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Model Optimization for Hip Replacement Cost Estimation

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STATUTORY DECLARATION

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Model optimization for hip replacement cost estimation

Like in most European countries, the number of elderly people in Austria is an increasing fraction of the overall population, posing new challenges to the welfare system. To simulate these changes in the Austrian demographic and their consequent effects on the public healthcare system, in particular the costs due to hip replacements, predictive models have been developed at the Institute of Health Care Engineering at Graz University of Technology.

In this work, new optimization strategies have been designed and implemented into existing models. It is shown that the efficiency of a reference baseline model can be increased by a factor of more than 30, which results in a significantly faster simulation. Furthermore, an improved precision of estimates is achieved, and the functionality is enhanced.

Keywords: Hip endoprosthesis, System Dynamics Modeling, costs, computational effort, simulation duration

Modelloptimierung zur Kostenabschätzung im Bereich Hüftendoprothetik

Wie in vielen europäischen Ländern steigt auch in Österreich die Anzahl an Senioren in Relation zur Gesamtbevölkerung an. Diese Entwicklung stellt eine neue Herausforderung für das Sozialsystem dar. Um diese Veränderungen in der Demographie und die mit ihnen verbundenen Auswirkungen auf das öffentliche Gesundheitssystem, insbesondere auf die Kosten in Bezug auf Hüftendoprothesen, zu simulieren, wurden am Institut für Health Care Engineering der Technischen Universität Graz bereits Modelle zur Vorhersage entwickelt.

Im Zuge dieser Arbeit wurden neue Optimierungsansätze gefunden und in die bestehenden Modelle implementiert. Es wird aufgezeigt, dass die Effizienz des Referenzmodels um das dreißigfache erhöht werden kann, wodurch die Dauer einer Simulation wesentlich gesenkt wird. Des Weiteren wird die Prognosegenauigkeit erhöht und der Funktionsumfang erweitert.

Schlüsselwörter: Hüftendoprothetik, System Dynamics Modellierung, Kosten, Rechenaufwand, Simulationsdauer

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List of abbreviations

SD	System Dynamics
AB	Agent-Based
DE	Discrete-Event
Fig.	Figure
AOC	Active Object Class
CSV	Comma-Separated Values
LDF	German: Leistungsbezogene Diagnosen-Fallgruppen
LKF	German:Leistungsorientierte Krankenanstaltenfinanzierung
AC	Activity component
DC	Day component
ICD	International Statistical Classification of Diseases and Related Health Problems
THR	Total hip endoprosthesis
PHR	Partial hip endoprosthesis
GUI	Graphical user interface
CPU	Central processing unit
MeMe	Tribological pairing: metal head / metal inlay
KeKe	Tribological pairing: ceramic head / ceramic inlay
MePoly	Tribological pairing: metal head / polyethylene - inlay
KePoly	Tribological pairing: ceramic head / polyethylene - inlay
cf	confer

1 Introduction

The number of elderly people in Austria is an increasing fraction of the overall population, like in most European countries. Coupled with climbing life expectancy, the effects of this relative and absolute ageing of the population severely impact welfare systems, especially the public healthcare system.

To simulate the changes in Austrian population and related effects on the public healthcare system, in particular the costs due to hip replacement, models have been developed at the Institute of Healthcare Engineering, TU Graz.

This thesis reviews state-of-the-art models and extends, optimizes and updates a baseline model by Herzog [1] in terms of usability, applicability and accuracy.

1.1 Review of existing models

1.1.1 Background

As mentioned above, the Austrian demographic is subject to a change tending towards higher ages. The current fraction of people over the age of 60 is 23 %, and this fraction is expected to increase up to 35% by the year 2060 in Styria as well as the whole of Austria (cf. Fig. 1) [2, 1].

