated. The time-trend of this proportion was characterised through linear regression models with the logarithmic transformation of time.

Results: The proportion of second-eye surgery was 30.0% and showed an increasing trend from 24.8% (95% Confidence Interval [CI] 21.6; 26.1) in November 2000 to 31.8% (95% CI 31.4; 33.6) in December 2002. This proportion was 1.9% (95% CI 0.9; 2.9) higher in women ($p < 0.001$) and held constant across time. Male patients aged less than 60 had the lowest proportion (22.6%; 95% CI 22.4; 22.9) and females between 70 and 79 had the highest proportion (27.4%; 95% CI 26.9; 27.9). The time-trend for the proportion of second-eye surgery in those aged over 80 years was greater than for younger ages, showing an increase of 9% at the end of the period for both males and females. Variations between regions decreased over time because regions with the lowest initial proportions of second-eye surgery (approximately 17%) showed a greater increase over the study period.

Conclusion: We predict greater utilization of second-eye surgery in patients aged 70 to 79 years and in women. A greater increase in the utilisation rates of second-eye surgery is expected in the regions with lower proportions and in older patients. The observed trend suggests that there will be a substantial proportion of unmet need for bilateral surgery.

Background

In the last few decades, cataract surgery rates have markedly increased in Western countries [1-4]. A substantial part of this increase is due to the increasing number of patients undergoing surgery in both eyes [4-6], that is, they have a second-eye cataract surgery after their first surgery. Several studies have demonstrated the benefit of second-eye surgery especially in stereopsis and in patient-reported visual disability[5,7-13]. Bilateral cataracts are usually removed one eye at a time, mainly due to the risk of major complications such as endophthalmitis. Some studies conclude that the benefits of second-eye surgery are greater when the time interval between surgeries is reduced[11,14].

Few studies have explored the factors associated with second-eye cataract surgery utilisation [15-17]. Gender differences have been reported to be more pronounced in second-eye surgery than in first-eye surgery across all age groups[6,17]. A greater age at operation has also been pointed out. According to Lundstrom et al[6], the increase in second-eye surgery rates has resulted in an increase of surgeries performed in the elderly.

Several studies have shown variations in the overall rate of cataract surgery within and among countries. These rates varied from 3.8 to 41.2 per 1,000 Medicare beneficiaries in distinct geographic areas in the USA[18,19] and from 16.7 to 61.8 per 10,000 inhabitants in the United Kingdom[20]. In Catalonia[21], the cataract surgery rate in 1993 was 21.9 per 10,000 inhabitants, with a ratio of 4.5 between the highest and lowest surgery rates in the 26 areas analysed. To date, the presence of geographic variations in second-eye cataract surgery utilisation and their influence on overall rates has not been studied.

In the United Kingdom, the proportion of second-eye surgery was 35% of all cataract surgeries performed in 1997[15]. In Sweden[4], a proportion of 36.8% was found in 1999, presenting an increasing tendency between 1992 and 1999. In the USA[5] and in Spain[16], during a 12-month follow-up, a quarter of the surgeries performed were second-eye surgeries. Despite recommendations for greater use of second-eye cataract surgery and the bilateral progression of the disease, there is a substantial proportion of unmet need for this treatment[16].

In this context of increasing unmet need for cataract surgery[22] and greater utilisation [1-4], the volume of second-eye surgery is important. The causes are the pressure on costs[5], the still important proportion of people who die before undergoing surgery despite the increase of surgery rates[22], and the management of waiting lists in the public health system, as prioritization systems are usually based on the visual acuity of both eyes, thus giving less priority to patients waiting for second-eye surgery [23-25].

The aim of this study was to estimate, over the total number of cataract surgeries in the public health system, the proportion of second-eye cataract surgery, evaluate its time-trend, and explore differences in utilisation by patients' gender, age, and region of residence.

Methods

Setting and patients

Information was obtained from the Minimum Data Set of Catalonia, which includes 172,125 episodes of cataract surgery performed between January 1999 and December 2002 (figure 1). The study period was chosen to be representative of the current cataract surgery rate: since 1999, the use of phacoemulsification in the outpatient setting has been widespread in Catalonia, and second-eye surgery has become routine. Privately financed cataract surgeries (10.4%) were excluded, resulting in 154,215 surgeries in public hospitals. Cataract surgery procedures (codes 13.1 to 13.59 and 13.71 of the ICD-9-CM) performed for senile cataract (codes 366.10 to 366.19, 366.8 and 366.9 of the ICD-9-CM) were included.

The information for each procedure included the patient's gender, age at surgery, and region of residence. Age at surgery was grouped into four categories: less than 60 years, between 60 and 69 years, between 70 and 79 years, and 80 years or older. Catalonia (6,343,110 inhabitants according to the 2001 census) was divided into seven health regions. Of the total number of surgeries, 1.5% (2,279) could not be assigned to a particular region and were excluded from the analysis of regions only.

The study followed the tenets of the Declaration of Helsinki and was approved by the ethical committee of the research centre.

Calculation of the proportion of second-eye surgery

The Minimum Data Set does not record whether a cataract procedure was a first- or second-eye operation. For the 154,215 public sector cataract surgeries included in the study (figure 1), surgeries in the same patient were identified through their blinded clinical record number and hospital identifier (corresponding to 115,104 patients). To reduce possible biases in the calculations due to errors in the registry, 561 surgeries of 185 patients with more than two recorded surgeries were excluded, as well as 451 surgeries dated less than 1 week after the first-eye surgery (not considered as different) and 309 surgeries in patients younger than 30 years (not considered as senile, figure 1).

Between 1999 and 2002, one-third of the patients (about 38,200) underwent surgery in both eyes (figure 1). In the

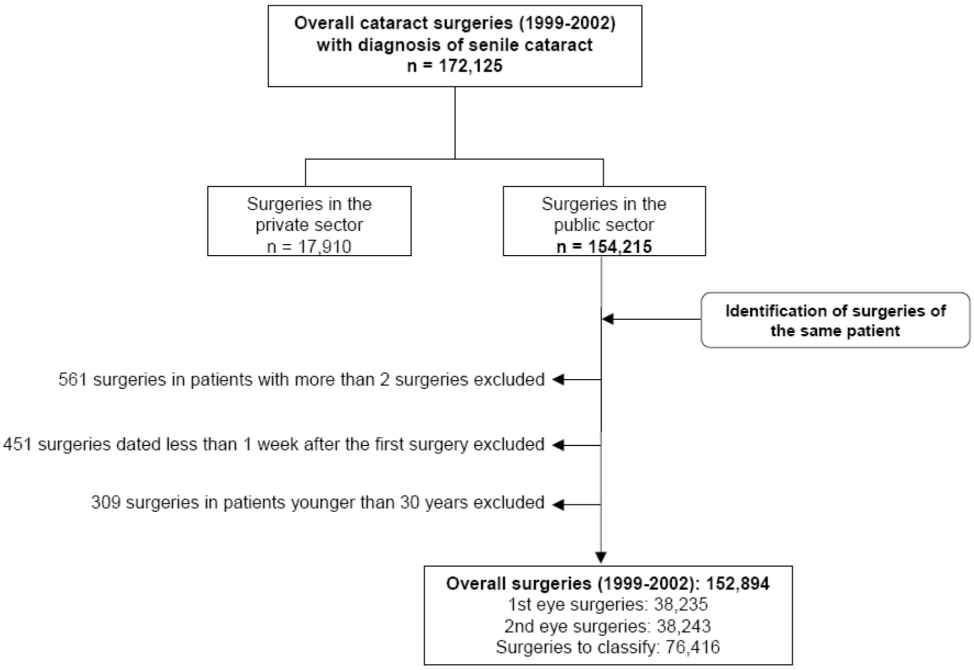

Figure 1
Flow diagram of data included in the analysis.

remaining 76,416 patients who underwent one surgery only in this period, it was necessary to establish whether the surgery corresponded to first-eye surgery without a second surgery before December 2002 or second-eye surgery with the first eye being operated on prior to January 1999. In order to classify these surgeries, the time interval between the first and second surgery in patients who underwent two surgeries in the study period was calculated. The mean time interval was 7.5 months with a median of 4.9 months and 95% of the patients underwent second-eye surgery 22 months or less after first-eye surgery. The 95th percentile was considered as the maximum time interval between the two surgeries, allowing errors in the identification of first- and second-eye surgeries to be reduced to 5%. Thus, the surgeries performed in the first 22 months (between January 1999 and October 2000) were used only to identify, when appropriate, the corresponding second-eye surgery performed from November 2000 onwards, while the unilateral surgeries performed after that date were considered as first-eye surgeries.

Analysis

The proportion of second-eye surgery was calculated for each month between November 2000 and December 2002 as number of second-eye surgeries divided by overall number of surgeries per month. The age and gender standardised rates in each region were calculated for both first- and second-eye surgery by direct standardisation to the 2001 population.

A linear regression model was adjusted with the observed monthly proportion of second-eye surgery as the dependent variable. This model included the natural logarithmic transformation of time in months (ranging from 1 to 26) as the independent variable because there was a linear relationship between the proportion of second-eye surgery and the log-transformation of time. Thus, the observed proportion of second-eye surgery was characterised throughout the study period. This proportion showed a logarithmic shape, starting with a pronounced increase but showing moderate growth at the end of the period.

Although the most appropriate model for proportions was the logistic model, the adjusted linear model provided similar predicted values and better goodness-of-fit statistics. For the sake of clarity in the interpretation of results, the linear regression model was used.

Two multivariate models were developed. One assessed differences in the proportion of second-eye surgery according to age and gender and the other assessed differences among regions. Both models included the logarithmic transformation of time, the coefficient(s) associated with the factors under study, and the interaction among them as independent variables.

Results

Between November 2000 and December 2002, 67,197 first-eye and 28,860 second-eye surgeries were performed. The mean age was 74.4 years at first-eye surgery and 75.0 years at second-eye surgery, while 58.5% of first-eye surgeries and 60.9% of second-eye surgeries were performed in women.

In the study period, the overall proportion of second-eye surgery was 30.0%. An increasing tendency in the proportion of second-eye surgery over time was observed (figure 2). Table 1 shows the proportion of second-eye surgery stratified by gender, age, and region. The highest proportions were found in women (31.1%, 95% CI 30.7; 31.5) and in patients aged 70 to 79 (31.4%, 95% CI 31.0; 31.8). Differences among regions ranged from a proportion of 25.5% (95% CI 24.5; 26.5) in Girona to 33.6% (95% CI 32.8; 34.5) in Barcelonès Nord-Maresme.

Residuals of the regression models were checked and normality was accepted for all of them (data not shown). The overall regression model (not including age, gender and region) showed a statistically significant increasing tendency and explained 59.4% of the variance in the proportions observed (figure 2). At the end of the study period, the adjusted proportion was 32.5% (95% CI 31.4; 33.6). Projecting to a 5-year time horizon showed that, in 2007, 35.7% (95% CI 33.6; 37.7) of cataract surgery would be performed in second eyes.

The regression model including gender and age showed that the effect of this two factors on the proportion of second-eye surgery was independent since no interaction between age and gender, or between age, gender and time was found. The proportion of second-eye surgery was 1.9% (95% CI 0.9%; 2.9%) greater for women ($p < 0.001$) than for men. This difference held constant across time since no significant interaction between gender and time was found ($p = 0.441$). Male patients aged less than 60 had the lowest proportion in oposition to females aged between 70 and 79 which had the highest proportion (figure 3). In all age groups the proportion of second-eye surgery significantly increased during the study period, this increase was greater as age increased (figure 3). Patients over 80 years of age had the highest increase in the proportion of second-eye surgery, reaching 32.9% (95% CI 31.3%; 34.5%) for males and 34.8% (95% CI 33.2%; 36.4%) for females at the end of the period studied (December 2002). Patients aged less than 60 years had the smallest increase reaching a proportion of 26.4% (95% CI 24.8%; 28.0%) for males and 28.3% (95% CI 26.7%; 29.9%) for females at the end of the period (figure 3).

Significant differences among health regions were found in the proportion of second-eye surgery when the logarithmic model including regions was adjusted (figure 4). The highest proportions were found in Barcelonès Nord-Maresme and Centre (approximately 32%), followed by Lleida and the City of Barcelona, which showed intermediate proportions. Finally, the remaining three regions had proportions of around 17%. The time trend showed that regions with the lowest proportion at the beginning of the study period (November 2000) had a significantly greater increasing tendency of around 4% (figure 4).

Variations in the overall rate of cataract surgery (first- and second-eye surgery) among regions were found. In 2001, the overall rate was 190.5 surgeries per 10,000 inhabitants aged 50 years or older and the rate of second-eye surgery was 55.3 surgeries per 10,000 inhabitants aged 50 years or older. Variation in age-gender standardised cataract surgery rates among regions ranged from 126.4 in Tarragona-Terres de l'Ebre to 238.4 in Barcelonès Nord-Maresme. Variations in the standardised rates of second-eye surgery ranged from 29.5 to 78.9 surgeries, corresponding to a ratio of 2.7, while those for first-eye surgery ranged from 97.2 to 159.4, corresponding to a ratio of 1.6.

Figure 5 shows the relationship between variations in the overall cataract surgery rate and variations in second-eye surgeries. In regions with the highest and lowest cataract surgery rates, variations with respect to the overall rate were mainly due to differences in second-eye surgery rates. Barcelonès Nord-Maresme and Centre, which showed the highest utilisation of cataract surgery, had a higher use of second-eye surgery.

Discussion

During the study period, 30% of cataract surgeries performed in the public system corresponded to second-eye surgery. The proportion found showed an increasing tendency. The extent and tendency of second-eye surgery were similar to those found in studies performed in the United Kingdom[15] and Sweden[4].

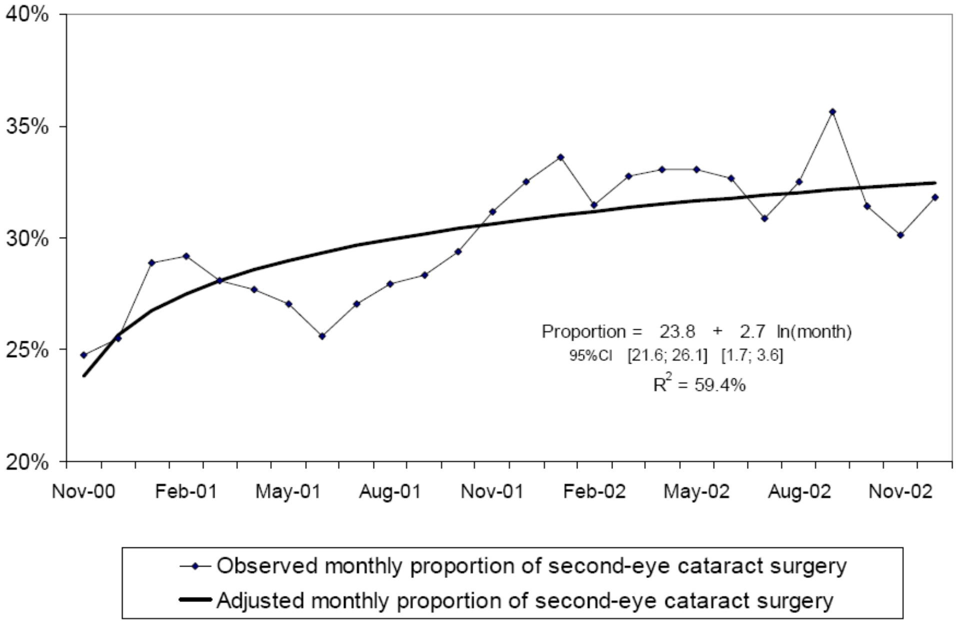

Figure 2
Observed and adjusted value of the proportion of second-eye cataract surgery in Catalonia.

Bearing in mind the bilateral progression of cataracts and the evidence of the effectiveness of second-eye surgery[5,7-13], the maximum theoretical limit of the proportion of second-eye surgery would be 50%, which would mean that all patients would undergo surgery on both eyes. However, Castells[8] pointed out that not all patients would benefit equally from second-eye surgery; some patients show general deterioration that would make them unsuitable for a second-surgery[6]. Therefore, a proportion of somewhat less than 50% can be expected. In Sweden, the projected volume of second-eye surgery is approximately 45%[6]. Thus, despite the increasing trend in the proportion of second-eye surgery observed in Catalonia and a projected proportion of around 36% in 2007, a substantial proportion of patients will probably not undergo this surgery. This information on unmet needs in cataract surgery is useful not only to health managers, but also to ophthalmologists.

The gender differences found in the present study agree with previous reports showing higher overall rates of cataract surgery and of second-eye surgery rates in women[6,17]. Although one of the most plausible explanations for this finding has been greater survival in women, our results suggest that other factors (such as preferences or comorbidity) have a greater influence than survival, as no interaction between age and gender was found.

The overall rate of cataract surgery is higher in older age groups[2-4,6]. Nevertheless, some studies[6] have found a flattening or decline in the utilisation of this surgery among the very old (patients aged around 80 or 85 years old) and a lower willingness to refer elderly patients for cataract surgery[26]. In agreement with the findings of our study, Castells *et al.*[16] found that older patients had a lower probability of undergoing bilateral surgery. Our

Table 1: Descriptive proportions of second-eye surgery between November 2000 and December 2002

	Proportion	95% Confidence Interval
Proportion of second-eye surgery in women	31.1	30.7; 31.5
Proportion of second-eye surgery in men	29.0	28.6; 29.5
Proportion of second-eye surgery by age groups		
Less than 60 years	27.0	25.9; 28.0
60 – 69 years	30.4	29.7; 31.0
70 – 79 years	31.4	31.0; 31.8
80 and older	28.1	27.5; 28.6
Proportion of second-eye surgery by region		
Lleida	26.9	25.9; 28.1
Tarragona-Terres de l'Ebre	25.6	24.5; 26.8
Girona	25.5	24.5; 26.5
Costa de Ponent	28.1	27.5; 28.9
Barcelonès Nord-Maresme	33.6	32.8; 34.5
Centre	32.8	32.2; 33.5
Barcelona Ciutat	30.9	30.4; 31.5

data show greater growth among the oldest patients, progressively reducing differences in bilateral cataract surgery utilisation among age groups. This tendency could be explained by broadening the indications for cataract surgery among the very old and by evidence showing that these patients derive as much benefit from second-eye surgery as younger patients[8]. Another factor is the tendency to shorten the time interval between first- and second-eye cataract surgery in the elderly[14] to increase the length of time a patient can benefit from bilateral surgery.

To our knowledge, the present study is the first to explore geographical variations in the proportion of second-eye surgery. The differences found among regions were not

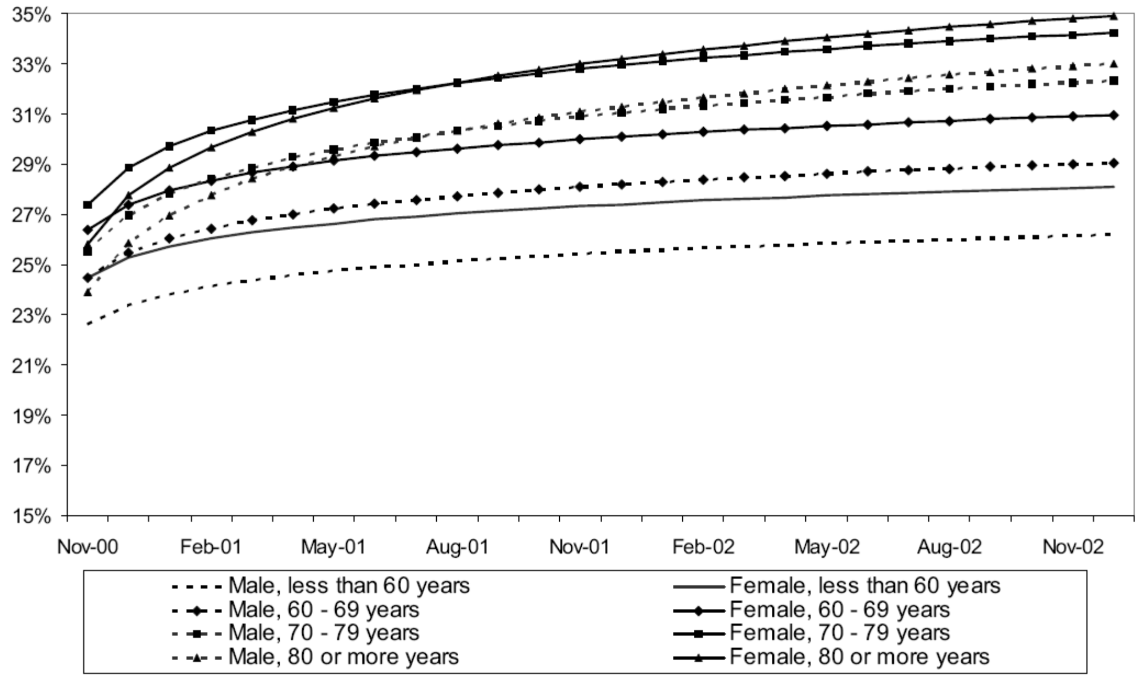

Figure 3
Adjusted value of the proportion of second-eye cataract surgery by age and gender.

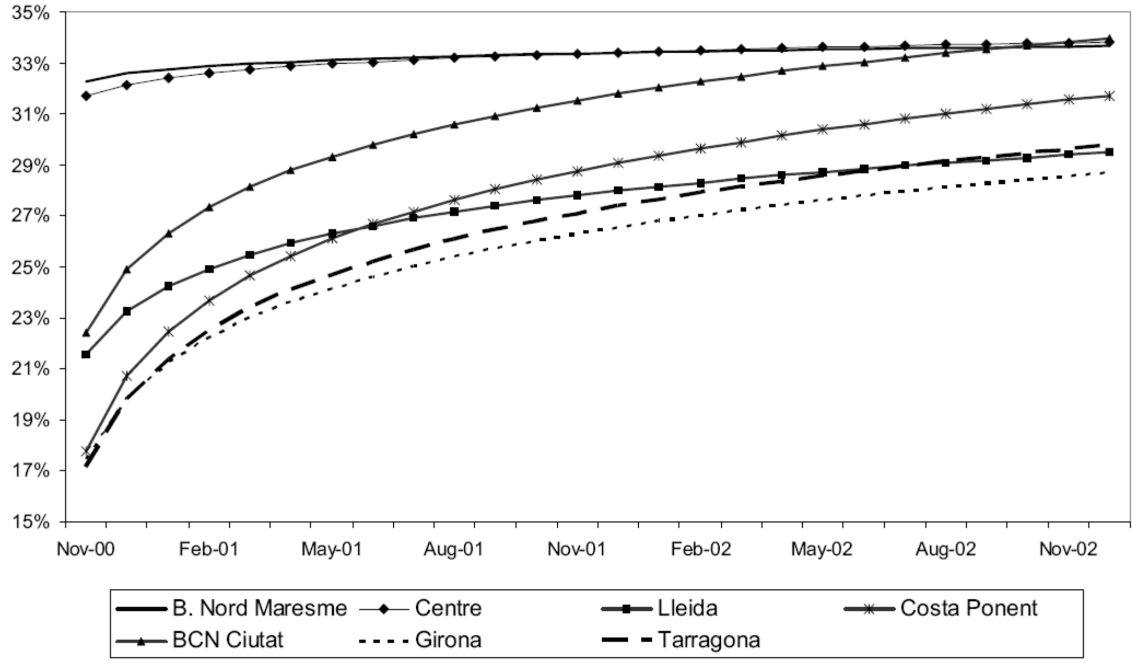

Figure 4
Adjusted value of the proportion of second-eye cataract surgery by region.

unexpected, especially in view of the wide variability in the overall rates of cataract surgery [18-21]. We expected a greater variation in second-eye cataract surgery utilisation and consequently, that this variations would contribute importantly to the differences observed in the global rate of cataract surgeries among regions. Because the benefit of second-eye cataract surgery is lower than that of first eye surgery, the decision made by the patient and the clinician is more influenced by factors other than patient preference (e.g.: accessibility or need perception). The influence of these factors in the context of the Spanish health system should be studied in future studies. However, throughout the study period, differences among regions diminished, with a more pronounced increase in the regions with lower initial proportions. The marginal increase in some regions might be due to high initial utilisation, close to the level at which the proportion of second-eye surgery settles (36%).

Lleida, Girona and Tarragona are the regions with the largest rural population and showed a marked increase, although these regions had the lowest proportions of second-eye surgery at the end of the period. The greatest increase in the proportion of second-eye surgeries was observed for the city of Barcelona (the capital and most populated city) and Costa de Ponent, which is adjacent to the city Barcelona. Barcelonès Nord-Maresme and Centre, which showed a steady, but high, proportion of second-eye surgeries, are regions with a substantial population density, which is mostly urban, and and are also adjacent to the city of Barcelona.

Several models were checked to adjust the tendency over time, including logistic regression and time-series analysis. The most appropriate option for adjusting the observed growth curve through time was the log-transformation of time because there was a linear relationship between the proportion of second-eye surgery and the log-transformation of time. Although a multivariate model including all three factors and time and the interactions among them was considered to be the most appropriate, the number of surgeries for some combinations of factors was too small to allow confident estimation due to the smaller number of surgeries in some regions. Thus, the analysis by regions was separated from the analysis by age and gender.

Another key point is the limitation to identify as first- or second-eye surgeries those surgeries of patients having only one surgery within the 4-year period. The threshold

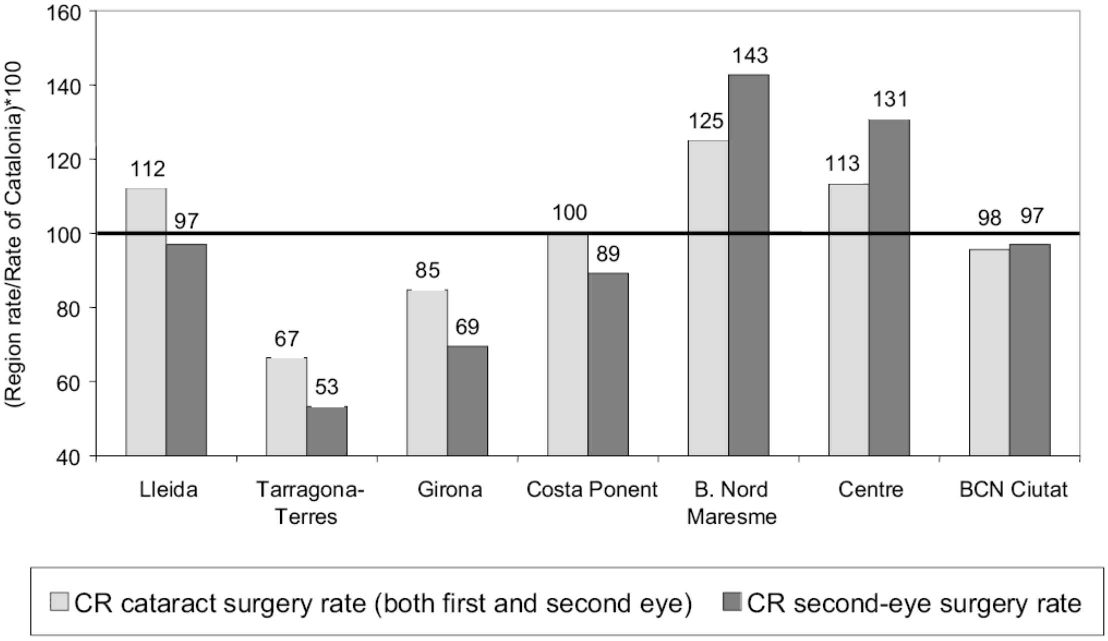

Figure 5

Comparative Ratio of the age-sex standardised overall cataract surgery rate and second-eye surgery rate, 2001. The first bar represents the comparative ratio (CR) between the overall surgery rate, standardised by age-sex, for each region with respect to the overall rate in Catalonia. The second bar represents the second-eye surgery rate for each region with respect to the overall second-eye surgery rate in Catalonia.

of 22 months was chosen in order to minimize missclassification errors, which would underestimate the proportion of second-eye surgeries for the months close to the threshold, and to allow sufficient time window to analyze time-trends with minimal influence of missclassification errors. The threshold was calculated for each region and little variation was found (data not shown).

The MDS of Catalonia is an exhaustive and systematic registry with mandatory inclusion of all surgical procedures performed in the public health system. This registry shows negligible magnitudes of missing values, with only 0.02% of cataract surgeries without the patient's gender and 0.03% without the patient's age at surgery, while only 0.16% of the total number of patients presented more than two cataract surgeries. To guarantee accurate identification of the number of surgeries per person, various forms of aggregation were tested and all provided similar proportions of second-eye cataract surgery (data not shown). One of the limitations of this study was the impossibility of identifying patients undergoing surgery in different hospitals, either in the public or in the private sector. However, some studies suggest that most patients undergo surgery in the same hospital[16,27]. Thus, the proportion of second-eye surgeries would not be seriously underestimated.

Conclusion

In conclusion, in Catalonia, the proportion of second-eye surgery is currently increasing. A reduction in variations among regions and age groups was observed (although not in gender differences), with the most pronounced growth among the oldest age groups and regions with lower utilisation of second-eye surgery. If the interval between surgeries is reduced, the proportion of second-eye surgeries will probably rise substantially, thus increasing the tension between supply, unmet need, and waiting list management. Likewise, the results of this study reveal the need to balance the greater accessibility to first-eye surgery to the elderly on the one hand and the enhanced benefit of bilateral cataract surgery to individuals on the other.

Competing interests

The author(s) declare that they have no competing interests.

Authors' contributions

All the authors have contributed to the achievement of this study. LH performed the main statistical analysis, participated in the design of the study, and drafted the manuscript. RR and MC participated in the design of the study, the statistical analysis and drafting of the manuscript. FC and EB participated in the design of the study and reviewed the manuscript. XC conceived of the study, and participated in its design and coordination and helped to draft and review the manuscript. All authors read and approved the final manuscript.

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2.3: Discrete-event simulation applied to analysis of waiting lists. Evaluation of a prioritization system for cataract surgery

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VALUE IN HEALTH

Discrete-Event Simulation Applied to Analysis of Waiting Lists. Evaluation of a Prioritization System for Cataract Surgery

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ABSTRACT

Objectives: To outline the methods used to build a discrete-event simulation model for use in decision-making in the context of waiting list management strategies for cataract surgery by comparing a waiting list prioritization system with the routinely used first-in, first-out (FIFO) discipline.

Methods: The setting was the Spanish health system. The model reproduced the process of cataract, from incidence of need of surgery (meeting indication criteria), through demand, inclusion on a waiting list, and surgery. "Nonexpressed Need" represented the population that, even with need, would not be included on a waiting list. Parameters were estimated from administrative data and research databases. The impact of introducing a prioritization system on the waiting list compared with the FIFO system was assessed. For all patients entering the waiting list, the main outcome variable was waiting time weighted by priority score. A sensitivity analysis with different scenarios of mean waiting time was used to compare the two alternatives.

Results: The prioritization system shortened waiting time (weighted by priority score) by 1.55 months (95% CI: 1.47; 1.62) compared with the FIFO system. This difference was statistically significant for all scenarios (which were defined from a waiting time of 4 months to 24 months under the FIFO system). A tendency to greater time savings in scenarios with longer waiting times was observed.

Conclusions: Discrete-event simulation is useful in decision-making when assessing health services. Introducing a waiting list prioritization system produced greater benefit than allocating surgery by waiting time only. Use of the simulation model would allow the impact of proposed policies to reduce waiting lists or assign resources more efficiently to be tested.

Keywords: cataract extraction, computer simulation, elective surgical procedures, methods, prioritization, waiting lists.

Introduction

Computer simulation techniques have allowed the introduction of modeling methodologies that analyze complex systems through virtual experimentation to assess the impact of interventions in health services. Discrete-event simulation, or queuing theory, is a well-known technique in operations research, and has mainly been developed in the context of military research and manufacturing systems. In the medical setting, Markov models and decision trees have been extensively used despite their limitations in reproducing health-care problems accurately. Discrete-event simulation is gaining popularity because of its flexibility in representing real systems by taking into account patient characteristics and the scarcity of resources present in health services provision [1,2].

Study of needs and demand for health services is important because substantial unmet needs are observed. The gap between needs and services provision may be too great to be resolved, but models that assess the impact of changes on the amount of resources used or the impact of health policies on the management of need and demand are useful in decision-making [3].

Cataracts, or lens opacity, is an important health problem because it is the major cause of blindness worldwide [4]. Moreover, its treatment (surgical extraction of the lens and insertion of a calibrated intraocular lens) is one of the most frequent surgical procedures and its use has increased in the last few years [5]. In developed countries, the prevalence of cataract is high, especially among the elderly [6]; thus, the volume of need and demand for surgery is too great for current supply, and waiting lists arise. The result of delayed surgery in developed countries is visual

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disability associated with moderate to low levels of visual acuity; however, in less developed countries, delayed surgery may lead to blindness.

The Spanish health-care system provides universal coverage. Cataract patients are referred by their family physician to the primary health-care ophthalmologist and then to the hospital. In 2003, cataract surgeries in the private sector represented less than 10% of overall cataract surgeries because mutual or private health insurance companies do not cover the cost of the intraocular lens.

Recently, several governments have considered the need to prioritize patients on waiting lists for elective surgery, which would modify the principle of first-in, first-out (FIFO), i.e., prioritization according to waiting time [7–11]. Indeed, prioritization is based on the fact that the need for surgery differs in patients with appropriate surgical indication and introduces levels of need. In the specific context of elective surgery, several interventions may be tested. We focused on prioritization of cataract surgery waiting lists to illustrate the potential of discrete-event simulation to reproduce a health-care system and to allow hypothetical interventions to be assessed without intervening in the real system. Waiting lists reflect a situation in which scarcity causes competition for resources and entries to and exits from the waiting list follow a stochastic law. Treating waiting lists as a queue allows patients to be prioritized and the impact of the time waited related to the level of need for surgery to be quantified. In Spain, a project has recently been developed (before the study presented here) to work on prioritization criteria for cataract surgery [12–14] and knee and hip replacement [12,13,15]. By using the conjoint analysis technique [16], a prioritization system was obtained including clinical (visual impairment and recovery probability), functional (difficulty in performing activities of daily living and ability to work) and social (have someone to look after the patient and be a caregiver) criteria. The general population, patients and relatives, clinical specialists and related health professionals were involved in the development of the prioritization system. The prioritization system showed acceptable validity and reliability in establishing priority for surgery. Possible scores range between 0 and 100, higher scores representing greater need. The highest weighted criterion was visual impairment, followed by limitation in performing activities of daily living. The Department of Health requires that this prioritization system be applied. Nevertheless, a guaranteed waiting time of less than 6 months has been established in Catalonia and waiting times have decreased.

The simulation model was used to compare this prioritization system with the FIFO system, which represents the current management of waiting lists, ordered according to time waited. Several previous experiences have taken advantage of simulation to assess prioritization of demand [17–20] and assessment of needs in health services [21–23].

The objective of the present article was to outline the methodology used to build a discrete-event simulation model as an aid to decision-making in the context of a health system with limited resources. Specifically, the method was applied to assess needs and prioritization of waiting lists for cataract surgery. The methods section shows the steps used to construct and implement the model and the results section includes some illustrative results according to the objective of comparing waiting list strategies. The final section includes discussion of the methodology and of the results obtained.

Methods

Conceptual Model

The conceptual model referred to individuals from the general population, aged 50 years or older, at risk of need for cataract surgery, and focused on demand in the health system of Catalonia (Spain).

Cataract was defined as visual impairment due to lens opacity, and criteria for surgical indication as any lens opacity and visual acuity of 0.5 or less. The need for cataract surgery was defined as the prevalence of need for surgery according to the indication criteria. The event "Incidence" was defined as the occurrence of need for surgery (Fig. 1). Need for surgery was divided into "Nonexpressed Need" (explained below) and "Expressed Need" or, equivalently, "Waiting List." Because senile cataracts are mostly bilateral and clinical guidelines recommend surgery on one eye at a time, "Nonexpressed Need" was divided into "Nonexpressed Need First Surgery" for persons with bilateral cataracts and "Nonexpressed Need Second Surgery" for persons who had already undergone surgery in one eye (aphakic). "Nonexpressed Need" represented the population that, even if they met the indication criteria, would not be included on a waiting list for several reasons (no perception of need, inaccessibility, preferences). This category was calculated by subtracting the number of patients on the waiting list from the number of prevalent cases. The event of expressing need (demand) was considered equivalent to the following process: an individual meeting indication criteria requests surgery in the public sector, he or she is indicated for surgery, assigned a priority score by an ophthalmologist and is included on a waiting list of the health system. Persons included on a waiting list were considered to have requested surgery. Moreover, because 24.7% of the inhabitants of Catalonia have double health-care coverage [24], the activity of the private sector for cataract surgery was taken into account (state "Private Sector"). Individuals may request surgery in the private sector after requesting

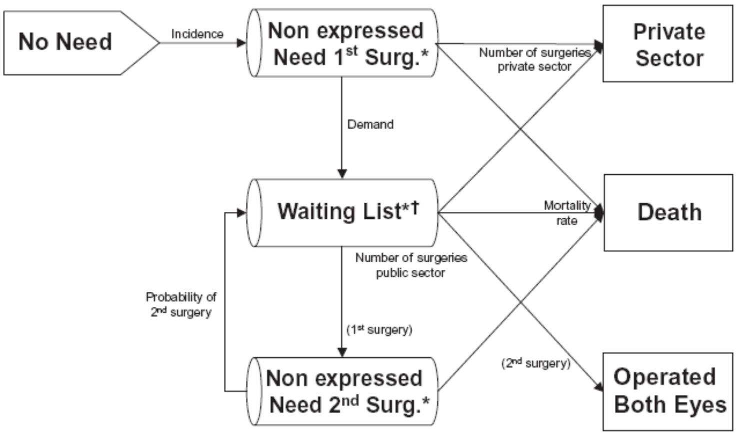

Figure 1 Conceptual model. *Prevalence of need is divided among these 3 states. †Patients on the waiting list have the priority score as an additional attribute.

surgery in the public sector and waiting for some time, or they may request surgery directly in the private sector, depending on their preferences. Figure 1 shows the flow chart for the conceptual model, which also includes the state of "Death."

The model included the following assumptions: 1) incident cases had bilateral cataracts (because cataract is an age-related disease); 2) patients did not improve (they remained the same or worsened) unless they underwent surgery; 3) there was no return from the private sector to the public sector waiting list [25,26]; 4) demand depended on supply capacity; 5) patients were operated on one eye at a time.

Importantly, the component "Waiting List," which was implemented as a queue, included the waiting list management discipline (according to FIFO or to the prioritization system).

Parameter Estimation

Once the conceptual model has been described in detail, data must be analyzed to obtain distributions for times to events and for attributes to be randomly assigned to entities (in our case, the entities represent persons meeting the indication criteria for cataract surgery and most attributes depend on age and sex). The parameterization of the model also includes the initial state, that is, how many entities (prevalent cases of need) are included in each of the components of the model ("Waiting List" and "Nonexpressed Need" for first and second surgery) and the value of their attributes.

The model's parameters were estimated from several sources, including administrative and research databases (Table 1). Data from similar settings were used when data from the study's setting were unavailable. Because this was a continuous-time model, the parameters for transitions between states were estimated as distributions of time to an event. Moreover, the possible changes in parameters related to supply and demand through the 5-year time horizon were taken into account and models including time were used to update some parameters at the beginning of each month. Table 1 shows a list of the parameters with their sources of information and their estimations for the current scenario.

To divide the initial distribution of prevalent cases of need for surgery among the states of "Nonexpressed Need" and "Waiting List," prevalence estimates of cases of bilateral cataract and aphakia (surgery in one eye) with need for surgery were projected onto the Catalan population. All calculations were stratified by age and sex. The distributions of age conditioned on sex were obtained through the projected prevalent cases. As there are no primary data on the prevalence of cataracts in Catalonia or Spain, the database of the North London Eye Study, a population-based study of the prevalence of eye diseases in North London [27], was used and prevalence was calculated by age and sex. The number of inhabitants in Catalonia by age and sex was obtained from the 2001 census. In the absence of incidence data, prevalence was also used to estimate incidence through the Podgor and Leske method [28]. The prevalence of cataracts was smoothed by adjusting a logistic model by age and sex and incidence was obtained. The number of incident cases was calculated by projecting the estimated incidence by age and sex onto the population. The time between two consecutive incident cases was generated through an exponential distribution, as this is a plausible distribution for interarrival times that occur at a constant rate. The census population and the number of deceased by age and sex, obtained from the 2001 mortality register, were used to estimate the mortality hazard function ($h(t)$). The model that has been shown to be most appropriate for adjusting the mortality rate by age is a Gompertz [29] function. Thus, the mortality hazard function by age was modeled through: $h(age) = \alpha \cdot e^{(\beta age)}$. Different functions were adjusted for

Table 1 Value of the parameters for the current scenario

Parameter	Source	Value
Related to initial state		
Nonexpressed Need first surgery backlog	NLES & Census data	318,752
Nonexpressed Need second surgery backlog	NLES & Census data	81,585
Waiting list backlog	Waiting lists register	19,586
Proportion of patients waiting for second eye surgery	Pilot test	0.209
Static parameters		
Incident cases per month	NLES & Census data	5695.04
Number of cases operated in the private sector per month	Hospital Discharge Minimum Data Set	383.47
Proportion of cases of the waiting list who switch to the private sector	Pilot test	0.0613
Top limit for waiting list contents (self-regulation)	Opportunistic	0.15
Increase in priority score (points)	Pilot test & Field work	2.57
Time between revisions of priority score (months)	Pilot test & Field work	1
Mortality hazard (Gompertz function)	Mortality register & Census data	
Male		$0.000018286\ e^{0.102374095\ \mathrm{age}}$
Female		$0.00000124309\ e^{0.129010243\ \mathrm{age}}$
Dynamic parameters		
Number of surgeries per month	Hospital Discharge Minimum Data Set	$s(t) = 2350 + 380\ \ln(60 + t)$*
Probability of second eye surgery	Hospital Discharge Minimum Data Set	$p(t) = 0.2805 + 0.0645725\ \ln(27 + t)$†
Number of bilateral cases entering the waiting list per month	Waiting lists register	$d(t) = \sec(t - 1) - 1266.5$‡

*From 3905.85 at t = 0–4169.25 at t = 60.
†From 0.493 at t = 0–0.568 at t = 60.
‡From 2632.96 at t = 0–2899.56 at t = 60.
Census data and Mortality register data were obtained from the National Institute of Statistics (INE).
Waiting lists register data and Hospital Discharge Minimum Data Set were obtained from the Catalan Department of Health.
NLES, North London Eye Study data, obtained from the authors; Pilot test: Pilot test of the introduction of the prioritization system in the clinical practice.

men and women. An approximate density function was calculated as the difference in probability of the cumulative distribution function, evaluated at 1-month intervals. The density function for lifetime represents the probability of a person aged x years of dying at age $x + t$ given he or she has survived until age $x + t - 1$ [30].

To calculate surgery rates and the probability of second-eye surgery, the Hospital Discharge Minimum Data Set of the Catalan health service was used. The procedures of cataract extraction (according to ICD9-CM classification) from 1999 through 2003 were included. The database structure allowed the public and private sectors to be differentiated and bilateral surgeries to be identified. The time between two successive surgeries was generated through an exponential distribution based on the monthly number of surgeries in the public sector. The model that best fitted the increase in the number of surgeries through time was a linear model using a logarithmic scale for time to predict future numbers of surgeries from December 2003 onwards. The model was specified as: $y = \beta_0 + \beta_1 \ln(t)$. Patients with one or two surgeries within the period were identified. The probability of second-eye surgery was calculated as the proportion of second-eye surgeries divided by that of first-eye surgeries. This was calculated monthly and a logarithmic-increasing time-trend was also estimated. The time between two successive surgeries was generated through an exponential distribution based on the monthly number of surgeries in the public sector.

Because no tendency was observed between 1999 and 2003, the number of surgeries in the private sector was estimated through the monthly mean of the previous two available years. An exponential distribution was used for the time between successive surgeries. The probability of a patient in the state of "Waiting List" switching to the private sector was calculated by using the available data on reasons for leaving the waiting list. Dependence on the time spent waiting or priority was considered for the transition probability from "Waiting List" to "Private Sector"; however, neither the number of surgeries in the private sector, nor the proportion of individuals coming from the public waiting list was modified according to the waiting time of the public sector.

The number of monthly entries to the waiting list in 2003 and the number of patients waiting in June 2004 were obtained from the health system's Waiting Lists Register. The time between successive inclusions on the waiting list was modeled with an exponential distribution based on the average number of bilateral patients entered on the waiting list per month (aphakic patients entered the waiting list according to the probability of second-eye surgery). The number of inclusions on the waiting list increased through time by the same amount as the number of surgeries, that is, demand depended on supply but supply did not depend on demand. A delayed dependence on the increase in the number of surgeries was introduced. Moreover, to reproduce the natural mechanisms of waiting list regulation, a reduction factor was applied when the number of patients on the waiting list exceeded a specific proportion of the initial number. The reduction factor was expressed as a percentage and was calculated as the inverse of the square root of the current number of patients on the waiting list minus the maximum permitted plus one. This factor was applied to both the entries for first and second-eye surgeries and caused the waiting list to have a steady volume.

A pilot study to assess the introduction of the prioritization system in clinical practice [31] was used to calculate the distributions of priority score at entry to the waiting list and the proportions of patients with bilateral cataract and aphakia on the waiting list. The priority scores of patients entering the waiting list showed wide variability. The mean priority score was 34.7 points with a standard deviation of 23.2 points. Observed scores covered the whole range (from 0 to 100) both for patients with bilateral cataract and for those with aphakia. Different empiric distributions of the priority score were used for bilateral and aphakic patients because a statistically significant difference was found between means. Moreover, for patients entering the waiting list twice, a correlation of 0.55 was forced between priority scores by simulating the priority score for the second eye taking into account the value for the first eye. Because the prioritization system includes clinical and functional criteria that may worsen over time, the increase in priority score through time waited was evaluated. Priority score was assessed on entry to the waiting list and after a waiting time ranging between 3 and 9 months in patients included on the waiting list of a teaching hospital (Hospital de l'Esperança). The relationship between time waited and the increase in priority score could not be adjusted through a regression model, but was modeled as an increase of 18 points (the mean increase) divided by 7 (the mean time, in months, between assessments) each month.

Simulation Model

The conceptual model (Fig. 1) was implemented using the package SIMUL8 Release 10 standard edition (SIMUL8 Corporation) [32]. The time units were months and the simulation horizon was 60 months (5 years). This horizon was considered sufficiently long to see how the system evolved without compromising the accuracy of the estimations that were unchanged throughout the time horizon. Lifetime horizon was not considered as appropriate because we were interested in analyzing need and utilization from the point of view of the health system, not in analyzing the evolution of individual patients. The initial state of the simulation imitated the current volume of patients in each state (that is, prevalent cases with the age and sex structure divided among the two states of "Nonexpressed Need" and "Waiting List"). These states were implemented as queues. SIMUL8 was linked to Excel to import and export data and to provide a more user–friendly interface.

Each patient had a set of attributes that included age, sex, priority for first- and second-eye surgery (when applicable), "type" of patient (bilateral or aphakic) and lifetime (conditioned by age and sex). The priority scores were generated when a patient entered the waiting list and took into account whether the patient had bilateral cataracts or aphakia. Under the prioritization system, the order of the patients on the waiting list according to priority score was updated each time that a new patient entered the waiting list and after updating the priority scores of the patients waiting the longest. Exits from the waiting list to surgery in the public or the private sector corresponded to patients at the front of the queue (with the highest priority score or the longest waiting time, according to the discipline). Moreover, the transition after surgery in the public sector depended on the "type" of patient.

Validation

The simulation model was verified during its implementation by checking the correctness of programming (debugging). Pilot runs were used to verify that simulated values corresponded to their respective input distributions.

Validation of the model should be checked, when possible, by quantitative statistical comparisons between the results of the model and real results obtained from observation of the system. Nevertheless, health-care systems may be too complex to allow reliable calculation of the result of interest and sometimes calculation may be even impossible. Additionally, even if we had obtained a sample of real-world data, it would have been auto-correlated, precluding the use of classical statistical techniques. In these cases, other types of validation, applying qualitative comparisons based on expert opinion, can be used to assess validity understood as the usefulness of the model to achieve the established objectives.

Due to the complexity of the system we modeled, the diversity of the sources, and the quality of the information used to estimate the parameters, the face validation [33] method was employed. This method consisted of presenting, in a systematic way, known results of the real system and the results of the model to a panel of 12 experts that included epidemiologists, statisticians, health economists, sociologists, ophthalmologists, and experts in simulation.

A sensitivity analysis was performed using a fractional factorial design of experiments, including all the input parameters and the uncertainty of their estimations.

Analysis of Results

Because waiting list management alternatives were compared and the impact of the time waited depended on the level of need, we considered that the waiting time weighted by priority score was the appropriate measure to use. This measure allowed waiting times to be compared between alternatives by taking into account how those times were assigned according to each patient's priority score. The mean weighted waiting time was calculated for all the patients (eyes) that entered the waiting list during the 5-year simulation horizon (those operated on in the public sector, those still waiting at the end of the simulation, those who switched to the private sector from the waiting list, and those who died while waiting); the weight was calculated as the priority score of each patient divided by the sum of the priority scores of all patients that entered the waiting list. Thus, the difference between the two alternatives can be interpreted as the time, weighted by need, saved or lost with one alternative versus the other (i.e., the prioritization system vs. the FIFO discipline). This comparison allows the benefit associated with the prioritization system to be quantified in terms of need-adjusted lifetime, giving greater importance to the time waited by patients with greater need, although lower weighted waiting times mean those patients with higher need waited for less time.

Our model was analyzed as a terminating simulation, i.e., one with a predetermined time horizon. To analyze the results, the fact that simulation is a sampling experiment obtained from a computer should be taken into account. If the executions start from the same initial conditions (representative of the real system), data from independent executions of the model can be analyzed simply. Confidence intervals may be constructed on a sample of means of independent runs and time plots of some variables are helpful to analyze the system's dynamic behavior [34].

Sample size (the number of replicates to be simulated) must be calculated to obtain sufficient precision for the result of interest. To do this, a first estimation of the variability of the result must be obtained from a trial with a small number of runs. Through the fixed-sample-size procedure [34], we calculated the number of replicates needed to obtain a prespecified precision of 0.1 months in estimating the difference in waiting time weighted by priority score between the FIFO and the prioritization system disciplines. First, we ran 10 replicates of the model and a standard deviation of 0.21 months was obtained. This value was used to calculate the sample size [34] with a 95% confidence level and resulted in 20 replications. These confidence intervals were based on Student's t distribution because, although the distribution function for some waiting times was clearly right-skewed, the assumption of normality could be accepted because the waiting time means of each run were calculated in sufficient numbers of patients [34].