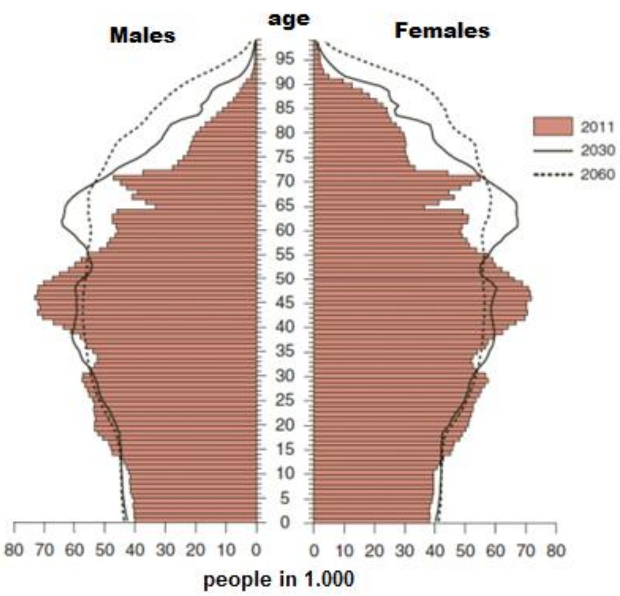

Fig. 1: Age-wise population distribution and forecast for Austria [2]

Hip replacement is a procedure that is highly age-related, as will be pointed out in Section 3.6.1. Two major indications for hip replacement, covering more than 92% of the procedures, are **arthrosis** and **fracture**, the latter mostly occurring at the neck of the femur [1]. In combination with the known demographic trend, this development poses new challenges to the Austrian public health care system.

Two different types of hip replacement procedures are distinguished:

- **Hemiarthroplasty**
  Hemiarthroplasty mainly refers to replacing the femoral head, while retaining the acetabular cup in its original state (partial hip endoprosthesis). This procedure is mainly prescribed after fracture of the femur neck where the acetabular cup is undamaged (cf. Fig. 7 of Section 3.6.1).
- **Total hip arthroplasty**
  In the case of total hip arthroplasty both parts of the joint, the acetabular cup and the femoral head, are replaced (total hip endoprosthesis). This procedure is mainly prescribed for patients suffering from arthrosis (cf. Fig. 6 of Section 3.6.1).

An important factor that determines the lifetime of hip endoprostheses is the material the implant is made of. The femoral head and the inlay of the acetabular cup constantly rub against each other when the patient moves, and these two materials these parts are made of are referred to as **tribological pairing**. The degradation of the tribological pairing and the aseptic prosthesis loosening caused by inflammatory processes are enhanced by the presence of rubbed-off particles [1, 3]. The following common tribological pairings were integrated in the baseline model [1, 4, 5, 6]:

- metal head / metal inlay (MeMe)
- metal head / ultra-high molecular weight polyethylene - inlay (MePoly)
- ceramic head / ceramic inlay (KeKe)
- ceramic head / ultra-high molecular weight polyethylene - inlay (KePoly)

Another important parameter is the type of fixation of the implant, for which two different options exist in the baseline model [1]. The prosthesis can either be anchored using bone cement, a polymethylmethacrylate based substance that fills the space between the bone and the implant, or be attached without cement, using special rough surfaces that enhance the natural osteointegration [1, 7, 8].

The latter method is preferably used for younger patients, as it conserves most of the surrounding bone and therefore allows re-implantation if needed in future. On the other hand side cementless fixation has less durability in comparison to cemented fixation [1, 8, 9, 4].

1.1.2 Working principle

The flowchart presented in Fig. 2 provides an overview about the operating principle of the baseline model. The model consists of several modules. The first module simulates the population development in Styria, based on demographic indicators including fertility, mortality, immigration and emigration. Based on this population data, the number of implantations per year is calculated using implantation statistics from 1996 to 2008. Subsequently, the number of people with implants is determined in a second step, where the rate of revisions, depending on the type of fixation and the tribological pairing, can be taken into account. For further description of the working principle the reader may refer to [1].