A warm-up period should be considered in some simulation models to remove the initial transitory state from the analyses. No warm-up period was considered, but the time waited by patients in the initial waiting list backlog was not used in the calculation of the average waiting times. Outcomes of the evolution of the system through the 5-year simulation horizon included the mean priority score of all patients on the waiting list.

A two-way sensitivity analysis was performed by forcing different waiting time scenarios (by changing the number of patients on the initial waiting list backlog) crossed with waiting list discipline. The different mean waiting times for patients undergoing surgery under the FIFO discipline were used to identify scenarios for comparison. Sensitivity analyses were based not only on the waiting time weighted by priority score, but also on calculating thresholds of priority score according to eventual warranty times. These thresholds meant that all patients with higher priority scores underwent surgery in less than the warranty time.

Results

Validation

The panel of experts compared the results of the model under the FIFO discipline and the prioritization system and considered the model's results to be valid and credible. The mean waiting time of 4.5 months (95% confidence interval [CI] from 4.2 to 4.7) was considered similar to the value of 4.38 months obtained from the health authority (CatSalut, Barcelona, October 2004) for the mean waiting time for cataract surgery in Catalonia, June 2004. The results were also validated by changing the waiting list discipline from FIFO to the prioritization system to assess the impact of the prioritization system on the behavior of the system, and the resulting differences were in the expected direction. The panel of experts considered all results as valid and credible and the model as useful in achieving the established objectives.

Moreover, the results of the sensitivity analysis to assess the impact of the uncertainty of the parameter estimations showed that waiting time weighted by priority score was insensitive to the variations in all the parameters and their first-order interactions.

Main Results

Trials for each waiting list discipline included 20 independent runs. Each run processed around 7630 individuals, representing 1% of the simulated population. Regardless of the waiting list discipline, the number of patients in the "Nonexpressed Need" states and the overall number of patients with need for surgery (also including patients on the waiting list) increased across the 5-year time horizon (data not shown). "Nonexpressed Need for First-Eye Surgery" represented 75.9% of overall initial need, "Nonexpressed Need for Second-Eye Surgery" represented 19.4% and the "Waiting List" represented 4.7%. After 5 years, overall need increased by 85,530 patients (a 20%

Table 2 Waiting times of patients included on the waiting list stratified by exit route

	Number of patients*		FIFO		Prioritization system		Paired differences†	
	Mean	%	Mean	95% CI	Mean	95% CI	Mean	95% CI
Operated patients	2246.70	89.6	4.48	[4.23; 4.73]	3.84	[3.64; 4.03]	0.65	[0.55; 0.74]
Patients still waiting	186.25	7.4	2.21	[2.01; 2.42]	5.75	[5.39; 6.12]	−3.54	[−3.84; −3.24]
Patients who switched to the private sector	13.40	0.5	4.71	[4.49; 4.93]	4.19	[3.64; 4.73]	0.52	[−0.21; 1.25]
Patients who died while waiting	60.20	2.4	2.19	[2.07; 2.31]	5.41	[5.10; 5.72]	−3.22	[−3.55; −2.90]

*Results shown for the FIFO discipline only, as they were similar between disciplines.

†The mean shown is the mean of the 20 differences between mean waiting time under FIFO and mean waiting time under the prioritization system using the same chain of random numbers.

Comparison between waiting list disciplines.

FIFO, first-in, first-out.

increase): "Nonexpressed Need for First- and Second-Eye Surgery" increased by 14% and 50%, respectively. The number of patients on the waiting list was stable throughout the 5-year period, as expected due to the regulation mechanism. Of the 152,780 patients who died during the 5-year period, 6020 (3.9%) did so while waiting for surgery. Of the 23,425 patients who underwent surgery in the private sector, 1340 (5.7%) switched from the public waiting list (data not shown).

For the comparison between the FIFO and the prioritization system, simulation of the current scenario of the waiting list for cataract surgery (data from 2003 to 2004) showed that the mean waiting time for patients undergoing surgery in the public sector was 4.5 months (95% CI from 4.2 to 4.7). When applying the prioritization system, the time was reduced to 3.8 months (95% CI from 3.6 to 4.0) (Table 2). Nevertheless, patients still waiting at the end of the simulation under the prioritization system had a mean waiting time of 5.8 months (95% CI from 5.4 to 6.1), which was 3.5 months longer than that for the FIFO system (95% CI from 3.2 to 3.8). Under the prioritization system, the waiting time of patients who died while waiting was 3.2 months longer (95% CI from 2.9 to 3.6) than that for the FIFO system (Table 2).

Simulation always started with the same initial conditions. Nevertheless, although the mean priority score was stable for the FIFO discipline (around 34 points), it substantially decreased when the prioritization system was applied (Fig. 2). After 12 months, this score stabilized at around 10 points with little variability.

Sensitivity Analysis

For all scenarios of waiting time for surgical patients under the FIFO discipline, the waiting time weighted by priority score under the prioritization system was lower (Table 3). The time saved with the prioritization system was around 2 months. Moreover, the longer the unweighted waiting time, the greater the benefit (Table 3). Figure 3 shows the benefit of applying the prioritization system for scenarios shown in Table 3 and other scenarios. Figure 3 also shows that, the higher the unweighted waiting time, the higher the benefit of applying the prioritization system.

Figure 4 shows the minimum priority score needed to undergo surgery under an eventual warranty time. That is, for the current scenario, patients with a priority score (at entry to the waiting list) higher than 40.0 points underwent surgery in less than 3 months. Conversely, patients with less than 12.4 points underwent

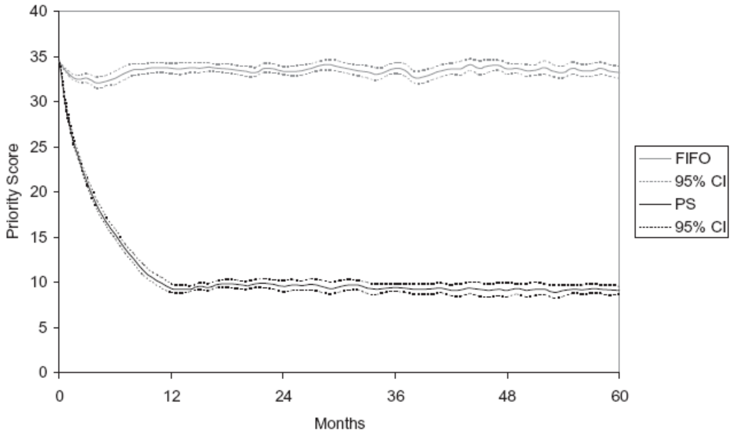

Figure 2 Evolution of the mean priority score of patients on the waiting list by waiting list discipline. FIFO, first-in, first-out; PS, prioritization system.

Table 3 Sensitivity analysis of unweighted and weighted waiting times by waiting list discipline and scenarios of unweighted waiting time of operated patients and paired differences between disciplines

Mean unweighted waiting time										Paired differences in waiting time	
Operated patients		Patients still waiting		Patients who switched to the private sector		Patients who died while waiting		Mean waiting time weighted by priority score		Waiting time weighted by priority score	
FIFO	Prioritization system	FIFO	Prioritization system	FIFO	Prioritization system	FIFO	Prioritization system	FIFO	Prioritization system	Mean	95% CI
4.48	3.84	2.21	5.75	4.71	4.19	2.19	5.41	3.76	2.22	1.55	[2.17; 2.38]
6.96	5.80	3.28	6.98	7.22	6.02	3.26	6.21	5.43	3.71	1.72	[1.50; 1.97]
11.31	8.96	5.15	8.85	11.60	10.51	5.00	8.16	8.00	6.07	1.94	[2.23; 2.56]
15.53	12.04	6.99	10.37	15.83	13.00	6.84	9.28	10.27	8.12	2.15	[2.87; 3.26]
19.70	14.99	8.70	11.90	20.01	14.36	9.14	10.42	12.36	9.91	2.45	[4.47; 4.88]

FIFO, first-in, first-out.

surgery after 12 months. For scenarios with higher waiting times, the profile was similar, but the threshold of priority indicating the highest waiting times increased. For example, for a warranty time of 6 months, the minimum priority score increased from 27.9 points for the current scenario (4.5 months of waiting time) to 72.5 points for the scenario with 19.7 months of waiting time (Fig. 4).

Figure 4 also shows which patients benefited from the prioritization system and which patients were penalized. For the current scenario, patients with priority scores higher than 27.9 points (56.8% of patients, according to the priority score distribution) had a waiting time of less than 6 months, although those with less than 12.4 points (23.6% of patients) waited for 12 months or longer. In all scenarios, patients with priority scores higher than 40 points (37.1%) had lower waiting times than the reference waiting time for the FIFO system.

Discussion

We used the example of cataract surgery waiting lists to illustrate that a discrete-event simulation model is useful in making decisions when assessing health services. The model described allows several factors that are commonly used separately by decision-makers to be integrated into a decision model.

When assessing the impact of interventions on health outcomes, the standard technique to represent the natural history of diseases is Markov models. Although Markov models ran as microsimulations can incorporate discrete events, our study shows the advantages of applying a full discrete-event simulation approach to analyze our specific problem in two key components of modeling. On the one hand, discrete-event simulation supplies model flexibility to represent epidemiological and care delivery events. On the other hand, the model output is more versatile.

When modeling health services, discrete-event simulation is a more flexible technique than Markov models. Although Markov models represent changes in patients' health status, discrete-event simulation has few restrictions and allows transparent representation of the underlying model, enabling all the characteristics of the real system (including facilities and resources) to be represented. Consequently, transitions may represent several kinds of action or changes. Moreover, although changes in the system are discrete, they occur on a continuous time scale, as each action is scheduled to happen at a time value drawn from a continuous random distribution. In discrete-event simulation, the patient is an explicit entity, characterized by attributes that can change through time or according to the patient's experience. Queues are a specific tool of discrete-event simulation. In our case, they allowed waiting list management to be modeled,

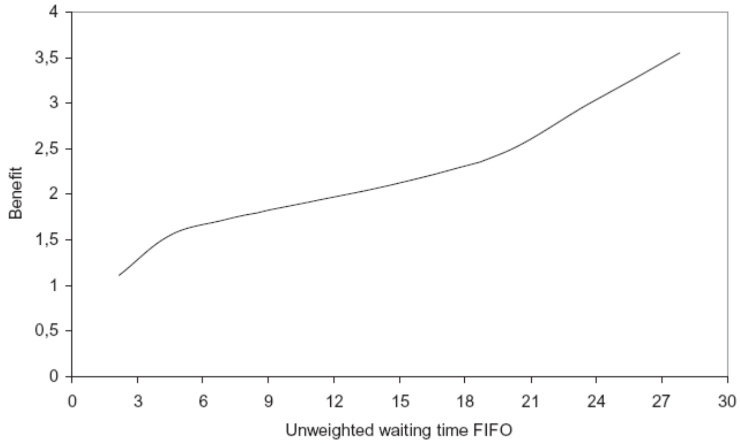

Figure 3 Benefit of introducing the prioritization system by unweighted waiting time of operated patients under the FIFO system. FIFO, first-in, first-out.

which could not have been performed with Markov models.

The output of discrete-event simulation models is not only survival (or time spent) by state as in Markov models, but also the number of incident cases, population prevalence in the different states, and their evolution through the simulation horizon, among others. Moreover, the analyses can be stratified by groups because labels are attached to cases. This feature overcomes the Markovian assumption.

In our application to the analysis of needs and demand for health services, an important feature of discrete-event simulation models is that they enable the prevalence of states with different health needs to be calculated over time in the whole population, allowing cost-utility analyses that take survival of the prevalent population into account. In contrast, Markov models analyze patients in the initial cohort only [35]. The key point when assessing health services is the prevalence of diseases and the availability and consumption of resources through time. The capacity of resources to meet needs and demand is limited and queues may arise. Waiting lists are a particular type of queue: patients are not physically queuing for the service, but they are waiting to receive a specific health service.

The model shows that the prioritization system was more beneficial than allocating surgery by waiting time only. Given the same number of surgeries, the prioritization system distributes waiting time according to priority; thus, patients with greater need wait less time. The mean benefit was 1.54 months less waiting time, weighted by priority. Moreover, the benefit of the prioritization system was greater for scenarios with longer waiting times. Currently, in Catalonia, as in other countries such as the United Kingdom, Canada or Sweden, a waiting-time guarantee of 6 months has been established and waiting times have been reduced. This reduction was reflected in our model. Nevertheless, our results were useful to show the benefit of prioritization for longer waiting times and that waiting lists are an artifact because a substantial volume of unmet needs remain in the population in addition to waiting lists, even though cataract surgery is a highly cost-effective procedure. The guarantee time of

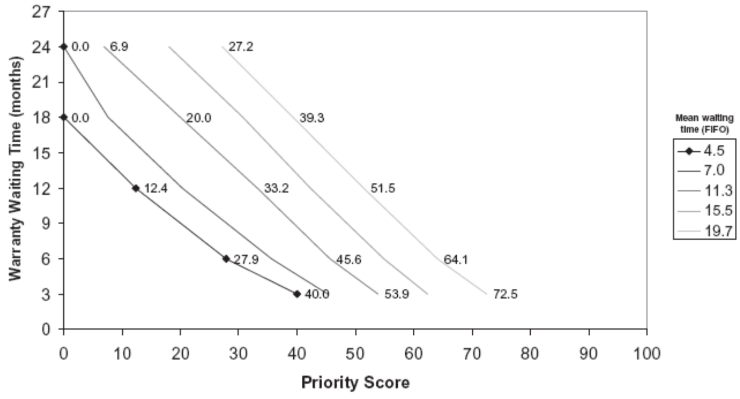

Figure 4 Minimum priority score (*x*-axis) to achieve an eventual warranty time (*y*-axis). Diamonds represent the results of the model in the scenario with current data. FIFO, first-in, first-out.

6 months was complied with in 56.8% of patients in our model (those with priority scores higher than 27).

Although the prioritization system was more beneficial at a population level, patients with lower priority scores had excessive waiting times. For example, patients with less than 12 points (23.6% of patients) would wait for 12 months or longer. Unless supply is increased, an excess waiting time of 1 years would exclude these patients from the system. Moreover, in our model, if the priority score had not been increased to take into account worsening of clinical criteria over time, these patients would never undergo surgery.

Importantly, the results of a discrete-event simulation model are only estimations that depend on the input values and, thus, on their quality. The principle of "garbage in-garbage out" applies. Moreover, the clarity and transparency of these models may lead their credibility to be overestimated, because models are always simplifications of reality.

The relationships among some parameters of the cataract model were difficult to assess, and several mathematical functions were defined to approximate their behavior within the system. These functions were used to simulate parameter relationships, such as the relationship between surgery and demand, and self-regulation of the waiting list. These relationships were not based on real data because the information needed to estimate them comes from sources with different levels of robustness and data must be compared over time. The results of estimating the parameters and the proposed relationships among them were also validated by a panel of experts and were considered as reasonable. Moreover, we checked through the multivariate sensitivity analysis that variations in these two parameters had little effect on the model's outputs.

Conclusions

Our study demonstrates that discrete-event simulation is a valid and robust tool to represent the flow of patients between need, waiting lists and surgery, considering that elective surgery is a scarce resource for which patients compete and that prioritization systems may be applied to assign surgeries according to need. Moreover, discrete-event simulation can be used as a tool for shared decision-making as patients can be presented with the expected waiting time according to their priority score and can decide whether they are willing to accept it.

Introducing a prioritization system for waiting lists was more beneficial than allocating surgery by waiting time only (FIFO) and the proportion of patients penalized with excessive waiting times was small and had low priority. In view of current data on waiting lists, testing the prioritization system through the simulation model allows definition of a (justifiable) level of need over which the public health system can appropriately meet demand. This alternative would make waiting list management transparent, would ensure that the waiting time of the most disabled patients is extremely reduced, and may be a less costly and more sustainable option than shock plans. Our results suggest that, under the prioritization system, patients with a priority score of 40.0 points or higher (37.13% of patients) would have a waiting time of 3 months or lower although those with a priority score of 27.9 points or lower (43.2% of patients) would wait 6 months or more.

The work performed for cataract surgery will be used in our future research to build models for other elective surgeries, such as arthroplasty and bariatric surgery, in which supply does not meet demand, and to perform cost-utility analyses of distinct interventions.

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Supplementary material for this article can be found at: http://www.ispor.org/publications/value/ViHsupplementary.asp

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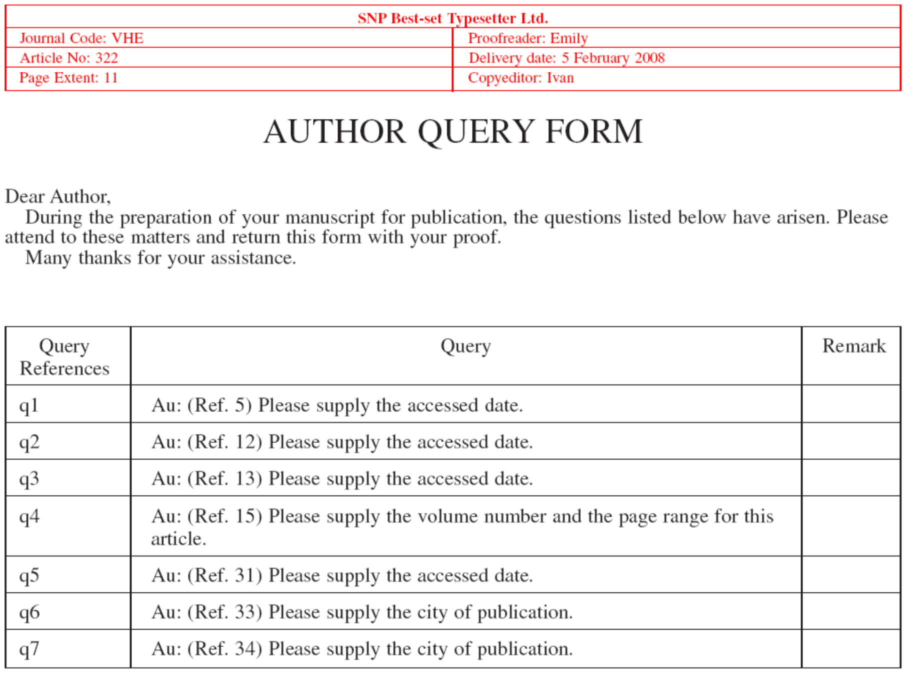

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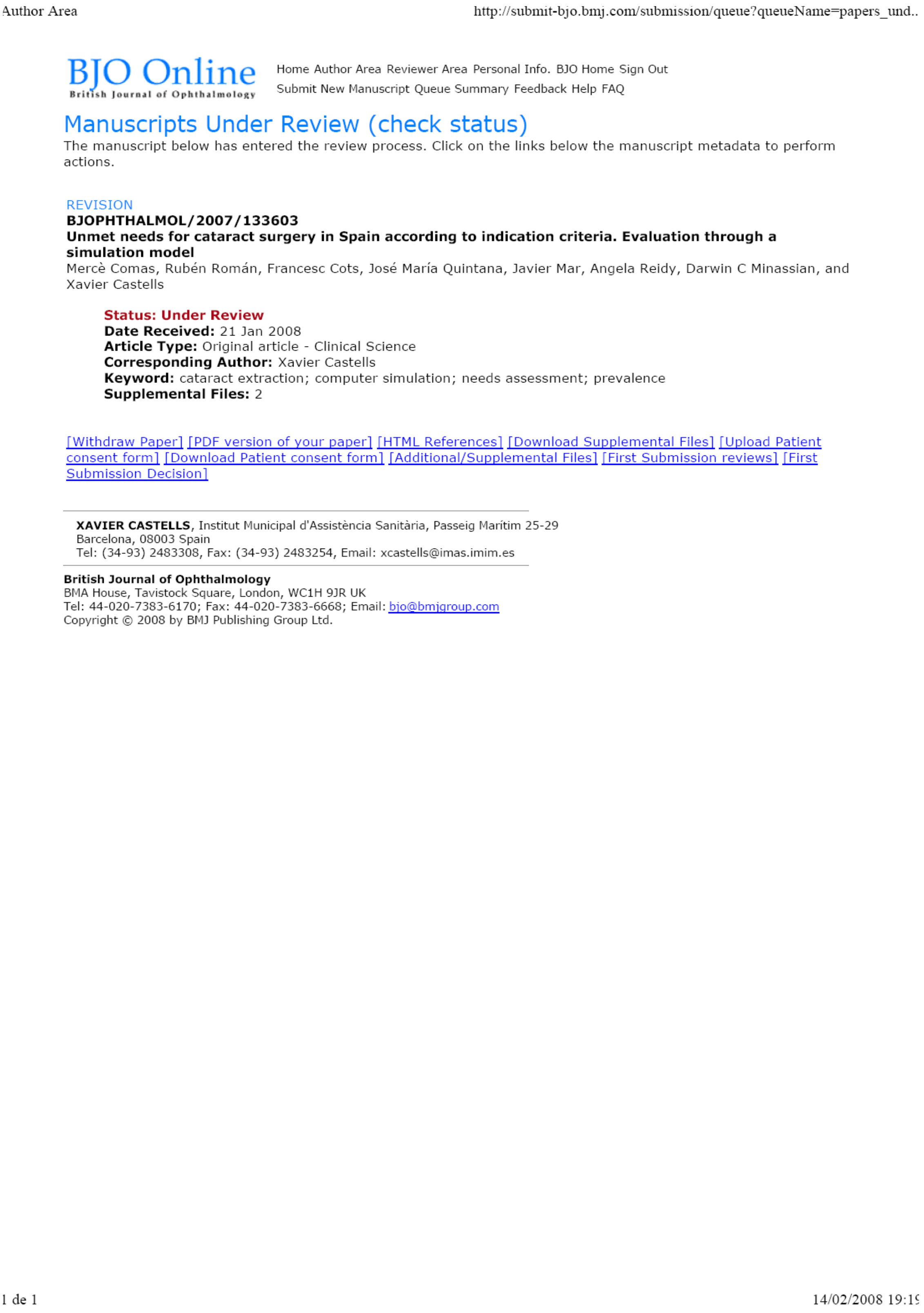
2.4: Unmet needs for cataract surgery in Spain according to indication criteria. Evaluation through a simulation model



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Unmet needs for cataract surgery in Spain according to indication criteria. Evaluation through a simulation model
Mercè Comas, Rubén Román, Francesc Cots, José María Quintana, Javier Mar, Angela Reidy, Darwin C Minassian, and Xavier Castells

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Unmet needs for cataract surgery in Spain according to indication criteria. Evaluation through a simulation model

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Running title: Unmet needs for cataract surgery.

Key words: cataract extraction; computer simulation; prevalence; elective surgical procedures; needs assessment.

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ABSTRACT

AIMS Despite the increase in cataract surgery rates, the volume of unmet needs for this type of surgery in the population is substantial due to ageing and widening of the indication criteria. Our objective was to assess future trends in needs for cataract surgery according to different scenarios of indication criteria.

METHODS A discrete-event simulation model was built for the population aged 50 years or older in five regions of Spain (45.7% of the population). Different scenarios of worse eye visual acuity thresholds for indication criteria were compared. Data from the North London Eye Study were used to project the baseline needs for surgery onto the study population. The surgery rate of each region was calculated using the Minimum Data Set. The model used data for the year 2003 and the simulation horizon was 5 years.

RESULTS The volume of need predicted for the year 2008 when scenarios of 0.5 (20/40) and 0.4 (20/50) visual acuity thresholds were used was 69,214 and 51,315 surgeries needed per 1 million inhabitants, respectively. However, unmet needs decreased when a 0.3 (20/70) threshold was used. The increment in the cataract surgery rate needed to prevent the cataract backlog from increasing was 60% for a 0.5 threshold and 50% for a 0.4 threshold.

CONCLUSION Application of indication criteria following current guidelines would substantially increase unmet needs for surgery in the next 5 years.

INTRODUCTION

In the last few years, the indication criteria for cataract surgery have been widened due to the introduction of less invasive technologies such as phacoemulsification and topical anesthesia, which have decreased surgical risk and improved the benefits of surgery. Thus, the relationship between benefit and risk[1] has been substantially modified. Broadening of the indication criteria has included lowering the threshold for visual acuity from 0.2 to 0.5 or 0.7.[2] However, the current guidelines for cataract surgery indication[3] widen substantially the indication criteria by considering whether the decrease in visual function caused by cataracts influences the patient's lifestyle, that is, whether the patient's visual function cannot satisfy the patient's needs, rather than a threshold for visual acuity.

A consequence of this change in the indication criteria is the wide variation found in the level of visual impairment in operated patients. Factors such as perceived need, variations in clinical practice, and accessibility to health services play an important role in the likelihood of undergoing surgery.

Despite the increase in cataract surgery rates in most Western countries, there is significant unmet need for surgery, explained by the widening of the indication criteria and the ageing of the population.[4] Some population-based studies that analyze the prevalence of cataract[5-10] show that an important proportion (30%) of the population older than 65 would benefit from surgery.

Our objective was to assess the impact of applying different visual acuity thresholds in indication criteria on three outcomes. First, on future trends in need for cataract surgery. Second, on the visual acuity level of the population with unmet needs. And, third, on the number of additional surgeries required to prevent the cataract backlog from increasing.

METHODS

A simulation model was built to represent the process of cataract (from incidence to surgery). The model is described in detail elsewhere,[11,12] but a summary of the methodology is reported below. The study complied with the Declaration of Helsinki and was approved by the ethics committee of Hospital del Mar-IMIM (Barcelona).

Setting

The model referred to individuals from the general population, aged 50 years or older, at risk of need for cataract surgery and focused on demand in the public health system of Spain, which provides universal coverage. Information was obtained from five regions of Spain (Andalusia, Aragon, the Basque Country, the Canary Islands and Catalonia), which account for 18.68 million people (45.7% of the Spanish population).

Indication criteria

Cataract was defined as visual impairment due to lens opacity, and criteria for surgical indication as any lens opacity under a given threshold for visual acuity (0.3 [20/70], 0.4 [20/50] and 0.5 [20/40] on the decimal scale were used). The least restrictive threshold was chosen to be 0.5 because, in most countries, it is the minimum legal visual acuity required for a driving license.[13]

Simulation model

The components of the simulation model represented the stages through which the target population would pass during the process, i.e., no need for surgery, need for surgery, surgery (in the public or private sector) and death. The transitions between stages represent concepts such as incidence or demand.[11]

The event “Incidence” was defined as the occurrence of need for surgery (fig 1). Need for surgery was divided into “Non-Expressed Need” (explained below) and “Expressed Need” or, equivalently, “Waiting List”. Because senile cataracts are mostly bilateral and interventions are performed on one eye at a time, “Non-Expressed Need” was divided into “Non-Expressed Need

First Surgery" for persons with bilateral cataracts and "Non-Expressed Need Second Surgery" for persons who had already undergone surgery in one eye (pseudophakic). "Non-Expressed Need" represented the population that, even if they met the indication criteria, would not be included on a waiting list for several reasons (no perception of need, inaccessibility, preferences, variations in clinical practice). "Non-Expressed Need" was calculated by subtracting the number of patients on the waiting list from the estimated number of prevalent cases. Expressing need was considered equivalent to the following process: requesting surgery, being indicated for surgery, and being included on a waiting list of the public health system. Because 10.3% of the inhabitants of Spain have double healthcare coverage,[14] the activity carried out in the private sector was taken into account (stage "Private Sector").

The model was implemented as a discrete-event simulation model. The time units were months and the simulation horizon was 60 months (5 years). We aimed to take into account the possible changes over the 5-year horizon in the parameters related to supply and demand. Thus, time-dependent models were used to update some parameters throughout the time horizon. Nevertheless, a 5-year horizon was sufficiently long to determine how the system evolved without compromising the accuracy of the estimations that were unchanged through time.

The model's parameters were estimated from several sources, including administrative and research databases (table 1).

Table 1: Sources of information of the model parameters.

Parameter	**Source of information**
Number of inhabitants by age and sex	Spanish Census
Prevalence of need of cataract surgery	North London Eye Study
Incidence of need of cataract surgery	North London Eye Study
Mortality	Spanish Mortality Register
Number of surgeries in the public and private sector	Hospital Discharge Minimum Data Set
Probability of second eye surgery	Hospital Discharge Minimum Data Set
Waiting List volume	Regional Waiting List Registers
Number of entries to the waiting list	Regional Waiting List Registers

The initial state of the simulation imitated the current volume of patients in each stage: prevalence of need was divided among the two stages of “Non-Expressed Need” and “Waiting List” by projecting the prevalence estimates of bilateral and pseudophakic individuals onto the study population. All calculations were made by stratifying by age (yearly) and sex. As there is no primary data on the prevalence of cataracts in Spain, data from the North London Eye Study (NLES) were used. The NLES is a population-based study on the prevalence of eye diseases in North London.[5] In the absence of incidence data, prevalence was also used to estimate incidence.[15] The mortality hazard function and the lifetime distribution were obtained through Gompertz models for men and women.[16]

To calculate the surgery rate and the probability of second-eye surgery, the procedures of cataract extraction (according to the ICD-9-CM classification) from 1999 to 2003 were included. The database structure allowed the public and private sectors to be differentiated and bilateral surgeries to be identified. Linear regression models were used to predict future numbers of surgeries and the probability of second-eye surgery from December 2003 onwards.[17] The number of monthly entries to the waiting list in 2003 and the number of patients waiting in June 2004 were obtained from the regional waiting lists registers. The number of inclusions on the waiting list was forced to have the same increase through time as the number of surgeries.

Analysis of results

Data from the NLES were used to analyze the distribution of worse eye visual acuity in people with prevalence of need. The distribution was calculated separately for people with bilateral cataracts and those who had already undergone surgery on one eye.

A sensitivity analysis of the surgery rate was performed to determine the extent to which the surgery rate would need to be increased to prevent the cataract backlog from increasing in the following 5 years.

RESULTS

The regions included in this study accounted for almost 6 million people aged 50 years old or older (32% of the overall population). The waiting lists accounted for 39,701 patients, representing 7.1%, 4.5% and 3.5% of the prevalence of need for surgery for visual acuity thresholds of 0.3 (20/70), 0.4 (20/50) and 0.5 (20/40), respectively. Simulation started with a surgery rate of 16,626 surgeries per million inhabitants aged 50 years old or older. Following the observed tendency in previous years, the surgery rate increased during the 5-year simulation horizon, reaching an increase of 6.7% by the end of the period (data not shown). The model predicted an overall volume of need for the year 2008 of almost 1.3 million people (a 13.3% increase), and almost 1 million (a 7.4% increase) for the 0.5 and 0.4 threshold scenarios, respectively (fig 2). When a visual acuity threshold of 0.3 was applied, a 5.26% decrease in the prevalence of need for surgery was observed after 5 years.

Figure 2 shows the percentage changes in the volume of prevalence of need for surgery after the 5-year simulation by visual acuity threshold. The stage of the model showing the greatest increase in all scenarios was “Non-Expressed Need for Second-Eye Surgery”, doubling its volume in 5 years when the 0.3 threshold was used (fig 2). The increment in cataract surgery rate needed to prevent the cataract backlog from increasing was 60% for indication criteria including a 0.5 visual acuity threshold, and 50% for a 0.4 threshold (data not shown).

The visual acuity distribution of the population with unmet need for surgery of the NLES database according to indication criteria is shown in table 2. For bilateral cataract, the most frequent level of visual acuity was 0.3-0.4 when the threshold was 0.5 or 0.4. However, when the threshold was 0.3, the distribution among the levels of visual acuity (0.1 or less, 0.1-0.2, and 0.2-0.3) was more balanced. The worse eye visual acuity distribution of pseudophakic cases showed the opposite pattern: the most frequent category was a visual acuity of 0.1 or less regardless of the indication criteria, while better levels of visual acuity (over 0.2) presented the lowest percentages (table 2).

Table 2: Visual acuity distribution among the population with prevalence of need defined according to different criteria for visual acuity. Data source: North London Eye Study (n=1,425).

	Bilateral cataracts				**Pseudophakia (one eye operated)**			
		Thresholds				**Thresholds**		
	N	**VA≤0.5**	**VA≤0.4**	**VA≤0.3**	**N**	**VA≤0.5**	**VA≤0.4**	**VA≤0.3**
VA≤0.1	58	12.2%	15.0%	26.6%	17	32.7%	34.0%	44.7%
0.1<VA≤0.2	87	18.4%	22.5%	39.9%	15	28.8%	30.0%	39.5%
0.2<VA≤0.3	73	15.4%	18.9%	33.5%	6	11.5%	12.0%	15.8%
0.3<VA≤0.4	168	35.4%	43.5%		12	23.1%	24.0%	
0.4<VA≤0.5	88	18.6%			2	3.8%		

VA: Visual acuity of the worse eye. Percent columns add up to 100%. The Snellen equivalent of the decimal visual acuities shown in the table is the following: 0.1=20/200; 0.2= 20/100; 0.3=20/70; 0.4=20/50 and 0.5=20/40.

DISCUSSION

This decision model allows the future prevalence of need for cataract surgery to be predicted in relation to trends in the population and in surgery supply. To our knowledge, this is the first study that uses discrete-event simulation to assess population needs for elective surgery, specifically cataract surgery. Minassian et al.[4] used the systems dynamics methodology to predict the need for cataract surgery in England and Wales and tested some interventions to prevent an increase in the cataract surgery backlog. Congdon et al.[18] pooled the results of several population-based studies and projected prevalence estimates to the US population to the year 2020.

Our model anticipated an increase in the number of people with need for surgery over a 5-year time horizon. However, the volume of unmet needs varied substantially, depending on the visual acuity threshold for surgical indication. When scenarios of visual acuity thresholds of 0.5 (20/40) and 0.4 (20/50) were used, the overall volume of need predicted for the year 2008 was 69,214 and 51,315 surgeries needed per 1 million inhabitants, respectively, indicating that the increase in the older population played a greater role than the increase in the number of surgeries. In view of the results of other studies,[4,18] this increase in the overall need for surgery was expected.

The model was also used to calculate the increment in the surgery rate that would be needed to prevent the cataract backlog from growing, resulting in increments of 60% and 50% for visual acuity thresholds of 0.5 and 0.4, respectively. These increments would result in cataract surgery rates of 26,602 and 24,939 per 1 million inhabitants aged 50 years or older. The cataract surgery rate in Spain (5,228 per 1 million inhabitants of all ages of the regions studied) is similar to that of other developed countries with universal health coverage.[19] Given that the rate at the end of the simulation was 17,740 surgeries per 1 million inhabitants aged 50 years or older, the surgery rate would need to be substantially increased to prevent the backlog from rising.

The increase in unmet needs was mainly explained by the group of patients with need for second-eye surgery, which was obviously a consequence of previously performed first-eye surgeries. Thus, these patients represent people whose disease has been partially treated and who could benefit from second-eye surgery.[20,21] The results of visual acuity in pseudophakic patients showed substantial visual impairment in the worse eye, regardless of the indication threshold.

Cataract surgery is an elective, highly cost-effective procedure. However, a substantial volume of need for cataract surgery remains in the population, in addition to waiting lists. Waiting lists cannot be used as an indicator of unmet needs, as they represent a small proportion of the overall need (people who have accessed the health services only) and would substantially underestimate the volume of unmet needs. It is important to identify the level of need for the population meeting the indication criteria, as there is evidence of absence of prioritization of people with unmet needs. A prioritization system has been developed in Spain[22] and is currently being applied in some regions. This system includes clinical, functional and social criteria, with visual impairment being the most important criterion, with a weight of 45% of the score.[23]

The visual acuity distributions of people with prevalence of need showed wide variability, covering the entire range of visual acuities under the indication threshold. Thus, when current supply cannot be increased to meet overall need, prioritization should be applied prior to entry to the waiting list, that is, at indication of surgery, in order to increase the system's efficiency by prioritizing patients who would benefit most from surgery. However, the threshold for visual acuity would need to be determined. The 0.5 visual acuity threshold may include more patients than criteria used in clinical practice while the 0.3 threshold may be too restrictive, even though it may represent a threshold without uncertainty; the results of the present study show that there are few differences in the probability of undergoing surgery with a visual acuity under 0.3.

Data from the NLES was used because primary data on the prevalence of cataracts in Spain is lacking. These data allowed us to characterize the level of need for the prevalent population more accurately than other studies based on the level of lens opacity alone[18] or on best-corrected visual acuity.[24] From a public health perspective, we were interested in characterizing the volume of vision impairing cataracts, because need is more closely related to the individual's visual acuity with own correction than to the clinical characteristics of the eyes. Although there are differences in risk factors exposure, the bias caused by using the prevalence estimates of the NLES to estimate the prevalence of cataracts in Spain would be small, as similar prevalence estimates for white population were obtained in European, Australian and US studies.[18,25]

Our model takes visual acuity into account as the only decision variable for surgical indication. Although visual acuity is a key factor, other variables are related to the appropriateness of cataract surgery indication, thus modifying demand and significantly contributing to the clinical decision-making process.[26,27] Another assumption of our model was that all prevalent cases had bilateral cataracts. Because cataract is age-related, this assumption is clinically credible. However, asymmetrical worsening of the eyes may lead to overestimation of the need for second-eye surgery.

Conclusions and recommendations

Given the current incidence, surgery rates and life expectancy, a substantial increase in the need for surgery is expected in the next 5 years. This increase is mainly due to the increase in the need for second-eye surgery. Since cataract surgery is not simultaneous, different attention should be paid to patients depending on whether they have already undergone surgery in one eye, as their level of need is conceptually different: although these patients have better visual acuity in the worse eye, patients with bilateral cataract will derive greater benefit from surgery in the first eye. Pseudophakic patients would also derive substantial benefit because their cataractous eye has substantial visual impairment. The lower level of worse eye visual acuity found in pseudophakic patients with unmet needs raises the question of whether indication criteria should take the visual acuity of the better eye into account, as it is closer to the patient's real need.

Based on our results, two recommendations can be made. Firstly, the cataract surgery rate should be increased and, secondly, prioritization should be performed at the indication stage. However, future research is needed to characterize levels of need in individuals not requesting surgery, as these individuals represent a substantial proportion of the population.

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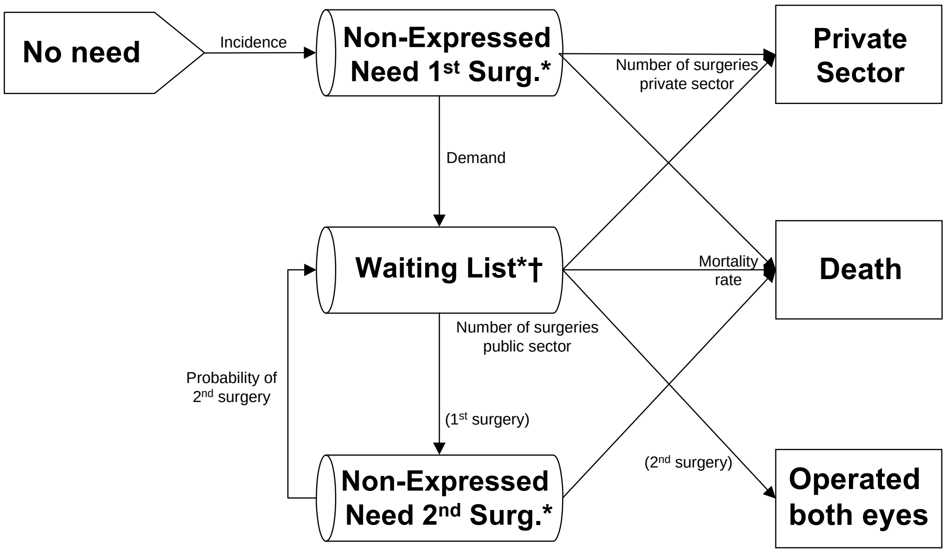
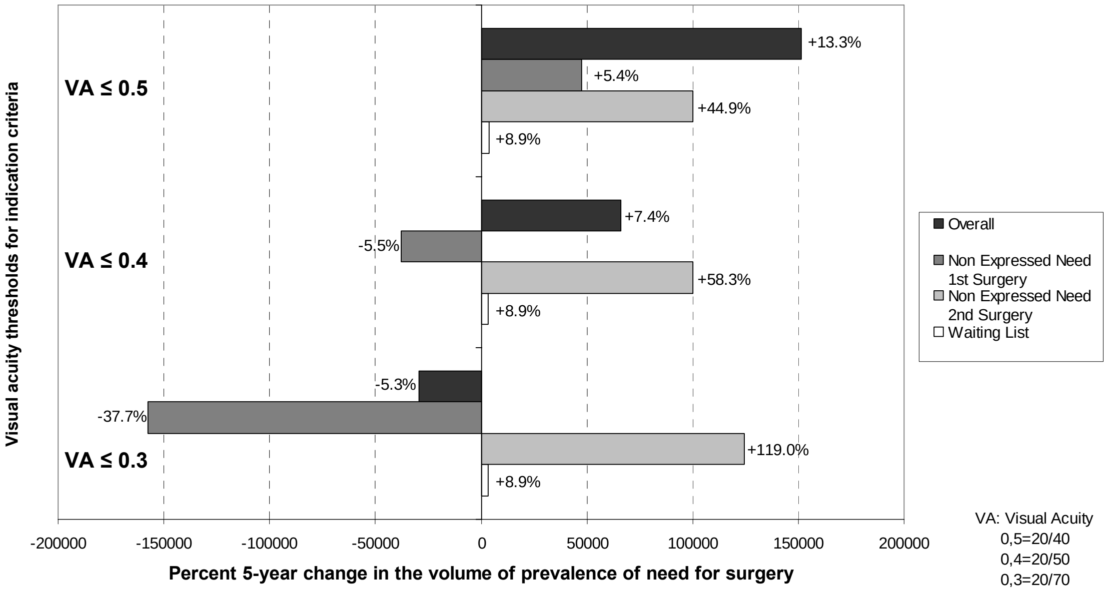
Figure 1: Conceptual model.



Legend: *: Prevalence of need is divided among these three stages.

Figure 2: Five-year change in the prevalence of need for surgery, divided by stages and by different visual acuity thresholds for indication criteria.



2.5: Geographical variations in the benefit of applying a prioritization system for cataract surgery in different regions of Spain

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Geographical variations in the benefit of applying a prioritization system for cataract surgery in different regions of Spain

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Abstract

Background

In Spain, there are substantial variations in the utilization of health resources among regions. Because the need for surgery differs in patients with appropriate surgical indication, introducing a prioritization system might be beneficial. Our objective was to assess geographical variations in the impact of applying a prioritization system in patients on the waiting list for cataract surgery in different regions of Spain by using a discrete-event simulation model.

Methods

A discrete-event simulation model to evaluate demand and waiting time for cataract surgery was constructed. The model was reproduced and validated in five regions of Spain and was fed administrative data (population census, surgery rates, waiting list information) and data from research studies (incidence of cataract). The benefit of introducing a prioritization system was contrasted with the usual first-in, first-out (FIFO) discipline. The prioritization system included clinical, functional and social criteria. Priority scores ranged between 0 and 100, with greater values indicating higher priority. The measure of results was the waiting time weighted by the priority score of each patient who had passed through the waiting list. Benefit was calculated as the difference in time weighted by priority score between operating according to waiting time or to priority.

Results

The mean waiting time for patients undergoing surgery according to the FIFO discipline varied from 1.97 months (95% CI 1.85; 2.09) in the Basque Country to 10.02 months (95% CI 9.91; 10.12) in the Canary Islands. When the prioritization system was applied, the mean waiting time was reduced to a minimum of 0.73 months weighted by priority score (95% CI 0.68; 0.78) in the Basque Country and a maximum of 5.63 months (95% CI 5.57; 5.69) in the Canary Islands. The waiting time weighted by priority score saved by the prioritization system varied from 1.12 months (95% CI 1.07; 1.16) in Andalusia to 2.73 months (95% CI 2.67; 2.80) in Aragon.

Conclusions

The prioritization system reduced the impact of the variations found among the regions studied, thus improving equity. Prioritization allocates the available resources within each region more efficiently and reduces the waiting time of patients with greater need. Prioritization was more beneficial than allocating surgery by waiting time alone.

Background

In the last few decades, cataract surgery rates have markedly increased in Western countries. This increase has been due to progressive population aging, improved surgical procedures and broadening of the indication criteria for cataract surgery produced by these improvements[1-4]. Broadening the indication criteria entails that patients with different disability levels can benefit from surgery, modifying the profile of people with unmet needs.

In Spain, the National Health System is decentralized in 17 regions. Each regional health system plans and manages their resources. Important variations in the utilization of health resources have been observed, especially in the elective surgery rate[5]. Studies evaluating the impact of different health policies on the management of need and demand, as well as resource utilization are useful in decision-making[6].

Recently, several health systems have considered the need to prioritize patients on waiting lists, which would entail modification of the current first-in, first-out (FIFO) principle through other models based on need[7-11]. Broadening the indication criteria for cataract surgery entails that the need for surgery differs in patients with appropriate surgical indication. Prioritization of patients by an explicit criterion other than the current FIFO principle would not only avoid unnecessary suffering but it is also expected to reduce the differences between the public demand and the health system utilization in terms of an improved efficiency. In Spain, a recent project has developed prioritization criteria for cataract surgery[12,13]. The objective was to create a prioritization system to ensure shorter waiting times for those patients with greater need, thus increasing the system’s efficiency. The resulting prioritization system was obtained using the conjoint analysis technique, and includes clinical (visual impairment and recovery probability), functional (difficulty in doing activities of daily living and ability to work) and social (have someone to look after the patient and be a caregiver) criteria. The most weighted criterion was visual impairment, followed by limitation in doing activities of daily living. Possible priority scores range between 0 and 100, higher scores representing greater need. Thus, in this system, need and priority are equivalent. A pilot study to assess the introduction of the prioritization system in clinical practice was carried out in Catalonia[14] and, Andalusia and Aragon[15].

The effect of introducing a prioritization system would differ in each region because health systems vary widely in terms of clinical practice and utilization rates. Studying these variations is of special interest within the Spanish health system, which provides universal coverage, given that each region manages its own resources.

Simulation techniques can be used to evaluate the impact of introducing a prioritization system in different health management scenarios. Discrete-event simulation (or queuing theory) is an appropriate tool for analyzing waiting lists[16-19], because waiting lists reflect a situation of scarcity and competition for resources, and entries to and exits from the waiting list follow a stochastic law. We defined several hypotheses about what we expected from the simulation model: 1) the prioritization system redistributes the overall waiting time across patients differently than the FIFO system by beneficiating those patients with greater need; 2) differences among regions in the benefit of applying the prioritization system will be due to differences in: surgery Rate, waiting list size and priority score distribution; 3) the model accurately reflects the real system. Several previous experiences have taken advantage of simulation to assess prioritization of demand[17-20] and needs assessment in health services[21,22]. Our objective was to assess geographical variations in the impact of applying a prioritization system in patients on the waiting list for cataract surgery in different regions of Spain, through a discrete-event simulation model.

Methods

Discrete-event simulation model

A conceptual model to represent the natural process of cataract, from incidence to surgery (Figure 1) was discussed and agreed on by a multidisciplinary expert panel composed of ophthalmologists, epidemiologists, health economists and statisticians. The model referred to individuals from the general population, aged 50 years or older, at risk of need for cataract surgery, and focused on the Spanish health system. The conceptual model was developed by taking into account demand, as well as the particular characteristics, in each of the regions studied: Aragon, Andalusia, Basque Country, the Canary Islands and Catalonia, which represent 45.7% of the Spanish population.

The indication criterion for cataract surgery was defined as any lens opacity causing a visual acuity of 0.5 or less, on a scale from 0 to 1, lower values indicating worse visual acuity[23]. Surgery for this indication was always considered to be appropriate. Need for cataract surgery was defined as meeting the indication criteria for surgery. Incidence was defined as the occurrence of need for surgery.

Need for cataract surgery (Figure 1) was separated into “Non-Expressed Need” and “Waiting List”. The state of “Non-Expressed Need” represented the population that, although meeting the indication criteria for surgery, was not included on a waiting list of the Spanish health system. Expressing need was considered equivalent to the following process: requesting surgery and being indicated by a specialist and included on a waiting list of the health system. A distinction was made between first- and second-eye surgery in the “Non-Expressed Need” state (Figure 1), given that senile cataracts are mainly bilateral and interventions are performed in one eye at a time. This distinction was not made in the waiting list, given that the waiting list does not distinguish between patients waiting for first- and those waiting for second-eye surgery. The activity carried out in the private sector was taken into account, given that its activity is high.

Parameter estimation

The information needed to estimate the model’s parameters was compiled for each region studied. Different information sources were used (Table 1), including administrative and research databases. When data from the study’s setting were unavailable, data from similar settings was used. The Hospital Discharge Minimum Data Set (HDMDS) of at least three consecutive years was obtained for each of the five regions. This database records all the operations performed in the public sector and allows bilateral operations to be identified. The cataract surgery rates performed in the public sector and the probability of second-eye surgery were obtained from the HDMDS.

Because we used a continuous-time model, the parameters of transitions between states were estimated as distributions of time to an event. Moreover, the possible changes in parameters throughout the 5-year time horizon were taken into account, such as the increase in the number of operations, the probability of second eye surgery[24] or the monthly number of entries to the waiting list (table 1). Since primary data on the prevalence of cataracts in Spain is lacking, a systematic review of prevalence studies of cataracts was carried out[25]. Based on this review the database of the North London Eye Study was used, a population-based study on the prevalence of eye diseases in North London[26]. Prevalence was calculated by age and sex, and its estimates were projected onto the population of each of the five regions studied. In the absence of incidence data, prevalence was used to estimate incidence[27]. The number of inhabitants in each region, as well as the number of deaths by age and sex, in 2001 was obtained from the Spanish National Statistics Institute.

The number of monthly entries to the waiting list in 2003 and the number of patients waiting were obtained from the waiting lists register of each region's health system. The pilot study to assess the introduction of the prioritization system in clinical practice with data from Catalonia[14], Andalusia and Aragon[15] was used to calculate the distributions of priority score at entry to the waiting list, as well as the proportions of patients with bilateral cataract or aphakia (those who had already undergone surgery in one eye). Different empirical distributions were used for bilateral and aphakic patients because statistically different scores were found for first- and second-eye surgery. In the absence of priority data for the Canary Islands and the Basque Country, in these two regions we used a pooled priority distribution of the three regions for which priority data was available. As the prioritization system included clinical and functional criteria that may worsen over time, an increase in priority score with time was evaluated and introduced. Table 1 summarizes the parameters introduced in the model and their sources of information and distribution functions.