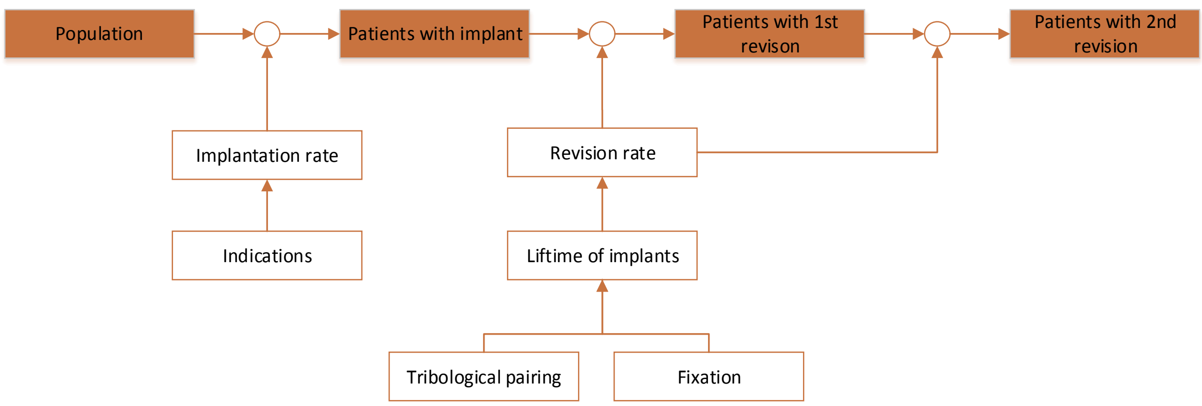

Fig. 2: Flow chart of the baseline model

1.2 Basics of modeling and simulation modeling

Modeling offers an opportunity to solve real world problems in cases where satisfactory experimental solutions are not possible. Since the entire complexity of the real world cannot be incorporated into the model, some simplifications must be made in the model building process. By disregarding (sufficiently) irrelevant aspects one can find a simplified but adequate representation of a problem as a model that can be solved with acceptable computational effort and contribute to understanding the solution in the real world [10]. The process of problem-solving by modeling is illustrated in Fig. 3.

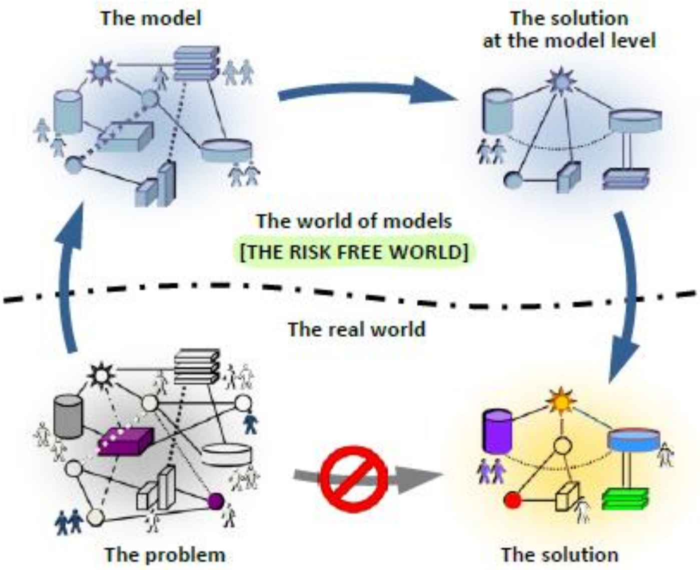

Fig. 3: The process of problem solving through modeling [11]

In contrast to analytical modeling, where only static relations between variables are permitted, simulation modeling allows for dynamic relations and behavior. Three main methods of simulation modeling can be distinguished [10] and are described in the following sections:

- System dynamics modeling (SD)
- Agent-based modeling (AB)
- Discrete event modeling (DE)

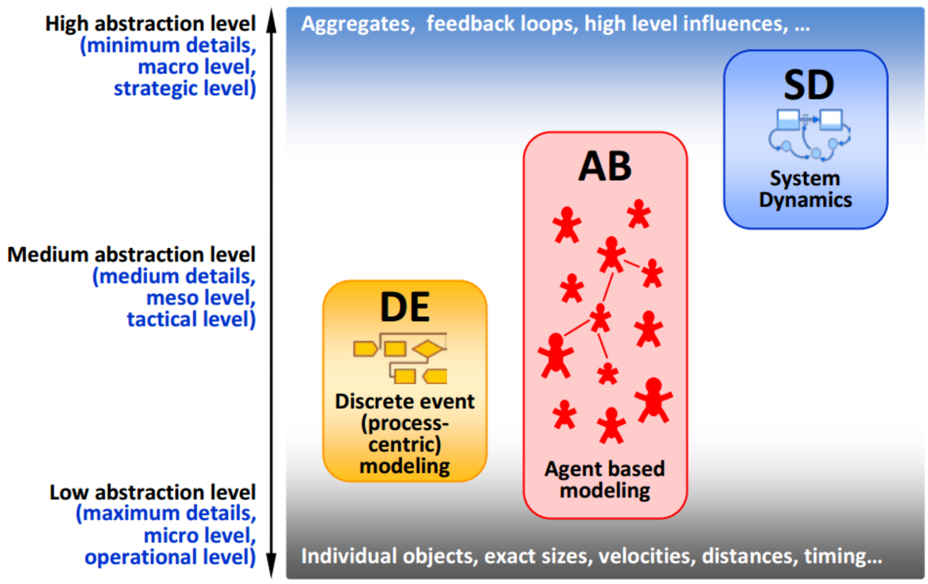

Fig. 4: Overview over the three major modeling methods and their abstraction levels [10]