Geographical variation was measured through rates (number of occurrences per 100,000 inhabitants), high/low ratio for rates, and coefficient of variation, defined as the ratio of the standard deviation relative to the mean.

Simulation

The conceptual model (Figure 1) was implemented as a discrete-event simulation model in the SIMUL8 v.10 package (SIMUL8 Corporation)[28] and was run with the corresponding data from each region. The time units were months and the simulation horizon was 60 months (5 years). Each patient was assigned a set of attributes, including age, sex, priority for first- and second-eye surgery (when applicable), "type" of patient (bilateral or aphakic) and lifetime. The priority scores were generated when a patient entered the waiting list and took into account whether the patient had bilateral cataracts or aphakia.

As the impact of the time waited depends on the level of need, the measure of results used as the main outcome was waiting time weighted by priority score, which can be interpreted as the time that a patient waits, due to the waiting list, weighted by his/her need for surgery. This measure allowed waiting times to be compared by taking into account how these times were assigned according to each patient's priority level. Thus, the difference between two simulations could be interpreted as the time, weighted by need, saved or lost with the prioritization system versus the FIFO discipline. The waiting time weighted by priority score included all patients who entered the waiting list: those undergoing surgery, those who were still waiting at the end of the simulation period, those who switched to the private sector, and those who died while on the waiting list. Trials were performed including 20 independent replications, each beginning with the same initial conditions. This sample size was calculated to obtain sufficient precision for comparison between waiting list disciplines[16]. The analyses were based not only on the waiting time weighted by priority score, but also on the raw waiting time of patients. Different thresholds of priority score according to eventual fixed guarantee times were calculated. These thresholds indicated the minimum priority score needed to be operated under a given guarantee time

Results

The expert panel evaluated the model's results and considered them to be valid and credible. Different patterns of aging were found among regions: Aragon, Catalonia and the Basque Country showed the greatest ageing, with more than 34% of their populations being over 50 years of age. In Andalusia and the Canary Islands, less than 30% of the population was over 50 years old. The estimated percentage of the population with need for cataract surgery was between one-fifth and one-fourth of the population over 50 years of age in all the regions studied (Table 2).

A coefficient of variation (COV) of 0.24 was found in surgery rates among the regions studied. In particular, the surgery rates found in Catalonia were greater than those in the Canary Islands and Andalusia (high/low ratio 1.76 and 1.69 respectively). The rates of entries to the waiting list were more homogeneous among regions than the surgery rates (COV: 0.1). The percentage of the prevalent population included on a waiting list was less than 6.5% in all regions. This percentage varied among the regions studied (COV: 0.62), Table 2. The results of the pilot study [14,15] showed significant differences in the mean priority score at entry to the waiting list among the three regions for which data were available (data not shown). Priority scores showed a dispersion that covered the entire range of possible values. The 25th and 75th percentiles of the assigned priority scores were 34 and 62 points respectively for first-eye surgery and 20 and 53 points for second-eye surgery in Andalusia, 7 and 46 for first-eye surgery and 6 and 21 for second-eye surgery in Aragon, and 20 and 52 for first-eye surgery and 6 and 41 for second-eye in Catalonia.

Simulation of the current waiting list scenario (FIFO) showed that the raw mean waiting time of patients who underwent surgery in the public sector varied from 1.97 months (95% CI 1.85; 2.09) in the Basque Country to 10.02 months (95% CI 9.91; 10.12) in the Canary Islands, Table 3. When the prioritization system was applied, the mean waiting time was reduced to 0.73 months weighted by priority score (95% CI 0.68; 0.78) in the Basque Country (lowest value) and 5.63 months (95% CI 5.57; 5.69) in the Canary Islands (highest value), Table 3. However, patients still waiting at the end of the simulation period had longer waiting times with the prioritization system than with the FIFO discipline. Differences of 11.3 raw months (95% CI 9.4; 13.3) in Andalusia, 4.7 months (95% CI 4.3; 5.1) in Aragon, 5.8 months (95% CI 5.3; 6.4) in the Basque Country, 12.4 months (95% CI 11.0; 13.7) in the Canary Islands and 6.9 months (95% CI 6.2; 7.6) in Catalonia were found. Patients who died while on the waiting list also had longer mean waiting times with the prioritization system than with the FIFO discipline, with waiting times increased by 8.3 months (95% CI 7.3; 9.4) in Andalusia, 4.4 months (95% CI 3.9; 4.8) in Aragon, 5.3 months (95% CI 4.7; 5.9) in the Basque Country, 8.8 months (95% CI 8.0; 9.6) in the Canary Islands and 5.8 months (95% CI 5.2; 6.5) in Catalonia.

The overall mean waiting time weighted by priority score, that is, considering each patient who entered the waiting list (operated patients, patients still waiting at the end of the simulation period, patients who switched to the private sector and patients who died while on the waiting list), was reduced in all the regions when the prioritization system was applied. The waiting time weighted by priority score saved by the prioritization system was 1.12 months (95% CI 1.07; 1.16) in Andalusia, 2.73 months (95% CI 2.67;

2.80) in Aragon, 1.20 months (95% CI 1.11; 1.28) in the Basque Country, 1.60 months (95% CI 1.51; 1.69) in the Canary Islands and 2.27 months (95% CI 2.17; 2.38) in Catalonia, Table 3.

Figure 2 shows the relationship between the priority score and the waiting time under the prioritization system, i.e., the minimum priority score required for a patient to undergo surgery under an eventual guarantee time, fixed at 3, 6, 12, 18 and 24 months. In patients with a priority score at entry to the waiting list of 40 or more points, the maximum guarantee time was 4 months in Andalusia, 1 month in Aragon, 1 month in the Basque Country, 8.5 months in the Canary Islands and 3 months in Catalonia. In addition, as the priority score at entry in the waiting list diminished, the maximum guarantee time increased. Patients with less than 20 points waited 18 months or more in Andalusia, more than 4 months in Aragon, more than 6 months in the Basque Country, more than 24 months in the Canary Islands, and more than 10 months in Catalonia. A decreasing trend was observed in differences in waiting time among regions as priority scores increased.

When the prioritization system was applied the waiting time range among regions was reduced in 10.64 months for patients within the 20-29 priority score interval with respect to patients in the 60- 69 priority score interval, Table 4. Under the current waiting list scenario (FIFO) there was no reduction in the waiting time range among regions. This range held constant around 8 months among all the priority score groups, Table 4.

Discussion

The model described allows several factors commonly used separately by decision-makers to be integrated into a complex but understandable system. Our findings show firstly that introducing a prioritization system improved the impact of cataract procedures by minimizing waiting time in patients according to their level of need and secondly that the benefit of applying the prioritization system varied substantially, depending on the specific characteristics of each region's local health system.

To measure the impact of waiting in accordance with patient's need, the waiting time weighted by priority score was used. Although this measure was based on individual data, it can be interpreted as a global measure of benefit since it took into account the priority scores of all patients who had been assigned a priority score. This measure is based on patients' need and not on health benefit. Unpublished analyses on the prioritization system showed that correlation between the priority score and the utility questionnaires EQ-5D and HUI-3 is low (0.1 and 0.15, respectively). As there is no evidence of relationship between need (priority) and benefit (utility), results were based on need only. The prioritization system reduced the waiting time up to half the time under the actual FIFO discipline (table 3). The waiting time was not measured at a fixed time point; instead it was measured as the average waiting time throughout the time horizon for all patients. Application of the priority system redistributed the total time waited across patients. The model shows how patients with greater need waited less than those with low levels of need. Previous experiences have concluded that assigning surgery according to priority criteria is more beneficial than assignation by waiting time[17-19]. Although the prioritization system was beneficial as a whole, patients with low priority scores had very long waiting times. However, application of the prioritization system should guarantee a maximum waiting time to these patients. Dunn et al.[29] showed that 80% of patients rated waits of 3 months or less as acceptable, while 25% regarded waits of 6 months or longer as too long. Moreover, patients with greater disability were those less tolerant with waiting times.

Several studies have observed geographical variations in clinical practice worldwide[30]. Most of the results found in other countries can be extrapolated to Spain, which offers universal coverage. In agreement with previous studies[31,32], the variation in clinical practice found among regions is notable. Nevertheless, the reasons for this variation are difficult to identify. A small percentage could be explained by demographic and morbidity characteristics of the populations but the main reasons are management features and the availability of resources. The results obtained suggest that prioritization systems reduce geographical variations in waiting time in patients with higher levels of need, that is, in those with high priority scores. Differences among regions in the overall waiting times were reduced when applying the prioritization system. The overall rank between the regions with the maximum and the minimum mean waiting time is reduced from 8.1 months under the FIFO discipline to 4.9 with the prioritization system. Table 4 shows how under the prioritization system the waiting time range among the regions was reduced as the priority score increased. Differences among patients with high priority scores were reduced substantially, while the results were uncertain in patients with medium or low priority scores.

The impact of introducing the prioritization system varied substantially among the regions studied, but reduced inequities among regions in patients with greater need.

Figure 2 shows that the curves for Andalusia and Catalonia became closer as the priority score increases. Patients with a priority score of 40 had similar waiting times in both regions (4 months in Andalusia and 3 months in Catalonia), while differences in waiting time increased substantially in patients with priority scores of 20 (18 months in Andalusia and around 11 months in Catalonia). This pattern, however, was not observed when comparing the curves among Catalonia and Aragon, which maintained the differences among curves independently of priority score. To sum up, the prioritization system improves equity in patients with greater need, but not necessarily in all other patients.

In the present study, the variability found in surgery rates was not related to population characteristics or to the needs of the population on the waiting list. This lack of association indicates the need to improve the effectiveness of some management policies. Less than 6.5% of the population with need for surgery is included on a waiting list and there is wide variability in the priority scores assigned. Waiting lists do not represent unmet needs, but rather an auto-regulation mechanism of the health system. If the surgery supply is insufficient to cover unmet needs, it seems reasonable to introduce prioritization systems, which involve modifying the indication thresholds in accordance with the resources available in the system. The effectiveness of prioritization systems would increase substantially if prioritization was applied at surgery indication instead of assigning priorities only to patients entering the waiting list. If there is a substantial unmet need, clinicians could decide not to refer patients with low priorities for surgery, as they would have excessive waiting times. This fact would have an impact on the indication criterion. Giving a guarantee time to each patient related to his/her level of need would further increase equity, since levels of need in patients on the waiting list differ widely. Thus, the introduction of a prioritization system should entail an analysis of the unmet needs in each region, or at least involve a reduction in the variations in the surgery rates among regions.

The variables that appeared to have the greatest influence on the benefit obtained from the prioritization system and its impact in the waiting time were the variability in the priority scores at entry to the waiting list, the surgery rate and the waiting list volume. It is expected that the greater the waiting list and the lower the surgery rate within each region, the greater the benefit of introducing the prioritization system, as this would increase the waiting of patients and thus the benefit from introducing the prioritization system. Moreover, the higher the variability within each region in the priority scores assigned to patients, the higher the impact that can be expected from the prioritization system. If all patients had the same priority score, prioritization would have no impact.

Using data from the North London Eye Study might introduce some bias to the prevalence estimation. However a systematic review of cataract prevalence studies carried out by this research team[25] showed little differences in the prevalence by age among studies performed in several countries with populations similar to the Spanish population. This result minimizes the possible bias caused by assuming that the same cataract prevalence applies to North London and Spain. We assume that little differences in cataract prevalence would be found among Spanish regions because differences were small among international studies. The effect of the prioritization system might be overestimated because pure FIFO systems are rare and clinicians might use some implicit prioritization. However, a pilot study carried out by Espallargues et al.[14] found a slight prioritization in the Spanish cataract surgery waiting list. We defined several mathematical functions to approximate the relationships among certain parameters within the system. Thus, the quality of the information introduced in the model strongly depended on the quality of the information obtained from the different regions[16]. However, all the estimations made were validated by a panel of experts and consensus was reached by all regions' representatives. Some characteristics were estimated through data from other regions when access to the source of information was limited or information was unavailable.

Conclusions

Discrete-event simulation is an appropriate and robust tool to study the impact and benefits of different health policy interventions in a context in which resources are scarce and there is wide variability in their management[16]. Introducing the prioritization system allows the impact of variations among regions to be reduced by improving the system's equity and effectiveness. On the one hand, effectiveness improves because patients with greater need have a shorter waiting time resulting in an overall saving of waiting time weighted by need. On the other hand, equity improves because the higher the need, the greater the reduction in differences in waiting time. However, the lower the priority, the greater increase in the differences among patients. The results of this study suggest that introducing the prioritization system would allocate the available resources within each region more efficiently.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All the authors have contributed to the achievement of this study. RR participated in the design of the study, the statistical analysis and drafted the manuscript. MC participated in the design of the study, the statistical analysis and helped to draft and review the manuscript. JM, EB, AJ and SG helped in the design of the study and the review of the manuscript, participated in the validation of the model and provided essential information for the development of the analysis. XC conceived the study, and participated in its design and coordination and helped to draft and review the manuscript. All authors read and approved the final manuscript.

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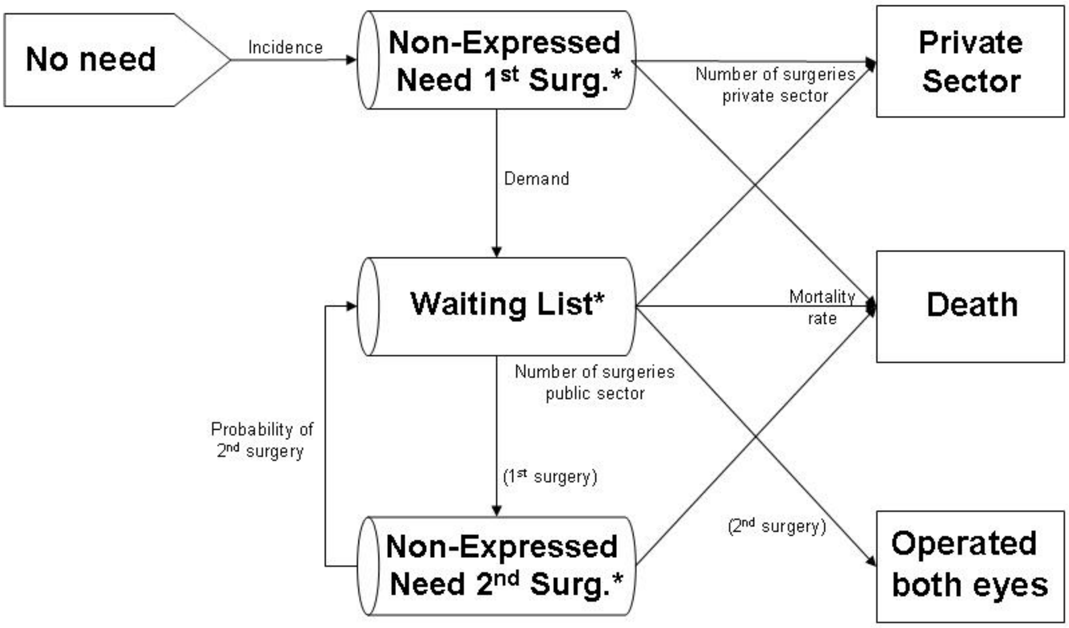
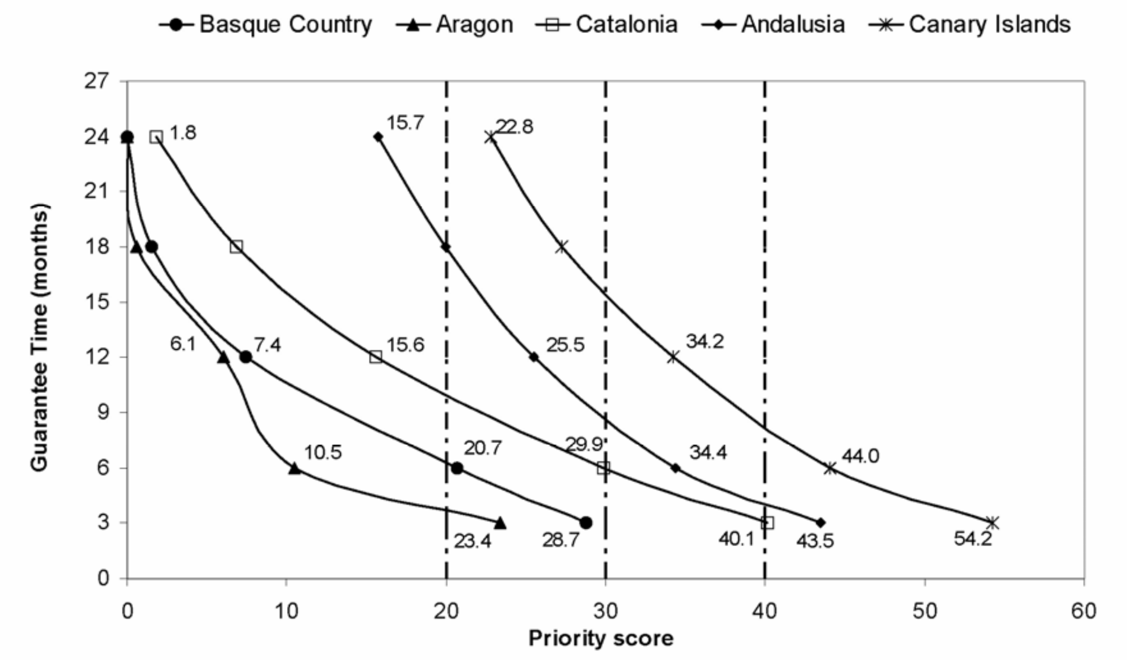
Figures

Figure 1 - Conceptual model.



*: Prevalence of need is divided among these 3 states.
†: Cases in the waiting list have the priority score as an additional attribute.

Figure 2 - Minimum priority scores for guarantee times.



Tables

Table 1 - Simulation model parameters, source of information and distribution function.

Parameter	Source	Distribution
Related to initial state		
Non Expressed Need 1st Surgery Backlog	North London Eye Study	Fixed value
Non Expressed Need 2nd Surgery Backlog	North London Eye Study	Fixed value
Waiting List Backlog	Waiting list register	Fixed value
Proportion of patients waiting for 2nd eye surgery	Pilot Study (Empirical)	Fixed value
Static parameters		
Incident cases per month	North London Eye Study	Poisson*
Number of operations in the private sector per month	Hospital Discharge Minimum Data Set	Poisson*
Proportion of cases of the waiting list who switch to the private sector	Pilot Study (Empirical)	Bernoulli
Top limit for waiting list contents (self-regulation)	Opportunistic	Fixed value
Increase in priority score	Pilot Study (Empirical)	Fixed value
Time between revisions of priority score	Pilot Study (Empirical)	Fixed value
Mortality	Spanish Mortality Register	Empirical lifetime density function
Dynamic parameters		
Number of surgeries per month	Hospital Discharge Minimum Data Set	Poisson*
Probability of second eye surgery	Hospital Discharge Minimum Data Set	Bernoulli
Number of bilateral cases entering the waiting list per month	Waiting list register	Poisson*

*Poisson distributions were generated as time between arrivals of the events through an Exponential distribution

Table 2 - Descriptive information on senile cataracts in the autonomous regions studied.

	Regions				
	Andalusia	**Aragon**	**Basque Country**	**Canary Islands**	**Catalonia**
Population	7,357,558	1,204,215	2,082,587	1,694,477	6,343,110
Population Over 50 years	2,142,202	457,631	744,419	449,819	2,164,467
% Population Over 50 years	29%	38%	36%	27%	34%
Prevalence					
% Prevalence in people over 50 years	22.4%	25.8%	22.8%	20.4%	23.5%
Surgery rate *					
Yearly rate	405	529	607	440	685
Surgery rate in people over 50 years	1,391	1,392	1,724	1,650	2,156
Waiting List	9,205	2,826	2,313	5,771	19,586
% of prevalent population	1.9%	2.4%	1.4%	6.3%	3.8%
Waiting List entry rate (2003) *	612	755	656	602	733
Mean priority (at entry to the waiting list)					
First surgery (SD)	47.1 (19.9)	28.3 (22.4)	39.3 (22.7) †	39.3 (22.7) †	36.5 (22.8)
Second surgery (SD)	36.8 (22.3)	13.7 (11.7)	28.8 (22.6) †	28.8 (22.6) †	26.1 (22.2)

* Nº of ocurrences/ 100,000 inhabitants
† A pooled Distribution was used in the absence of empirical data
SD: Standard Deviation.

Table 3 - Raw waiting times (FIFO) and times weighted by priority score (FIFO, prioritization system)

			Waiting times weighted by priority score					
	Raw waiting times (FIFO)		**FIFO System**		**Prioritization system**		**Benefit of the priorization system**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Andalusia	2.91	[0.09]	2.81	[0.09]	1.69	[0.11]	1.12	[0.08]
Aragon	5.19	[0.21]	4.89	[0.18]	2.16	[0.12]	2.73	[0.12]
Basque Country	1.97	[0.27]	1.93	[0.26]	0.73	[0.11]	1.20	[0.16]
Canary Islands	10.02	[0.24]	7.23	[0.21]	5.63	[0.13]	1.60	[0.16]
Catalonia	4.48	[0.57]	4.26	[0.52]	1.99	[0.36]	2.27	[0.20]

FIFO: First-in, first-out. SD: Standard Deviation.

Table 4 - Maximum and minimum waiting time weighted by priority score for given priority scores (FIFO and prioritization system)

Priority Scores	Waiting times weighted by priority score					
	FIFO System			Prioritization System		
	Maximum*	Minimum[†]	Difference	Maximum*	Minimum[†]	Difference
20-29	10.01	1.96	8.05	11.32	0.54	10.78
30-39	10.01	1.97	8.04	2.75	0.17	2.58
40-49	10.01	1.97	8.04	1.01	0.08	0.93
50-59	10.02	1.97	8.05	0.34	0.04	0.3
60-69	10.02	1.97	8.05	0.17	0.03	0.14

* Maximum waiting times belong to the Canary Islands (see table 3)

[†] Minimum waiting times belong to the Basque Country (see table 3)

Appendix 3: Visual logic codes

3.1: System initialization

3.1.1: Clear initial state

```
VL SECTION: Clear initial state On OK Dialog
  Clear Sheet    Initial state Need 1st[1,1]
  Clear Sheet    Initial state Need 2nd[1,1]
  Clear Sheet    Initial state Waiting List[1,1]
```

3.1.2: Create initial state

```
VL SECTION: Create initial state On OK Dialog
  SET Reset for saving initial state  =  1
  Reset Clock    Random set
```

3.1.3: Save initial state

```
VL SECTION: Save initial state On OK Dialog
  'Saves initial state Need 1st
  SET i  =  1
  Clear Sheet    Initial state Need 1st[1,1]
  LOOP 1 >>> j >>> Need 1st Backlog.Count Contents
    Select Current Work Item    Need 1st Backlog ,  j
    SET Initial state Need 1st[1,i]  =  Age0
    SET Initial state Need 1st[2,i]  =  Sex
    SET Initial state Need 1st[3,i]  =  Type
    SET Initial state Need 1st[4,i]  =  Time of death
    SET Initial state Need 1st[5,i]  =  Expire time
    SET i  =  i+1
```

```
'Saves Initial State Need 2nd
SET i  =  1
Clear Sheet    Initial state Need 2nd[1,1]
LOOP 1 >>> j >>> Need 2nd Backlog.Count Contents
  Select Current Work Item    Need 2nd Backlog ,  j
  SET Initial state Need 2nd[1,i]  =  Age0
  SET Initial state Need 2nd[2,i]  =  Sex
  SET Initial state Need 2nd[3,i]  =  Type
  SET Initial state Need 2nd[4,i]  =  Time of death
  SET Initial state Need 2nd[5,i]  =  Expire time
  SET i  =  i+1
'Saves initial state Waiting List
SET i  =  1
Clear Sheet    Initial state Waiting List[1,1]
LOOP 1 >>> j >>> Waiting List Backlog.Count Contents
  Select Current Work Item    Waiting List Backlog ,  j
  SET Initial state Waiting List[1,i]  =  Age0
  SET Initial state Waiting List[2,i]  =  Sex
  SET Initial state Waiting List[3,i]  =  Type
  SET Initial state Waiting List[4,i]  =  Time of death
  SET Initial state Waiting List[5,i]  =  Expire time
  SET Initial state Waiting List[6,i]  =  PriorityScore
  SET Initial state Waiting List[7,i]  =  PriorityScore1
  SET Initial state Waiting List[8,i]  =  PriorityScore2
  SET i  =  i+1
SET Reset for saving initial state  =  0
SET Number of run  =  0
```

3.2: In objects

3.2.1: Incident cases

VL SECTION: **Incident cases Entry Logic**

```
  SET Sex  =  Sex dist
  SET Type  =  11
  SET Backlog WL  =  0
```

```
 IF Sex  =  0
  SET Age0  =  Age Male
  SET i  =  2
  SET i  =  0
  WHILE i  <=  [105-Age0]*12
   Set Prob-Profile Distrib Column    Time to Death distr ,  i+1 ,  i ,
                    100*[EXP[[[0-Alfa Male]/Beta Male]*[EXP[Beta Male*[Age0+[[i-1]/12]]]-
                    EXP[Beta Male*Age0]]]-
                    EXP[[[0-Alfa Male]/Beta Male]*[EXP[Beta Male*[Age0+[i/12]]]-
                    EXP[Beta Male*Age0]]]]
   SET i  =  i+1
  SET Time of death  =  Time to Death distr
 ELSE IF Sex  =  1
  SET Age0  =  Age Female
  SET i  =  0
  WHILE i  <=  [105-Age0]*12
   Set Prob-Profile Distrib Column    Time to Death distr ,  i+1 ,  i ,
                    100*[EXP[[[0-Alfa Female]/Beta Female]*[EXP[Beta Female*[Age0+[[i-1]/12]]]-
                    EXP[Beta Female*Age0]]]-
                    EXP[[[0-Alfa Female]/Beta Female]*[EXP[Beta Female*[Age0+[i/12]]]-
                    EXP[Beta Female*Age0]]]]
   SET i  =  i+1
  SET Time of death  =  Time to Death distr
 SET Born  =  Simulation Time
 SET Expire time  =  Time of death
```

3.2.2: Demand

VL SECTION: **Demand Action Logic**

```
 SET PriorityScore  =  Priority dist Bilateral
 SET PriorityScore1  =  PriorityScore
 SET Expire time  =  [Time of death-Simulation Time]+Born
 SET Entry WL1  =  Simulation Time
```

VL SECTION: **Demand Route-In After Logic**

```
 SET Expire time  =  [Time of death-Simulation Time]+Born
 SET Type  =  21
```

3.2.3: Surgery

VL SECTION: **Surgery Action Logic**

```
 SET Expire time  =  [Time of death-Simulation Time]+Born
 SET Total surgeries  =  Total surgeries+1
```

VL SECTION: **Surgery Route-In Before Logic**

```
 IF Increase in priority on off  =  "Increase priority score"
   IF Simulation Time  >=  Time to review
     SET i  =  1
     WHILE i  <=  Waiting List.Count Contents
       Select Current Work Item    Waiting List ,  i
       IF Type  =  21
         IF Simulation Time-Entry WL1  >=  Time to review*[Inc Prior 1+1]
           IF ROUND[Simulation Time-Entry WL1]-
                   [Time to review*ROUND[ROUND[Simulation Time-Entry WL1]/Time to review]]  =  0
             SET PriorityScore  =  PriorityScore+Increase in priority
             SET Inc Prior 1  =  Inc Prior 1+1
       ELSE
         IF Simulation Time-Entry WL2  >=  Time to review*[Inc Prior 2+1]
           IF ROUND[Simulation Time-Entry WL2]-
                   [Time to review*ROUND[ROUND[Simulation Time-Entry WL2]/Time to review]]  =  0
             SET PriorityScore  =  PriorityScore+Increase in priority
             SET Inc Prior 2  =  Inc Prior 2+1
       SET i  =  i+1
       IF PriorityScore  >  100
         SET PriorityScore  =  100
```

VL SECTION: **Surgery Route-In After Logic**

```
 'Saves priority score and type of patient
 SET Waiting time and priority score[23,Total surgeries]  =  Type
 SET Waiting time and priority score[24,Total surgeries]  =  Backlog WL
 SET Waiting time and priority score[25,Total surgeries]  =  PriorityScore
 '1st eye
 IF Type  =  21
   'Public sector and need of 2nd surgery
   SET Priority score 1 surg  =  PriorityScore
   SET Exit WL1  =  Simulation Time
   SET SecondNoYes  =  Prob Second
   IF SecondNoYes  =  1
     SET Next transition  =  1
     'Back to  WL to have 2nd surgery
     SET PriorityScore2  =  [r priorities*PriorityScore1]+Difference in priorities noise
     SET PriorityScore2  =  ROUND[PriorityScore2]
     IF PriorityScore2  >  100
       SET PriorityScore2  =  100
     IF PriorityScore2  <=  Cut priority score 2
       SET PriorityScore2  =  Priority dist aphakic conditioned
     SET PriorityScore  =  PriorityScore2
     SET Type  =  22
     SET Entry WL2  =  Simulation Time
     SET Backlog WL  =  0
   ELSE
     SET Next transition  =  2
     'Goes to 'Non Expressed Need 2nd Surgery'
     SET Type  =  12
```

```
  'Saves waiting time
  SET Waiting time and priority score[21,Total surgeries]  =  Simulation Time-Entry WL1
  SET Waiting time and priority score[22,Total surgeries]  =  PriorityScore1
  SET Waiting time and priority score[27,Total surgeries]  =  0
  IF Inc Prior 1  >  0
    LOOP 1 >>> j >>> Inc Prior 1
      SET Waiting time and priority score[27,Total surgeries]  =
                  Waiting time and priority score[27,Total surgeries]+
                  [Time to review*[Waiting time and priority score[22,Total surgeries]+
                  [[j-1]*Increase in priority]]]
  SET Waiting time and priority score[27,Total surgeries]  =
          Waiting time and priority score[27,Total surgeries]+
          [[Waiting time and priority score[21,Total surgeries]-
          [Time to review*Inc Prior 1]]*Waiting time and priority score[25,Total surgeries]]
'2n eye
ELSE
  SET Next transition  =  3
  SET Exit WL2  =  Simulation Time
  SET Priority score 2 surg  =  PriorityScore
  SET Age  =  Age0+[[Simulation Time-Born]/12]
  'Saves waiting time
  SET Waiting time and priority score[21,Total surgeries]  =  Simulation Time-Entry WL2
  SET Waiting time and priority score[22,Total surgeries]  =  PriorityScore2
  SET Waiting time and priority score[27,Total surgeries]  =  0
  IF Inc Prior 2  >  0
    LOOP 1 >>> j >>> Inc Prior 2
      SET Waiting time and priority score[27,Total surgeries]  =
                  Waiting time and priority score[27,Total surgeries]+
                  [Time to review*[Waiting time and priority score[22,Total surgeries]+
                  [[j-1]*Increase in priority]]]
  SET Waiting time and priority score[27,Total surgeries]  =
          Waiting time and priority score[27,Total surgeries]+
          [[Waiting time and priority score[21,Total surgeries]-
          [Time to review*Inc Prior 2]]*Waiting time and priority score[25,Total surgeries]]
```

```
'All
SET Waiting time and priority score[26,Total surgeries]  =
      Waiting time and priority score[22,Total surgeries]*Waiting time and priority score[21,Total surgeries]
SET Waiting time and priority score[28,Total surgeries]  =
      TRUNC[Waiting time and priority score[22,Total surgeries]/10]+1
IF Waiting time and priority score[22,Total surgeries]  =  100
  SET Waiting time and priority score[28,Total surgeries]  =  10
SET Waiting time and priority score[29,Total surgeries]  =
      TRUNC[Waiting time and priority score[25,Total surgeries]/10]+1
IF Waiting time and priority score[25,Total surgeries]  =  100
  SET Waiting time and priority score[29,Total surgeries]  =  10
```

3.2.4: Private

```
VL SECTION: Private Action Logic
  IF Type  =  21
    SET Exit WL1  =  Simulation Time
  IF Type  =  22
    SET Exit WL2  =  Simulation Time
  SET Age  =  Age0+[[Simulation Time-Born]/12]
```

```
'Saves waiting time and priority score
SET N private  =  N private+1
IF Type  =  21
  SET Waiting time and priority score[41,N private]  =  Simulation Time-Entry WL1
  SET Waiting time and priority score[42,N private]  =  PriorityScore1
IF Type  =  22
  SET Waiting time and priority score[41,N private]  =  Simulation Time-Entry WL2
  SET Waiting time and priority score[42,N private]  =  PriorityScore2
SET Waiting time and priority score[43,N private]  =  Type
SET Waiting time and priority score[44,N private]  =  Backlog WL
SET Waiting time and priority score[45,N private]  =  PriorityScore
SET Waiting time and priority score[46,N private]  =
       Waiting time and priority score[41,N private]*Waiting time and priority score[42,N private]
SET Waiting time and priority score[47,N private]  =  0
IF Type  =  21
  IF Inc Prior 1  >  0
    LOOP 1 >>> j >>> Inc Prior 1
      SET Waiting time and priority score[47,N private]  = Waiting time and priority score[47,N private]+
                   [Time to review*[Waiting time and priority score[42,N private]+[[j-1]*Increase in priority]]]
  SET Waiting time and priority score[47,N private]  =  Waiting time and priority score[47,N private]+
         [[Waiting time and priority score[41,N private]-
         [Time to review*Inc Prior 1]]*Waiting time and priority score[45,N private]]
ELSE
  IF Inc Prior 2  >  0
    LOOP 1 >>> j >>> Inc Prior 2
      SET Waiting time and priority score[47,N private]  =
                   Waiting time and priority score[47,N private]+
                   [Time to review*[Waiting time and priority score[42,N private]+[[j-1]*Increase in priority]]]
  SET Waiting time and priority score[47,N private]  = Waiting time and priority score[47,N private]+
         [[Waiting time and priority score[41,N private]-
         [Time to review*Inc Prior 2]]*Waiting time and priority score[45,N private]]
SET Waiting time and priority score[48,N private]  =  Backlog need 1st
```

VL SECTION: **Private Route-In After Logic**

```
SET Route Private  =  Access Private
'1: takes the case from Non Expressed Need 1st; 2: from Waiting List.
IF Route Private  =  1
  Set Route In Priority    Private ,  Need 1st ,  1
  Set Route In Priority    Private ,  Waiting List ,  2
ELSE
  Set Route In Priority    Private ,  Need 1st ,  2
  Set Route In Priority    Private ,  Waiting List ,  1
```

3.2.5: Dying

VL SECTION: **Dying Action Logic**

```
SET Age  =  Age0+[[Simulation Time-Born]/12]
IF Type  =  21
  SET Exit WL1  =  Simulation Time
IF Type  =  22
  SET Exit WL2  =  Simulation Time
'Saves waiting time and priority score
SET N dead  =  N dead+1
IF Type  =  21
  SET Waiting time and priority score[51,N dead]  =  Simulation Time-Entry WL1
  SET Waiting time and priority score[52,N dead]  =  PriorityScore1
IF Type  =  22
  SET Waiting time and priority score[51,N dead]  =  Simulation Time-Entry WL2
  SET Waiting time and priority score[52,N dead]  =  PriorityScore2
SET Waiting time and priority score[53,N dead]  =  Type
SET Waiting time and priority score[54,N dead]  =  Backlog WL
SET Waiting time and priority score[55,N dead]  =  PriorityScore
SET Waiting time and priority score[56,N dead]  =
          Waiting time and priority score[51,N dead]*Waiting time and priority score[52,N dead]
SET Waiting time and priority score[57,N dead]  =  0
IF Type  =  21
  IF Inc Prior 1  >  0
    LOOP 1 >>> j >>> Inc Prior 1
      SET Waiting time and priority score[57,N dead]  =  Waiting time and priority score[57,N dead]+
                  [Time to review*[Waiting time and priority score[52,N dead]+[[j-1]*Increase in priority]]]
  SET Waiting time and priority score[57,N dead]  =  Waiting time and priority score[57,N dead]+
          [[Waiting time and priority score[51,N dead]-
          [Time to review*Inc Prior 1]]*Waiting time and priority score[55,N dead]]
ELSE
  IF Inc Prior 2  >  0
    LOOP 1 >>> j >>> Inc Prior 2
      SET Waiting time and priority score[57,N dead]  =  Waiting time and priority score[57,N dead]+
                  [Time to review*[Waiting time and priority score[52,N dead]+[[j-1]*Increase in priority]]]
  SET Waiting time and priority score[57,N dead]  =  Waiting time and priority score[57,N dead]+
          [[Waiting time and priority score[51,N dead]-
          [Time to review*Inc Prior 2]]*Waiting time and priority score[55,N dead]]
SET Waiting time and priority score[58,N dead]  =  Backlog need 1st
SET Waiting time and priority score[59,N dead]  =  Backlog need 2nd
```

3.3: Reset

3.3.1: Before reset

```
VL SECTION: Before Reset Logic
  'Obeyed immediately user click RESET button (before initializes simulation objects and before On Reset logic)
  '***************  INPUTS  **********************
  Get from EXCEL    Inputs[1,1] ,  "[DATA.XLS]MainInputs" ,  1 ,  1 ,  30 ,  30
  SET Time to review  =  Inputs[3,24]
  SET Increase in priority  =  Inputs[3,23]
  SET Proportion  =  Inputs[3,27]
  SET Monthly Incident cases  =  Inputs[3,4]*Proportion
  SET Monthly Private Sector cases  =  Inputs[3,16]*Proportion
  Set Prob-Profile Distrib Column    Access Private ,  1 ,  1 ,  100*[1-Inputs[3,15]]
  SET Need 1st Backlog initial  =  ROUND[Inputs[3,7]*Proportion]
  SET Need 2nd Backlog initial  =  ROUND[Inputs[3,8]*Proportion]
  SET Waiting List Backlog initial  =  ROUND[Inputs[3,10]*Proportion]
  Set Prob-Profile Distrib Column    Prob Aphakic WL ,  1 ,  1 ,  [1-Inputs[3,11]]*100
  SET Top threshold for WL contents  =  ROUND[[1+Inputs[4,20]]*Waiting List Backlog initial]
  'For time-dependent inputs, see 'Update Surgery Supply' visual logic.
  SET Supply  =  Inputs[3,13]*Proportion
  Set Prob-Profile Distrib Column    Prob Second ,  1 ,  0 ,  [1-Inputs[3,14]]*100
  SET Monthly cases entering the WL  =  [Proportion*
          [[Inputs[6,13]+[Inputs[8,13]*[LOG[[Inputs[10,13]-Inputs[6,19]]+Simulation Time]]]]-Inputs[4,19]]]
  'Calculus of distributions parameters
  SET Mu incidence  =  1/Monthly Incident cases
  SET Mu supply  =  1/Supply
  SET Mu demand  =  1/Monthly cases entering the WL
  SET Mu private  =  1/Monthly Private Sector cases
  'Distributions
  Get from EXCEL    Input distributions[1,1] ,  "[DATA.XLS]Distributions" ,  1 ,  1 ,  16 ,  100
  Set Prob-Profile Distrib Column    Sex dist ,  1 ,  0 ,  Input distributions[2,9]
  LOOP 1 >>> i >>> 50
   Set Prob-Profile Distrib Column    Age Male ,  i ,  Input distributions[1,i+14] ,  Input distributions[2,i+14]
   Set Prob-Profile Distrib Column    Age Female ,  i ,  Input distributions[1,i+14] ,
                      Input distributions[3,i+14]
  SET i  =  1
```

```
WHILE Input distributions[6,i+8]  <>  ""
  Set Prob-Profile Distrib Column    Priority dist Bilateral ,  i ,  Input distributions[6,i+8] ,
                       Input distributions[7,i+8]
  SET i  =  i+1
SET i  =  1
WHILE Input distributions[9,i+8]  <>  ""
  Set Prob-Profile Distrib Column    Priority dist Aphakic ,  i ,  Input distributions[9,i+8] ,
                       Input distributions[10,i+8]
  SET i  =  i+1
Set Distribution Parameters    Difference in priorities noise ,  Normal ,  Input distributions[12,12] ,
          Input distributions[13,12] ,  0 ,  0
SET r priorities  =  Input distributions[12,14]
SET i  =  1
WHILE Input distributions[12,i+19]  <>  ""
  Set Prob-Profile Distrib Column    Priority dist aphakic conditioned ,  i ,  Input distributions[12,i+19] ,
                       Input distributions[13,i+19]
  SET i  =  i+1
SET Cut priority score 2  =  Input distributions[12,i+18]
```

3.3.2: On reset

VL SECTION: **Reset Logic**

```
 'Obeyed just after SIMUL8 has initialized all simulation objects at time zero
 Set Route In Discipline    Hidden show results ,  Locked
 SET Number of run  =  Number of run+1
 SET N private  =  0
 SET N dead  =  0
 SET Total surgeries  =  0
 Clear Sheet    Waiting time and priority score[1,1]
 IF Number of run  =  1
   Clear Sheet    Mean waiting list contents through time[0,0]
   Clear Sheet    Percent second surgeries[0,0]
```

```
IF Reset for saving initial state  =  1
 'Generation of the initial state
 WHILE Need 1st Backlog.Count Contents  <  Need 1st Backlog initial
  Add Work To Queue    Patients ,  Need 1st Backlog
  SET Sex  =  Sex dist
  SET Type  =  11
  IF Sex  =  0
   SET Age0  =  Age Male
   SET i  =  0
   WHILE i  <=  [105-Age0]*12
    Set Prob-Profile Distrib Column    Time to Death distr ,  i+1 ,  i ,
                100*[EXP[[[0-Alfa Male]/Beta Male]*[EXP[Beta Male*[Age0+[[i-1]/12]]]-
                EXP[Beta Male*Age0]]]-
                EXP[[[0-Alfa Male]/Beta Male]*[EXP[Beta Male*[Age0+[i/12]]]-
                EXP[Beta Male*Age0]]]]
    SET i  =  i+1
   SET Time of death  =  Time to Death distr
  ELSE IF Sex  =  1
   SET Age0  =  Age Female
   SET i  =  0
   WHILE i  <=  [105-Age0]*12
    Set Prob-Profile Distrib Column    Time to Death distr ,  i+1 ,  i ,
                100*[EXP[[[0-Alfa Female]/Beta Female]*[EXP[Beta Female*[Age0+[[i-1]/12]]]-
                EXP[Beta Female*Age0]]]-
                EXP[[[0-Alfa Female]/Beta Female]*[EXP[Beta Female*[Age0+[i/12]]]-
                EXP[Beta Female*Age0]]]]
    SET i  =  i+1
   SET Time of death  =  Time to Death distr
  SET Expire time  =  Time of death
 WHILE Need 2nd Backlog.Count Contents  <  Need 2nd Backlog initial
  Add Work To Queue    Patients ,  Need 2nd Backlog
  SET Sex  =  Sex dist
  SET Type  =  12
  IF Sex  =  0
   SET Age0  =  Age Male
   SET i  =  0
   WHILE i  <=  [105-Age0]*12
    Set Prob-Profile Distrib Column    Time to Death distr ,  i+1 ,  i ,
                100*[EXP[[[0-Alfa Male]/Beta Male]*[EXP[Beta Male*[Age0+[[i-1]/12]]]-
                EXP[Beta Male*Age0]]]-
```

```
                EXP[[[0-Alfa Male]/Beta Male]*[EXP[Beta Male*[Age0+[i/12]]]-
                EXP[Beta Male*Age0]]]]
    SET i  =  i+1
   SET Time of death  =  Time to Death distr
  ELSE IF Sex  =  1
   SET Age0  =  Age Female
   SET i  =  0
   WHILE i  <=  [105-Age0]*12
    Set Prob-Profile Distrib Column    Time to Death distr ,  i+1 ,  i ,
                100*[EXP[[[0-Alfa Female]/Beta Female]*[EXP[Beta Female*[Age0+[[i-1]/12]]]-
                EXP[Beta Female*Age0]]]-
                EXP[[[0-Alfa Female]/Beta Female]*[EXP[Beta Female*[Age0+[i/12]]]-
                EXP[Beta Female*Age0]]]]
    SET i  =  i+1
   SET Time of death  =  Time to Death distr
  SET Expire time  =  Time of death
 WHILE Waiting List Backlog.Count Contents  <  Waiting List Backlog initial
  Add Work To Queue    Patients ,  Waiting List Backlog
  SET Sex  =  Sex dist
  SET Type  =  20+Prob Aphakic WL
  'Priority is assigned independently from age and sex
  IF Type  =  21
   SET PriorityScore1  =  Priority dist Bilateral
   SET PriorityScore  =  PriorityScore1
  ELSE
   SET PriorityScore2  =  Priority dist Aphakic
   SET PriorityScore  =  PriorityScore2
  IF Sex  =  0
   SET Age0  =  Age Male
   SET i  =  0
   WHILE i  <=  [105-Age0]*12
    Set Prob-Profile Distrib Column    Time to Death distr ,  i+1 ,  i ,
      100*[EXP[[[0-Alfa Male]/Beta Male]*[EXP[Beta Male*[Age0+[[i-1]/12]]]-
      EXP[Beta Male*Age0]]]-
      EXP[[[0-Alfa Male]/Beta Male]*[EXP[Beta Male*[Age0+[i/12]]]-
      EXP[Beta Male*Age0]]]]
    SET i  =  i+1
   SET Time of death  =  Time to Death distr
  ELSE IF Sex  =  1
   SET Age0  =  Age Female
```

```
      SET i  =  0
      WHILE i  <=  [105-Age0]*12
        Set Prob-Profile Distrib Column    Time to Death distr ,  i+1 ,  i ,
                        100*[EXP[[[0-Alfa Female]/Beta Female]*[EXP[Beta Female*[Age0+[[i-1]/12]]]-
                        EXP[Beta Female*Age0]]]-
                        EXP[[[0-Alfa Female]/Beta Female]*[EXP[Beta Female*[Age0+[i/12]]]-
                        EXP[Beta Female*Age0]]]]
        SET i  =  i+1
      SET Time of death  =  Time to Death distr
    SET Expire time  =  Time of death
IF Reset for saving initial state  =  0
  'Picks up the patients of the initial state
  SET i  =  1
  WHILE Need 1st Backlog.Count Contents  <  Need 1st Backlog initial
    Add Work To Queue    Patients ,  Need 1st Backlog
    SET Age0  =  Initial state Need 1st[1,i]
    SET Sex  =  Initial state Need 1st[2,i]
    SET Type  =  Initial state Need 1st[3,i]
    SET Time of death  =  Initial state Need 1st[4,i]
    SET Expire time  =  Initial state Need 1st[5,i]
    SET Backlog need 1st  =  1
    SET i  =  i+1
  SET i  =  1
  WHILE Need 2nd Backlog.Count Contents  <  Need 2nd Backlog initial
    Add Work To Queue    Patients ,  Need 2nd Backlog
    SET Age0  =  Initial state Need 2nd[1,i]
    SET Sex  =  Initial state Need 2nd[2,i]
    SET Type  =  Initial state Need 2nd[3,i]
    SET Time of death  =  Initial state Need 2nd[4,i]
    SET Expire time  =  Initial state Need 2nd[5,i]
    SET Backlog need 2nd  =  1
    SET i  =  i+1
  SET i  =  1
  WHILE Waiting List Backlog.Count Contents  <  Waiting List Backlog initial
    Add Work To Queue    Patients ,  Waiting List Backlog
    SET Age0  =  Initial state Waiting List[1,i]
    SET Sex  =  Initial state Waiting List[2,i]
    SET Type  =  Initial state Waiting List[3,i]
    SET Time of death  =  Initial state Waiting List[4,i]
    SET Expire time  =  Initial state Waiting List[5,i]
```

```
      SET PriorityScore  =  Initial state Waiting List[6,i]
      SET PriorityScore1  =  Initial state Waiting List[7,i]
      SET PriorityScore2  =  Initial state Waiting List[8,i]
      SET Backlog WL  =  1
      SET i  =  i+1
```

3.4: Time checks

```
VL SECTION: Time Check Logic
  'Repeated at a set time interval
  Schedule Event    Update Surgery Supply ,  1
  Schedule Event    Mean priority waiting list ,  1
  Schedule Event    Percent of second eyes in the WL ,  1
  IF Validation yes_no  =  "Validation"
    IF Simulation Time  =  Results Collection Period
      Set Route In Discipline    Hidden show results ,  Circulate
```

3.4.1: Update of dynamic inputs

```
VL SECTION: Update Surgery Supply
  Schedule Event    Update Surgery Supply ,  1
  IF Simulation Time  >  0
    SET Supply  =  Proportion*[Inputs[6,13]+[Inputs[8,13]*[LOG[Inputs[10,13]+Simulation Time]]]]
    Set Prob-Profile Distrib Column    Prob Second ,  1 ,  0 ,
            100*[1-[Inputs[6,14]+[Inputs[8,14]*LOG[Inputs[10,14]+Simulation Time]]]]
    SET Monthly cases entering the WL  =  Proportion*
            [[Inputs[6,13]+[Inputs[8,13]*[LOG[[Inputs[10,13]-Inputs[6,19]]+Simulation Time]]]]-Inputs[4,19]]
    IF Waiting List.Count Contents  >  Top threshold for WL contents
      SET Monthly cases entering the WL  =  Monthly cases entering the WL*
                    [1/SQRT[[Waiting List.Count Contents-Top threshold for WL contents]+1]]
      Set Prob-Profile Distrib Column    Prob Second ,  1 ,  0 ,
                    100*[1-[[Inputs[6,14]+[Inputs[8,14]*LOG[Inputs[10,14]+Simulation Time]]]*
                    [1/SQRT[[Waiting List.Count Contents-Top threshold for WL contents]+1]]]]
    SET Mu supply  =  1/Supply
    SET Mu demand  =  1/Monthly cases entering the WL
```

3.4.2: Priority score and contents of the queues through time

```
VL SECTION: Mean priority waiting list
  'Mean priority score of the waiting list through time
  Schedule Event    Mean priority waiting list ,  1
  SET Sum aux  =  0
  LOOP 1 >>> i >>> Waiting List.Count Contents
    Select Current Work Item    Waiting List ,  i
    IF Type  =  21
      SET Sum aux  =  Sum aux+PriorityScore1
    IF Type  =  22
      SET Sum aux  =  Sum aux+PriorityScore2
  IF Waiting List.Count Contents  >  0
    SET Mean PS through time[20+Number of run,Simulation Time]  =
           Sum aux/Waiting List.Count Contents
  'Monthly number of cases in the waiting list
  SET Mean waiting list contents through time[Number of run,Simulation Time]  =
           Waiting List.Count Contents
  'Monthly number of cases in Need 1st
  SET Mean Need 1st contents through time[Number of run,Simulation Time]  =  Need 1st.Count Contents
  'Monthly number of cases in Need 2nd
  SET Mean Need 2nd contents through time[Number of run,Simulation Time]  =
           Need 2nd.Count Contents
```

3.4.3: Proportion of cases waiting for second eye surgery through time

```
VL SECTION: Percent of second eyes in the WL
  '% of second eyes waiting through time
  Schedule Event    Percent of second eyes in the WL ,  1
  SET Sum aux  =  0
  LOOP 1 >>> i >>> Waiting List.Count Contents
    Select Current Work Item    Waiting List ,  i
    IF Type  =  22
      SET Sum aux  =  Sum aux+1
  IF Waiting List.Count Contents  >  0
    SET Percent second surgeries[Number of run,Simulation Time]  =
                  Sum aux/Waiting List.Count Contents
  ELSE
    SET Percent second surgeries[Number of run,Simulation Time]  =  0
```

3.5: End run

VL SECTION: **End Run Logic**

```
  'Obeyed when the simulation reaches end of "Results Collection Period"
  '****** Waiting time and priority score of those operated
  'Overall
  SET N  =  0
  SET Sum WT  =  0
  SET Sum PS  =  0
  SET Sum PS surg  =  0
  SET SumWTPS  =  0
  SET SumWTPS surg  =  0
  LOOP 1 >>> i >>> Total surgeries
    SET Sum WT  =  Sum WT+Waiting time and priority score[21,i]
  SET Sum of times  =  Sum WT
  SET Sum WT  =  0
```

```
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    SET Sum WT  =  Sum WT+Waiting time and priority score[21,i]
    SET Sum PS  =  Sum PS+Waiting time and priority score[22,i]
    SET Sum PS surg  =  Sum PS surg+Waiting time and priority score[25,i]
    SET SumWTPS  =  SumWTPS+Waiting time and priority score[26,i]
    SET SumWTPS surg  =  SumWTPS surg+Waiting time and priority score[27,i]
    SET N  =  N+1
SET Mean WT[21,Number of run+2]  =  Sum WT/N
SET Mean PS[21,Number of run+2]  =  Sum PS/N
SET Mean PS surg[21,Number of run+2]  =  Sum PS surg/N
SET Mean WT[39,Number of run+2]  =  N
SET Sum WTPS SS[1,Number of run+2]  =  SumWTPS
SET Sum WTPS SS[9,Number of run+2]  =  SumWTPS surg
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    SET Sum WT  =  Sum WT+[[Waiting time and priority score[21,i]-Mean WT[21,Number of run+2]]*
                   [Waiting time and priority score[21,i]-Mean WT[21,Number of run+2]]]
    SET Sum PS  =  Sum PS+[[Waiting time and priority score[22,i]-Mean PS[21,Number of run+2]]*
                   [Waiting time and priority score[22,i]-Mean PS[21,Number of run+2]]]
    SET Sum PS surg  =  Sum PS surg+
                   [[Waiting time and priority score[25,i]-Mean PS surg[21,Number of run+2]]*
                   [Waiting time and priority score[25,i]-Mean PS surg[21,Number of run+2]]]
SET Stdev WT[1,Number of run+2]  =  SQRT[Sum WT/[N-1]]
SET Stdev PS[1,Number of run+2]  =  SQRT[Sum PS/[N-1]]
SET Stdev PS surg[1,Number of run+2]  =  SQRT[Sum PS surg/[N-1]]
'1st surgery
SET N  =  0
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
SET SumWTPS  =  0
SET SumWTPS surg  =  0
```

```
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[23,i]  =  21
      SET Sum WT  =  Sum WT+Waiting time and priority score[21,i]
      SET Sum PS  =  Sum PS+Waiting time and priority score[22,i]
      SET Sum PS surg  =  Sum PS surg+Waiting time and priority score[25,i]
      SET SumWTPS  =  SumWTPS+Waiting time and priority score[26,i]
      SET SumWTPS surg  =  SumWTPS surg+Waiting time and priority score[27,i]
      SET N  =  N+1
SET Mean WT[22,Number of run+2]  =  Sum WT/N
SET Mean PS[22,Number of run+2]  =  Sum PS/N
SET Mean PS surg[22,Number of run+2]  =  Sum PS surg/N
SET Mean WT[40,Number of run+2]  =  N
SET Sum WTPS SS[2,Number of run+2]  =  SumWTPS
SET Sum WTPS SS[10,Number of run+2]  =  SumWTPS surg
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[23,i]  =  21
      SET Sum WT  =  Sum WT+[[Waiting time and priority score[21,i]-Mean WT[22,Number of run+2]]*
                 [Waiting time and priority score[21,i]-Mean WT[22,Number of run+2]]]
      SET Sum PS  =  Sum PS+[[Waiting time and priority score[22,i]-Mean PS[22,Number of run+2]]*
                 [Waiting time and priority score[22,i]-Mean PS[22,Number of run+2]]]
      SET Sum PS surg  =  Sum PS surg+
                 [[Waiting time and priority score[25,i]-Mean PS surg[22,Number of run+2]]*
                 [Waiting time and priority score[25,i]-Mean PS surg[22,Number of run+2]]]
SET Stdev WT[2,Number of run+2]  =  SQRT[Sum WT/[N-1]]
SET Stdev PS[2,Number of run+2]  =  SQRT[Sum PS/[N-1]]
SET Stdev PS surg[2,Number of run+2]  =  SQRT[Sum PS surg/[N-1]]
'2nd surgery
SET N  =  0
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
SET SumWTPS  =  0
SET SumWTPS surg  =  0
```

```
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[23,i]  =  22
      SET Sum WT  =  Sum WT+Waiting time and priority score[21,i]
      SET Sum PS  =  Sum PS+Waiting time and priority score[22,i]
      SET Sum PS surg  =  Sum PS surg+Waiting time and priority score[25,i]
      SET SumWTPS  =  SumWTPS+Waiting time and priority score[26,i]
      SET SumWTPS surg  =  SumWTPS surg+Waiting time and priority score[27,i]
      SET N  =  N+1
SET Mean WT[23,Number of run+2]  =  Sum WT/N
SET Mean PS[23,Number of run+2]  =  Sum PS/N
SET Mean PS surg[23,Number of run+2]  =  Sum PS surg/N
SET Mean WT[41,Number of run+2]  =  N
SET Sum WTPS SS[3,Number of run+2]  =  SumWTPS
SET Sum WTPS SS[11,Number of run+2]  =  SumWTPS surg
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[23,i]  =  22
      SET Sum WT  =  Sum WT+[[Waiting time and priority score[21,i]-Mean WT[23,Number of run+2]]*
                 [Waiting time and priority score[21,i]-Mean WT[23,Number of run+2]]]
      SET Sum PS  =  Sum PS+[[Waiting time and priority score[22,i]-Mean PS[23,Number of run+2]]*
                 [Waiting time and priority score[22,i]-Mean PS[23,Number of run+2]]]
      SET Sum PS surg  =  Sum PS surg+
                 [[Waiting time and priority score[25,i]-Mean PS surg[23,Number of run+2]]*
                 [Waiting time and priority score[25,i]-Mean PS surg[23,Number of run+2]]]
SET Stdev WT[3,Number of run+2]  =  SQRT[Sum WT/[N-1]]
SET Stdev PS[3,Number of run+2]  =  SQRT[Sum PS/[N-1]]
SET Stdev PS surg[3,Number of run+2]  =  SQRT[Sum PS surg/[N-1]]
```

```
'****** Waiting time and priority score of those who are still waiting
IF Validation yes_no  =  "No validation"
  SET i  =  1
  WHILE i  <=  Waiting List.Count Contents
    Select Current Work Item    Waiting List ,  i
    IF Type  =  21
      SET Waiting time and priority score[31,i]  =  Results Collection Period-Entry WL1
      SET Waiting time and priority score[32,i]  =  PriorityScore1
    ELSE
      SET Waiting time and priority score[31,i]  =  Results Collection Period-Entry WL2
      SET Waiting time and priority score[32,i]  =  PriorityScore2
    SET Waiting time and priority score[33,i]  =  Type
    SET Waiting time and priority score[34,i]  =  Backlog WL
    SET Waiting time and priority score[35,i]  =  PriorityScore
    SET Waiting time and priority score[36,i]  =  Waiting time and priority score[31,i]*
          Waiting time and priority score[32,i]
    SET Waiting time and priority score[37,i]  =  0
    IF Type  =  21
      IF Inc Prior 1  >  0
        LOOP 1 >>> j >>> Inc Prior 1
          SET Waiting time and priority score[37,i]  =  Waiting time and priority score[37,i]+
                    [Time to review*[Waiting time and priority score[32,i]+[[j-1]*Increase in priority]]]
      SET Waiting time and priority score[37,i]  =  Waiting time and priority score[37,i]+
                    [[Waiting time and priority score[31,i]-[Time to review*Inc Prior 1]]*
                    Waiting time and priority score[35,i]]
    ELSE
      IF Inc Prior 2  >  0
        LOOP 1 >>> j >>> Inc Prior 2
          SET Waiting time and priority score[37,i]  =  Waiting time and priority score[37,i]+
                    [Time to review*[Waiting time and priority score[32,i]+[[j-1]*Increase in priority]]]
      SET Waiting time and priority score[37,i]  =  Waiting time and priority score[37,i]+
          [[Waiting time and priority score[31,i]-[Time to review*Inc Prior 2]]*
          Waiting time and priority score[35,i]]
    SET i  =  i+1
  'Overall
  SET N  =  0
  SET Sum WT  =  0
  SET Sum PS  =  0
  SET Sum PS surg  =  0
  SET SumWTPS  =  0
  SET SumWTPS surg  =  0
```

```
LOOP 1 >>> i >>> Waiting List.Count Contents
  SET Sum WT  =  Sum WT+Waiting time and priority score[31,i]
SET Sum of times  =  Sum of times+Sum WT
SET Sum WT  =  0
LOOP 1 >>> i >>> Waiting List.Count Contents
  IF Waiting time and priority score[34,i]  =  0
    SET Sum WT  =  Sum WT+Waiting time and priority score[31,i]
    SET Sum PS  =  Sum PS+Waiting time and priority score[32,i]
    SET Sum PS surg  =  Sum PS surg+Waiting time and priority score[35,i]
    SET SumWTPS  =  SumWTPS+Waiting time and priority score[36,i]
    SET SumWTPS surg  =  SumWTPS surg+Waiting time and priority score[37,i]
    SET N  =  N+1
SET Mean WT[25,Number of run+2]  =  Sum WT/N
SET Mean PS[25,Number of run+2]  =  Sum PS/N
SET Mean PS surg[25,Number of run+2]  =  Sum PS surg/N
SET Mean WT[43,Number of run+2]  =  N
SET Sum WTPS SS[5,Number of run+2]  =  SumWTPS
SET Sum WTPS SS[13,Number of run+2]  =  SumWTPS surg
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
LOOP 1 >>> i >>> Waiting List.Count Contents
  IF Waiting time and priority score[34,i]  =  0
    SET Sum WT  =  Sum WT+[[Waiting time and priority score[31,i]-Mean WT[25,Number of run+2]]*
                 [Waiting time and priority score[31,i]-Mean WT[25,Number of run+2]]]
    SET Sum PS  =  Sum PS+[[Waiting time and priority score[32,i]-Mean PS[25,Number of run+2]]*
                 [Waiting time and priority score[32,i]-Mean PS[25,Number of run+2]]]
    SET Sum PS surg  =  Sum PS surg+
                 [[Waiting time and priority score[35,i]-Mean PS surg[25,Number of run+2]]*
                 [Waiting time and priority score[35,i]-Mean PS surg[25,Number of run+2]]]
SET Stdev WT[5,Number of run+2]  =  SQRT[Sum WT/[N-1]]
SET Stdev PS[5,Number of run+2]  =  SQRT[Sum PS/[N-1]]
SET Stdev PS surg[5,Number of run+2]  =  SQRT[Sum PS surg/[N-1]]
'1st surgery
SET N  =  0
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
SET SumWTPS  =  0
SET SumWTPS surg  =  0
```

```
LOOP 1 >>> i >>> Waiting List.Count Contents
  IF Waiting time and priority score[34,i]  =  0
    IF Waiting time and priority score[33,i]  =  21
      SET Sum WT  =  Sum WT+Waiting time and priority score[31,i]
      SET Sum PS  =  Sum PS+Waiting time and priority score[32,i]
      SET Sum PS surg  =  Sum PS surg+Waiting time and priority score[35,i]
      SET SumWTPS  =  SumWTPS+Waiting time and priority score[36,i]
      SET SumWTPS surg  =  SumWTPS surg+Waiting time and priority score[37,i]
      SET N  =  N+1
SET Mean WT[26,Number of run+2]  =  Sum WT/N
SET Mean PS[26,Number of run+2]  =  Sum PS/N
SET Mean PS surg[26,Number of run+2]  =  Sum PS surg/N
SET Mean WT[44,Number of run+2]  =  N
SET Sum WTPS SS[6,Number of run+2]  =  SumWTPS
SET Sum WTPS SS[14,Number of run+2]  =  SumWTPS surg
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
LOOP 1 >>> i >>> Waiting List.Count Contents
  IF Waiting time and priority score[34,i]  =  0
    IF Waiting time and priority score[33,i]  =  21
      SET Sum WT  =  Sum WT+[[Waiting time and priority score[31,i]-Mean WT[26,Number of run+2]]*
                [Waiting time and priority score[31,i]-Mean WT[26,Number of run+2]]]
      SET Sum PS  =  Sum PS+[[Waiting time and priority score[32,i]-Mean PS[26,Number of run+2]]*
                [Waiting time and priority score[32,i]-Mean PS[26,Number of run+2]]]
      SET Sum PS surg  =  Sum PS surg+
                [[Waiting time and priority score[35,i]-Mean PS surg[26,Number of run+2]]*
                [Waiting time and priority score[35,i]-Mean PS surg[26,Number of run+2]]]
SET Stdev WT[6,Number of run+2]  =  SQRT[Sum WT/[N-1]]
SET Stdev PS[6,Number of run+2]  =  SQRT[Sum PS/[N-1]]
SET Stdev PS surg[6,Number of run+2]  =  SQRT[Sum PS surg/[N-1]]
'2nd surgery
SET N  =  0
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
SET SumWTPS  =  0
SET SumWTPS surg  =  0
```

```
  LOOP 1 >>> i >>> Waiting List.Count Contents
    IF Waiting time and priority score[34,i]  =  0
      IF Waiting time and priority score[33,i]  =  22
        SET Sum WT  =  Sum WT+Waiting time and priority score[31,i]
        SET Sum PS  =  Sum PS+Waiting time and priority score[32,i]
        SET Sum PS surg  =  Sum PS surg+Waiting time and priority score[35,i]
        SET SumWTPS  =  SumWTPS+Waiting time and priority score[36,i]
        SET SumWTPS surg  =  SumWTPS surg+Waiting time and priority score[37,i]
        SET N  =  N+1
  SET Mean WT[27,Number of run+2]  =  Sum WT/N
  SET Mean PS[27,Number of run+2]  =  Sum PS/N
  SET Mean PS surg[27,Number of run+2]  =  Sum PS surg/N
  SET Mean WT[45,Number of run+2]  =  N
  SET Sum WTPS SS[7,Number of run+2]  =  SumWTPS
  SET Sum WTPS SS[15,Number of run+2]  =  SumWTPS surg
  SET Sum WT  =  0
  SET Sum PS  =  0
  SET Sum PS surg  =  0
  LOOP 1 >>> i >>> Waiting List.Count Contents
    IF Waiting time and priority score[34,i]  =  0
      IF Waiting time and priority score[33,i]  =  22
        SET Sum WT  =  Sum WT+[[Waiting time and priority score[31,i]-Mean WT[27,Number of run+2]]*
                [Waiting time and priority score[31,i]-Mean WT[27,Number of run+2]]]
        SET Sum PS  =  Sum PS+[[Waiting time and priority score[32,i]-Mean PS[27,Number of run+2]]*
                [Waiting time and priority score[32,i]-Mean PS[27,Number of run+2]]]
        SET Sum PS surg  =  Sum PS surg+
                [[Waiting time and priority score[35,i]-Mean PS surg[27,Number of run+2]]*
                [Waiting time and priority score[35,i]-Mean PS surg[27,Number of run+2]]]
  SET Stdev WT[7,Number of run+2]  =  SQRT[Sum WT/[N-1]]
  SET Stdev PS[7,Number of run+2]  =  SQRT[Sum PS/[N-1]]
  SET Stdev PS surg[7,Number of run+2]  =  SQRT[Sum PS surg/[N-1]]
'****** Waiting time and priority score of those who went to private from waiting list
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
SET SumWTPS  =  0
SET SumWTPS surg  =  0
SET N  =  0
```

```
LOOP 1 >>> i >>> N private
  IF Waiting time and priority score[43,i]-10  >  10
    '(only the cases from the waiting list (type=21 or 22) are used to calculate the total waiting time)
    SET Sum WT  =  Sum WT+Waiting time and priority score[41,i]
SET Sum of times  =  Sum of times+Sum WT
SET Sum WT  =  0
LOOP 1 >>> i >>> N private
  IF Waiting time and priority score[43,i]  >  20
    '(only the cases from the waiting list (type=21 or 22) are used to calculate the mean waiting time)
    IF Waiting time and priority score[44,i]  =  0
      SET Sum WT  =  Sum WT+Waiting time and priority score[41,i]
      SET Sum PS  =  Sum PS+Waiting time and priority score[42,i]
      SET Sum PS surg  =  Sum PS surg+Waiting time and priority score[45,i]
      SET SumWTPS  =  SumWTPS+Waiting time and priority score[46,i]
      SET SumWTPS surg  =  SumWTPS surg+Waiting time and priority score[47,i]
      SET N  =  N+1
SET Mean WT[30,Number of run+2]  =  Sum WT/N
SET Mean PS[30,Number of run+2]  =  Sum PS/N
SET Mean PS surg[30,Number of run+2]  =  Sum PS surg/N
SET Mean WT[47,Number of run+2]  =  N
SET Sum WTPS SS[17,Number of run+2]  =  SumWTPS
SET Sum WTPS SS[19,Number of run+2]  =  SumWTPS surg
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
```

```
LOOP 1 >>> i >>> N private
  IF Waiting time and priority score[43,i]  >  20
    '(only the cases from the waiting list (type=21 or 22) are used to calculate the mean waiting time)
    IF Waiting time and priority score[44,i]  =  0
      SET Sum WT  =  Sum WT+[[Waiting time and priority score[41,i]-Mean WT[30,Number of run+2]]*
                  [Waiting time and priority score[41,i]-Mean WT[30,Number of run+2]]]
      SET Sum PS  =  Sum PS+[[Waiting time and priority score[42,i]-Mean PS[30,Number of run+2]]*
                  [Waiting time and priority score[42,i]-Mean PS[30,Number of run+2]]]
      SET Sum PS surg  =  Sum PS surg+
                  [[Waiting time and priority score[46,i]-Mean PS surg[30,Number of run+2]]*
                  [Waiting time and priority score[46,i]-Mean PS surg[30,Number of run+2]]]
IF N  >  1
  SET Stdev WT[10,Number of run+2]  =  SQRT[Sum WT/[N-1]]
  SET Stdev PS[10,Number of run+2]  =  SQRT[Sum PS/[N-1]]
  SET Stdev PS surg[10,Number of run+2]  =  SQRT[Sum PS surg/[N-1]]
ELSE
  SET Stdev WT[10,Number of run+2]  =  0
  SET Stdev PS[10,Number of run+2]  =  0
  SET Stdev PS surg[10,Number of run+2]  =  0
'****** Waiting time and priority score of those who died while waiting
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
SET SumWTPS  =  0
SET SumWTPS surg  =  0
SET N  =  0
LOOP 1 >>> i >>> N dead
  IF Waiting time and priority score[53,i]  >  20
    '(only the cases from the waiting list (type=21 or 22) are used to calculate the total waiting time)
    SET Sum WT  =  Sum WT+Waiting time and priority score[51,i]
SET Sum of times  =  Sum of times+Sum WT
SET Mean WT[52,Number of run+2]  =  Sum of times
SET Sum WT  =  0
```

```
LOOP 1 >>> i >>> N dead
  IF Waiting time and priority score[53,i]  >  20
    '(only the cases from the waiting list (type=21 or 22) are used to calculate the mean waiting time)
    IF Waiting time and priority score[54,i]  =  0
      SET Sum WT  =  Sum WT+Waiting time and priority score[51,i]
      SET Sum PS  =  Sum PS+Waiting time and priority score[52,i]
      SET Sum PS surg  =  Sum PS surg+Waiting time and priority score[55,i]
      SET SumWTPS  =  SumWTPS+Waiting time and priority score[56,i]
      SET SumWTPS surg  =  SumWTPS surg+Waiting time and priority score[57,i]
      SET N  =  N+1
SET Mean WT[35,Number of run+2]  =  Sum WT/N
SET Mean PS[35,Number of run+2]  =  Sum PS/N
SET Mean PS surg[35,Number of run+2]  =  Sum PS surg/N
SET Mean WT[49,Number of run+2]  =  N
SET Sum WTPS SS[21,Number of run+2]  =  SumWTPS
SET Sum WTPS SS[23,Number of run+2]  =  SumWTPS surg
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum PS surg  =  0
LOOP 1 >>> i >>> N dead
  IF Waiting time and priority score[53,i]-10  >  10
    '(only the cases from the waiting list (type=21 or 22) are used to calculate the mean waiting time)
    IF Waiting time and priority score[54,i]  =  0
      SET Sum WT  =  Sum WT+[[Waiting time and priority score[51,i]-Mean WT[35,Number of run+2]]*
                 [Waiting time and priority score[51,i]-Mean WT[35,Number of run+2]]]
      SET Sum PS  =  Sum PS+[[Waiting time and priority score[52,i]-Mean PS[35,Number of run+2]]*
                 [Waiting time and priority score[52,i]-Mean PS[35,Number of run+2]]]
      SET Sum PS surg  =  Sum PS surg+
                 [[Waiting time and priority score[57,i]-Mean PS surg[35,Number of run+2]]*
                 [Waiting time and priority score[57,i]-Mean PS surg[35,Number of run+2]]]
IF N  >  1
  SET Stdev WT[15,Number of run+2]  =  SQRT[Sum WT/[N-1]]
  SET Stdev PS[15,Number of run+2]  =  SQRT[Sum PS/[N-1]]
  SET Stdev PS surg[15,Number of run+2]  =  SQRT[Sum PS surg/[N-1]]
ELSE
  SET Stdev WT[15,Number of run+2]  =  0
  SET Stdev PS[15,Number of run+2]  =  0
  SET Stdev PS surg[15,Number of run+2]  =  0
```

```
'***** Calculus of correlation between waiting time and priority
SET N  =  0
SET Sum WT  =  0
SET Sum PS  =  0
SET Sum crossprod  =  0
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    SET N  =  N+1
    SET Sum crossprod  =  Sum crossprod+
                    [[Waiting time and priority score[21,i]-Mean WT[21,Number of run+2]]*
                    [Waiting time and priority score[22,i]-Mean PS[21,Number of run+2]]]
SET Correlation between WT and PS[21,Number of run+1]  =
          Sum crossprod/[[[N-1]*Stdev WT[1,Number of run+2]]*Stdev PS[1,Number of run+2]]
'***** Calculus of Priority Score threshold to warrant surgery before t months
LOOP 1 >>> j >>> 5
  SET Max priority score by waiting time[20+j,Number of run+1]  =  0
  LOOP 1 >>> i >>> Total surgeries
    IF Waiting time and priority score[24,i]  =  0
      IF Waiting time and priority score[21,i]  >=  Warranty Times SS[1,j]
        IF Waiting time and priority score[22,i]  >  Max priority score by waiting time[20+j,Number of run+1]
          SET Max priority score by waiting time[20+j,Number of run+1]  =
                                        Waiting time and priority score[22,i]
```

```
'***** Mean waiting time by priority score group
'At entry
LOOP 1 >>> j >>> 10
 SET Sum WT  =  0
 SET N  =  0
 LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[28,i]  =  j
   IF Waiting time and priority score[24,i]  =  0
    SET Sum WT  =  Sum WT+Waiting time and priority score[21,i]
    SET N  =  N+1
 SET WT by PS[[3*j]-2,3+Number of run]  =  N
 IF N  >  0
  SET WT by PS[[3*j]-1,3+Number of run]  =  Sum WT/N
 ELSE
  SET WT by PS[[3*j]-1,3+Number of run]  =  ""
 SET Sum WT  =  0
 IF N  >  1
  LOOP 1 >>> i >>> Total surgeries
   IF Waiting time and priority score[28,i]  =  j
    IF Waiting time and priority score[24,i]  =  0
     SET Sum WT  =  Sum WT+
                         [[Waiting time and priority score[21,i]-WT by PS[[3*j]-1,3+Number of run]]*
                         [Waiting time and priority score[21,i]-WT by PS[[3*j]-1,3+Number of run]]]
  SET WT by PS[3*j,3+Number of run]  =  Sum WT/[N-1]
 ELSE
  IF N  =  1
   SET WT by PS[3*j,3+Number of run]  =  0
  ELSE
   SET WT by PS[3*j,3+Number of run]  =  ""
```

```
'Final
LOOP 1 >>> j >>> 10
  SET Sum WT  =  0
  SET N  =  0
  LOOP 1 >>> i >>> Total surgeries
    IF Waiting time and priority score[29,i]  =  j
      IF Waiting time and priority score[24,i]  =  0
        SET Sum WT  =  Sum WT+Waiting time and priority score[21,i]
        SET N  =  N+1
  SET WT by PS[40+[[3*j]-2],3+Number of run]  =  N
  IF N  >  0
    SET WT by PS[40+[[3*j]-1],3+Number of run]  =  Sum WT/N
  ELSE
    SET WT by PS[40+[[3*j]-1],3+Number of run]  =  ""
  SET Sum WT  =  0
  IF N  >  1
    LOOP 1 >>> i >>> Total surgeries
      IF Waiting time and priority score[29,i]  =  j
        IF Waiting time and priority score[24,i]  =  0
          SET Sum WT  =  Sum WT+
                             [[Waiting time and priority score[21,i]-WT by PS[40+[[3*j]-1],3+Number of run]]*
                             [Waiting time and priority score[21,i]-WT by PS[40+[[3*j]-1],3+Number of run]]]
    SET WT by PS[40+[3*j],3+Number of run]  =  Sum WT/[N-1]
  ELSE
    IF N  =  1
      SET WT by PS[40+[3*j],3+Number of run]  =  0
    ELSE
      SET WT by PS[40+[3*j],3+Number of run]  =  ""
'***** Percentiles of waiting time
Clear Sheet    Ordered WT[1,1]
'Overall
SET k  =  1
WHILE Waiting time and priority score[24,k]  =  1
  SET k  =  k+1
SET Ordered WT[1,1]  =  Waiting time and priority score[21,k]
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[21,i]  <  Ordered WT[1,1]
      SET Ordered WT[1,1]  =  Waiting time and priority score[21,i]
SET Ordered WT[1,Mean WT[39,Number of run+2]]  =  Waiting time and priority score[21,k]
```

```
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[21,i]  >  Ordered WT[1,Mean WT[39,Number of run+2]]
      SET Ordered WT[1,Mean WT[39,Number of run+2]]  =  Waiting time and priority score[21,i]
LOOP 2 >>> j >>> Mean WT[39,Number of run+2]-1
  SET Ordered WT[1,j]  =  Ordered WT[1,Mean WT[39,Number of run+2]]
  LOOP 1 >>> i >>> Total surgeries
    IF Waiting time and priority score[24,i]  =  0
      IF Waiting time and priority score[21,i]  <  Ordered WT[1,j]
        IF Waiting time and priority score[21,i]  >  Ordered WT[1,j-1]
          SET Ordered WT[1,j]  =  Waiting time and priority score[21,i]
'1st surgery
SET k  =  1
SET Condition  =  0
WHILE Condition  =  0
  WHILE Waiting time and priority score[24,k]  =  1
    SET k  =  k+1
  WHILE Waiting time and priority score[23,k]  <>  21
    SET k  =  k+1
  IF Waiting time and priority score[24,k]  =  0
    SET Condition  =  1
SET Ordered WT[2,1]  =  Waiting time and priority score[21,k]
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[23,i]  =  21
      IF Waiting time and priority score[21,i]  <  Ordered WT[2,1]
        SET Ordered WT[2,1]  =  Waiting time and priority score[21,i]
SET Ordered WT[2,Mean WT[40,Number of run+2]]  =  Waiting time and priority score[21,k]
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[23,i]  =  21
      IF Waiting time and priority score[21,i]  >  Ordered WT[2,Mean WT[40,Number of run+2]]
        SET Ordered WT[2,Mean WT[40,Number of run+2]]  =  Waiting time and priority score[21,i]
LOOP 2 >>> j >>> Mean WT[40,Number of run+2]-1
  SET Ordered WT[2,j]  =  Ordered WT[2,Mean WT[40,Number of run+2]]
  LOOP 1 >>> i >>> Total surgeries
    IF Waiting time and priority score[24,i]  =  0
      IF Waiting time and priority score[23,i]  =  21
        IF Waiting time and priority score[21,i]  <  Ordered WT[2,j]
          IF Waiting time and priority score[21,i]  >  Ordered WT[2,j-1]
            SET Ordered WT[2,j]  =  Waiting time and priority score[21,i]
```

```
'2nd surgery
SET k  =  1
SET Condition  =  0
WHILE Condition  =  0
  WHILE Waiting time and priority score[24,k]  =  1
    SET k  =  k+1
  WHILE Waiting time and priority score[23,k]  <>  22
    SET k  =  k+1
  IF Waiting time and priority score[24,k]  =  0
    SET Condition  =  1
SET Ordered WT[3,1]  =  Waiting time and priority score[21,k]
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[23,i]  =  22
      IF Waiting time and priority score[21,i]  <  Ordered WT[3,1]
        SET Ordered WT[3,1]  =  Waiting time and priority score[21,i]
SET Ordered WT[3,Mean WT[41,Number of run+2]]  =  Waiting time and priority score[21,k]
LOOP 1 >>> i >>> Total surgeries
  IF Waiting time and priority score[24,i]  =  0
    IF Waiting time and priority score[23,i]  =  22
      IF Waiting time and priority score[21,i]  >  Ordered WT[3,Mean WT[41,Number of run+2]]
        SET Ordered WT[3,Mean WT[41,Number of run+2]]  =  Waiting time and priority score[21,i]
LOOP 2 >>> j >>> Mean WT[41,Number of run+2]-1
  SET Ordered WT[3,j]  =  Ordered WT[3,Mean WT[41,Number of run+2]]
  LOOP 1 >>> i >>> Total surgeries
    IF Waiting time and priority score[24,i]  =  0
      IF Waiting time and priority score[23,i]  =  22
        IF Waiting time and priority score[21,i]  <  Ordered WT[3,j]
          IF Waiting time and priority score[21,i]  >  Ordered WT[3,j-1]
            SET Ordered WT[3,j]  =  Waiting time and priority score[21,i]
'* Saving
'Minimum
LOOP 1 >>> i >>> 3
  SET Percentiles of WT[[[i-1]*10]+1,Number of run+2]  =  Ordered WT[i,1]
```

```
'5% percentile
LOOP 1 >>> i >>> 3
  IF Mean WT[38+i,Number of run+2]/20  =  TRUNC[Mean WT[38+i,Number of run+2]/20]
    SET Percentiles of WT[[[i-1]*10]+2,Number of run+2]  =
                    Ordered WT[i,Mean WT[38+i,Number of run+2]/20]
  ELSE
    SET Percentiles of WT[[[i-1]*10]+2,Number of run+2]  =
                    [Ordered WT[i,TRUNC[Mean WT[38+i,Number of run+2]/20]]+
                    Ordered WT[i,1+TRUNC[Mean WT[38+i,Number of run+2]/20]]]/2
'10% percentile
LOOP 1 >>> i >>> 3
  IF Mean WT[38+i,Number of run+2]/10  =  TRUNC[Mean WT[38+i,Number of run+2]/10]
    SET Percentiles of WT[[[i-1]*10]+3,Number of run+2]  =
                    Ordered WT[i,Mean WT[38+i,Number of run+2]/10]
  ELSE
    SET Percentiles of WT[[[i-1]*10]+3,Number of run+2]  =
                    [Ordered WT[i,TRUNC[Mean WT[38+i,Number of run+2]/10]]+
                    Ordered WT[i,1+TRUNC[Mean WT[38+i,Number of run+2]/10]]]/2
'25% percentile
LOOP 1 >>> i >>> 3
  IF Mean WT[38+i,Number of run+2]/4  =  TRUNC[Mean WT[38+i,Number of run+2]/4]
    SET Percentiles of WT[[[i-1]*10]+4,Number of run+2]  =
                    Ordered WT[i,Mean WT[38+i,Number of run+2]/4]
  ELSE
    SET Percentiles of WT[[[i-1]*10]+4,Number of run+2]  =
                    [Ordered WT[i,TRUNC[Mean WT[38+i,Number of run+2]/4]]+
                    Ordered WT[i,1+TRUNC[Mean WT[38+i,Number of run+2]/4]]]/2
'50% percentile
LOOP 1 >>> i >>> 3
  IF Mean WT[38+i,Number of run+2]/2  =  TRUNC[Mean WT[38+i,Number of run+2]/2]
    SET Percentiles of WT[[[i-1]*10]+5,Number of run+2]  =
                    Ordered WT[i,Mean WT[38+i,Number of run+2]/2]
  ELSE
    SET Percentiles of WT[[[i-1]*10]+5,Number of run+2]  =
                    [Ordered WT[i,TRUNC[Mean WT[38+i,Number of run+2]/2]]+
                    Ordered WT[i,1+TRUNC[Mean WT[38+i,Number of run+2]/2]]]/2
```

```
'75% percentile
LOOP 1 >>> i >>> 3
  IF Mean WT[38+i,Number of run+2]*[3/4]  =  TRUNC[Mean WT[38+i,Number of run+2]*[3/4]]
    SET Percentiles of WT[[[i-1]*10]+6,Number of run+2]  =
                    Ordered WT[i,Mean WT[38+i,Number of run+2]*[3/4]]
  ELSE
    SET Percentiles of WT[[[i-1]*10]+6,Number of run+2]  =
                    [Ordered WT[i,TRUNC[Mean WT[38+i,Number of run+2]*[3/4]]]+
                    Ordered WT[i,1+TRUNC[Mean WT[38+i,Number of run+2]*[3/4]]]]/2
'90% percentile
LOOP 1 >>> i >>> 3
  IF Mean WT[38+i,Number of run+2]*[9/10]  =  TRUNC[Mean WT[38+i,Number of run+2]*[9/10]]
    SET Percentiles of WT[[[i-1]*10]+7,Number of run+2]  =
                    Ordered WT[i,Mean WT[38+i,Number of run+2]*[9/10]]
  ELSE
    SET Percentiles of WT[[[i-1]*10]+7,Number of run+2]  =
                    [Ordered WT[i,TRUNC[Mean WT[38+i,Number of run+2]*[9/10]]]+
                    Ordered WT[i,1+TRUNC[Mean WT[38+i,Number of run+2]*[9/10]]]]/2
'95% percentile
LOOP 1 >>> i >>> 3
  IF Mean WT[38+i,Number of run+2]*[19/20]  =  TRUNC[Mean WT[38+i,Number of run+2]*[19/20]]
    SET Percentiles of WT[[[i-1]*10]+8,Number of run+2]  =
                    Ordered WT[i,Mean WT[38+i,Number of run+2]*[19/20]]
  ELSE
    SET Percentiles of WT[[[i-1]*10]+8,Number of run+2]  =
                    [Ordered WT[i,TRUNC[Mean WT[38+i,Number of run+2]*[19/20]]]+
                    Ordered WT[i,1+TRUNC[Mean WT[38+i,Number of run+2]*[19/20]]]]/2
'Maximum
LOOP 1 >>> i >>> 3
  SET Percentiles of WT[[[i-1]*10]+9,Number of run+2]  =
                    Ordered WT[i,Mean WT[38+i,Number of run+2]]
'***** Results from results summary
Get Result   Results Summary SS[1,3+Number of run] ,  Current Run ,  Incident cases: Number Entered
Get Result   Results Summary SS[2,3+Number of run] ,  Current Run ,  Need 1st: Average queue size
Get Result   Results Summary SS[3,3+Number of run] ,  Current Run ,  Need 1st: Current Contents
Get Result   Results Summary SS[4,3+Number of run] ,  Current Run ,  Need 2nd: Items Entered
SET Results Summary SS[4,3+Number of run]  =
        Results Summary SS[4,3+Number of run]-Backlog need 2nd
Get Result   Results Summary SS[5,3+Number of run] ,  Current Run ,  Need 2nd: Average queue size
Get Result   Results Summary SS[6,3+Number of run] ,  Current Run ,  Need 2nd: Current Contents
Get Result   Results Summary SS[7,3+Number of run] ,  Current Run ,
        Demand: Number Completed Jobs
```

```
Get Result    Results Summary SS[8,3+Number of run] ,  Current Run ,
          Second: Number Completed Jobs
Get Result    Results Summary SS[9,3+Number of run] ,  Current Run ,  Waiting List: Average queue size
Get Result    Results Summary SS[10,3+Number of run] ,  Current Run ,  Waiting List: Current Contents
Get Result    Results Summary SS[11,3+Number of run] ,  Current Run ,
          Waiting List: Maximum queue size
Get Result    Results Summary SS[12,3+Number of run] ,  Current Run ,
          Private Sector: Number Completed
Get Result    Results Summary SS[13,3+Number of run] ,  Current Run ,  Death: Number Completed
```

3.6: End trial

VL SECTION: **End Trial Logic**

```
'Warranty times
LOOP 1 >>> j >>> 5
  SET Max priority score by waiting time[2,21+j]  =  Warranty Times SS[1,j]
  SET Max priority score by waiting time[20+j,1]  =  Warranty Times SS[1,j]
```

```
'Data for mean priority score and mean number of cases in Waiting List, Need 1st and Need 2nd evolution
LOOP 1 >>> j >>> Results Collection Period
  SET Sum PS  =  0
  SET Sum aux  =  0
  SET Sum aux1  =  0
  SET Sum aux2  =  0
  LOOP 1 >>> i >>> Number of run
    SET Sum PS  =  Sum PS+Mean PS through time[20+i,j]
    SET Sum aux  =  Sum aux+Mean waiting list contents through time[i,j]
    SET Sum aux1  =  Sum aux1+Mean Need 1st contents through time[i,j]
    SET Sum aux2  =  Sum aux2+Mean Need 2nd contents through time[i,j]
  SET Mean PS through time[22+Number of run,j]  =  Sum PS/Number of run
  SET Mean waiting list contents through time[2+Number of run,j]  =  Sum aux/Number of run
  SET Mean Need 1st contents through time[2+Number of run,j]  =  Sum aux1/Number of run
  SET Mean Need 2nd contents through time[2+Number of run,j]  =  Sum aux2/Number of run
  SET Sum PS  =  0
  SET Sum aux  =  0
  SET Sum aux1  =  0
  SET Sum aux2  =  0
  LOOP 1 >>> i >>> Number of run
    SET Sum PS  =  Sum PS+
                        [[Mean PS through time[20+i,j]-Mean PS through time[22+Number of run,j]]*
                        [Mean PS through time[20+i,j]-Mean PS through time[22+Number of run,j]]]
    SET Sum aux  =  Sum aux+[[Mean waiting list contents through time[i,j]-
                        Mean waiting list contents through time[2+Number of run,j]]*
                        [Mean waiting list contents through time[i,j]-
                        Mean waiting list contents through time[2+Number of run,j]]]
    SET Sum aux1  =  Sum aux1+[[Mean Need 1st contents through time[i,j]-
                        Mean Need 1st contents through time[2+Number of run,j]]*
                        [Mean Need 1st contents through time[i,j]-
                        Mean Need 1st contents through time[2+Number of run,j]]]
    SET Sum aux2  =  Sum aux2+[[Mean Need 2nd contents through time[i,j]-
                        Mean Need 2nd contents through time[2+Number of run,j]]*
                        [Mean Need 2nd contents through time[i,j]-
                        Mean Need 2nd contents through time[2+Number of run,j]]]
  SET Mean PS through time[24+Number of run,j]  =  SQRT[Sum PS/[Number of run-1]]
  SET Mean waiting list contents through time[3+Number of run,j]  =  SQRT[Sum aux/[Number of run-1]]
  SET Mean Need 1st contents through time[3+Number of run,j]  =  SQRT[Sum aux1/[Number of run-1]]
  SET Mean Need 2nd contents through time[3+Number of run,j]  =  SQRT[Sum aux2/[Number of run-1]]
```

```
'Data for % of second eyes evolution
LOOP 1 >>> j >>> Results Collection Period
 SET Sum aux  =  0
 LOOP 1 >>> i >>> Number of run
  SET Sum aux  =  Sum aux+Percent second surgeries[i,j]
 SET Percent second surgeries[2+Number of run,j]  =  100*[Sum aux/Number of run]
'**************EXPORT RESULTS TO EXCEL*****************
'Of runs
Set in EXCEL    Mean WT[39,3] ,  "[DATA.XLS]Outputs Runs" ,  2 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[21,3] ,  "[DATA.XLS]Outputs Runs" ,  3 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev WT[1,3] ,  "[DATA.XLS]Outputs Runs" ,  4 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[40,3] ,  "[DATA.XLS]Outputs Runs" ,  5 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[22,3] ,  "[DATA.XLS]Outputs Runs" ,  6 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev WT[2,3] ,  "[DATA.XLS]Outputs Runs" ,  7 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[41,3] ,  "[DATA.XLS]Outputs Runs" ,  8 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[23,3] ,  "[DATA.XLS]Outputs Runs" ,  9 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev WT[3,3] ,  "[DATA.XLS]Outputs Runs" ,  10 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[43,3] ,  "[DATA.XLS]Outputs Runs" ,  11 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[25,3] ,  "[DATA.XLS]Outputs Runs" ,  12 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev WT[5,3] ,  "[DATA.XLS]Outputs Runs" ,  13 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[44,3] ,  "[DATA.XLS]Outputs Runs" ,  14 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[26,3] ,  "[DATA.XLS]Outputs Runs" ,  15 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev WT[6,3] ,  "[DATA.XLS]Outputs Runs" ,  16 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[45,3] ,  "[DATA.XLS]Outputs Runs" ,  17 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[27,3] ,  "[DATA.XLS]Outputs Runs" ,  18 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev WT[7,3] ,  "[DATA.XLS]Outputs Runs" ,  19 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[47,3] ,  "[DATA.XLS]Outputs Runs" ,  20 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[30,3] ,  "[DATA.XLS]Outputs Runs" ,  21 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev WT[10,3] ,  "[DATA.XLS]Outputs Runs" ,  22 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[49,3] ,  "[DATA.XLS]Outputs Runs" ,  23 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean WT[35,3] ,  "[DATA.XLS]Outputs Runs" ,  24 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev WT[15,3] ,  "[DATA.XLS]Outputs Runs" ,  25 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS[21,3] ,  "[DATA.XLS]Outputs Runs" ,  26 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS[1,3] ,  "[DATA.XLS]Outputs Runs" ,  27 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS[22,3] ,  "[DATA.XLS]Outputs Runs" ,  28 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS[2,3] ,  "[DATA.XLS]Outputs Runs" ,  29 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS[23,3] ,  "[DATA.XLS]Outputs Runs" ,  30 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS[3,3] ,  "[DATA.XLS]Outputs Runs" ,  31 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS[25,3] ,  "[DATA.XLS]Outputs Runs" ,  32 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS[5,3] ,  "[DATA.XLS]Outputs Runs" ,  33 ,  5 ,  1 ,  Number of run
```

```
Set in EXCEL    Mean PS[26,3] ,  "[DATA.XLS]Outputs Runs" ,  34 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS[6,3] ,  "[DATA.XLS]Outputs Runs" ,  35 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS[27,3] ,  "[DATA.XLS]Outputs Runs" ,  36 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS[7,3] ,  "[DATA.XLS]Outputs Runs" ,  37 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS[30,3] ,  "[DATA.XLS]Outputs Runs" ,  38 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS[10,3] ,  "[DATA.XLS]Outputs Runs" ,  39 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS[35,3] ,  "[DATA.XLS]Outputs Runs" ,  40 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS[15,3] ,  "[DATA.XLS]Outputs Runs" ,  41 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS surg[21,3] ,  "[DATA.XLS]Outputs Runs" ,  42 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS surg[1,3] ,  "[DATA.XLS]Outputs Runs" ,  43 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS surg[22,3] ,  "[DATA.XLS]Outputs Runs" ,  44 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS surg[2,3] ,  "[DATA.XLS]Outputs Runs" ,  45 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS surg[23,3] ,  "[DATA.XLS]Outputs Runs" ,  46 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS surg[3,3] ,  "[DATA.XLS]Outputs Runs" ,  47 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS surg[25,3] ,  "[DATA.XLS]Outputs Runs" ,  48 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS surg[5,3] ,  "[DATA.XLS]Outputs Runs" ,  49 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS surg[26,3] ,  "[DATA.XLS]Outputs Runs" ,  50 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS surg[6,3] ,  "[DATA.XLS]Outputs Runs" ,  51 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS surg[27,3] ,  "[DATA.XLS]Outputs Runs" ,  52 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS surg[7,3] ,  "[DATA.XLS]Outputs Runs" ,  53 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS surg[30,3] ,  "[DATA.XLS]Outputs Runs" ,  54 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS surg[10,3] ,  "[DATA.XLS]Outputs Runs" ,  55 ,  5 ,  1 ,  Number of run
Set in EXCEL    Mean PS surg[35,3] ,  "[DATA.XLS]Outputs Runs" ,  56 ,  5 ,  1 ,  Number of run
Set in EXCEL    Stdev PS surg[15,3] ,  "[DATA.XLS]Outputs Runs" ,  57 ,  5 ,  1 ,  Number of run
Set in EXCEL    Correlation between WT and PS[21,2] ,  "[DATA.XLS]Outputs Runs" ,  58 ,  5 ,  1 ,
         Number of run
Set in EXCEL    Max priority score by waiting time[21,1] ,  "[DATA.XLS]Outputs Runs" ,  59 ,  4 ,  5 ,
         Number of run+1
Set in EXCEL    Results Summary SS[1,4] ,  "[DATA.XLS]Outputs Runs" ,  64 ,  5 ,  13 ,  Number of run
Set in EXCEL    Sum WTPS SS[1,3] ,  "[DATA.XLS]Outputs Runs" ,  77 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[2,3] ,  "[DATA.XLS]Outputs Runs" ,  80 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[3,3] ,  "[DATA.XLS]Outputs Runs" ,  83 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[5,3] ,  "[DATA.XLS]Outputs Runs" ,  86 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[6,3] ,  "[DATA.XLS]Outputs Runs" ,  89 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[7,3] ,  "[DATA.XLS]Outputs Runs" ,  92 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[17,3] ,  "[DATA.XLS]Outputs Runs" ,  95 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[21,3] ,  "[DATA.XLS]Outputs Runs" ,  98 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[9,3] ,  "[DATA.XLS]Outputs Runs" ,  101 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[10,3] ,  "[DATA.XLS]Outputs Runs" ,  104 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[11,3] ,  "[DATA.XLS]Outputs Runs" ,  107 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[13,3] ,  "[DATA.XLS]Outputs Runs" ,  110 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[14,3] ,  "[DATA.XLS]Outputs Runs" ,  113 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[15,3] ,  "[DATA.XLS]Outputs Runs" ,  116 ,  5 ,  1 ,  Number of run
```

```
Set in EXCEL    Sum WTPS SS[19,3] ,  "[DATA.XLS]Outputs Runs" ,  119 ,  5 ,  1 ,  Number of run
Set in EXCEL    Sum WTPS SS[23,3] ,  "[DATA.XLS]Outputs Runs" ,  122 ,  5 ,  1 ,  Number of run
Set in EXCEL    WT by PS[1,4] ,  "[DATA.XLS]Outputs Runs" ,  125 ,  5 ,  30 ,  Number of run
Set in EXCEL    WT by PS[41,4] ,  "[DATA.XLS]Outputs Runs" ,  155 ,  5 ,  30 ,  Number of run
Set in EXCEL    Percentiles of WT[1,3] ,  "[DATA.XLS]Outputs Runs" ,  185 ,  5 ,  9 ,  Number of run
Set in EXCEL    Percentiles of WT[11,3] ,  "[DATA.XLS]Outputs Runs" ,  194 ,  5 ,  9 ,  Number of run
Set in EXCEL    Percentiles of WT[21,3] ,  "[DATA.XLS]Outputs Runs" ,  203 ,  5 ,  9 ,  Number of run
Set in EXCEL    Mean WT[52,3] ,  "[DATA.XLS]Outputs Runs" ,  212 ,  5 ,  1 ,  Number of run
'Of Months
Set in EXCEL    Number of run ,  "[DATA.XLS]Outputs Months" ,  1 ,  2 ,  1 ,  1
Set in EXCEL    Mean PS through time[22+Number of run,1] ,  "[DATA.XLS]Outputs Months" ,  2 ,  4 ,  1 ,
        Results Collection Period
Set in EXCEL    Mean PS through time[24+Number of run,1] ,  "[DATA.XLS]Outputs Months" ,  3 ,  4 ,  1 ,
        Results Collection Period
Set in EXCEL    Percent second surgeries[2+Number of run,1] ,  "[DATA.XLS]Outputs Months" ,  6 ,  4 ,
        1 ,  Results Collection Period
Set in EXCEL    Mean waiting list contents through time[2+Number of run,1] ,
        "[DATA.XLS]Outputs Months" ,  7 ,  4 ,  2 ,  Results Collection Period
Set in EXCEL    Mean Need 1st contents through time[2+Number of run,1] ,
        "[DATA.XLS]Outputs Months" ,  11 ,  4 ,  2 ,  Results Collection Period
Set in EXCEL    Mean Need 2nd contents through time[2+Number of run,1] ,
        "[DATA.XLS]Outputs Months" ,  15 ,  4 ,  2 ,  Results Collection Period
'The end
Close Results Window
Beep
Display Message    "Data has been transferred to Excel"
```

3.7: Additional menus

VL SECTION: **Initialize Number of run On OK Dialog**

```
SET Number of run  =  0
```