Omissions and simplifications in the model building process lead to (and require) a certain degree of abstraction. Fig. 4 shows the three main methods of simulation modeling supported by Anylogic® (XJ Technologies Company; St. Petersburg, Russia) as well as their corresponding abstraction level.

1.2.1 System dynamics modeling

The **system dynamics** approach was developed in the 1950s and can be described as follows [10], cited from [12]:

> *"System dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System dynamics is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations."*

System dynamics models typically consist of stock and flow variables that build feedback loops. The latter define the change of the stocks over time, where the stock variables represent accumulations and characterize system states [1].

For example, the number of people (in a population) with hip endoprosthesis is a stock variable whereas the amount of hip replacement surgeries per year is a flow variable.

1.2.2 Agent-based modeling

Agent-based modeling is based on knowing (or being able to simulate) the behavior of single objects in a defined environment. The overall model behavior then results from the interaction of these objects, also referred to as agents, with each other or the environment. The agent-environment interaction usually is a function of time. The agent behavior itself may be defined by simple rules in state-charts or using internal models. Internal models normally benefit from the system dynamics approach as well as the discrete event modeling. A drawback of agent-based models is their higher demand with respect to CPU power and memory [10].

For the hip endoprosthesis model, a possible agent-based approach would be to model every patient that undergoes hip replacement surgery as a single agent, with an internal logic that lets the patient/agent age every year and finally die, based on a life-expectancy model.

From this example one may observe that agents do not necessarily have to interact, as one person with hip replacement does not affect another person with hip replacement. However it should be noted that there is no need to limit agents to physical people. Nearly everything can be an agent, even a completely passive object, as long as the internal logic can be described [10].

1.2.3 Discrete event modeling

As cited from [10],

> *"The idea of discrete event modeling method is this: the modeler is suggested to think about the system being modeled as of a process, i.e. a sequence of operations being performed over entities."*

An entity can for instance be a patient whereas the operation can for example be a hip replacement surgery. Similar to agent-based modeling the entities are not limited to be physical entities, but can also be products, tasks, events or similar.

Discrete event models are typically represented in a process flowchart. These models usually start with a 'source' generating entities and end with a 'sink' removing them. As resources performing operations (e.g. doctors) may be limited, entities will start to queue.

Discrete event models are usually stochastic since entity creation and times for operations are normally stochastic. Therefore several simulation runs need to be carried out to obtain useful output [10].

1.3 The LKF-System

In 1997 the **LKF-System** (German: Leistungsorientierte Krankenanstaltenfinanzierung) was introduced for merit-based funding of healthcare providers in the Austrian public healthcare system. Previous payment/reimbursement systems had mainly been based on the duration of a patient's stay in a specific facility. The reformed funding system became necessary when the required durations of hospitalization decreased rapidly due to advances in treatment. As a consequence of this decrease, the former system no longer reflected the real costs, or would instead incentivize long hospitalizations. The LKF-system now enables diagnosis-related billing based on the International Statistical Classification of Diseases and Related Health Problems (ICD) or alternatively a special checklist issued by the Austrian Ministry of Health [13].

The new system is additionally meant to encourage standardized documentation in all participating hospitals and therefore also to provide important data for decision-making and controlling in the Austrian public healthcare system. [13]

The billing is based on the LDF-allowance (German: Leistungsbezogene Diagnosen-Fallgruppen), signifying so-called treatment-related diagnosis groups. The Austrian Federal Ministry of Health determines the LDF-allowance based on detailed investigations in selectively chosen 'reference hospitals'. Patients in these hospitals were grouped according to the treatment they received and their diagnosis. This led to the definition of 998 LDF groups. The applicable LDF-allowance was then calculated as the median of the costs per patient for every specific group, where the allowance itself consists of two parts. The first part represents the specific procedure itself, while the second part represents the costs due to care. The parts are referred to as 'Activity Component' and 'Day Component', respectively [13, 14].

The system also defines limits for the duration of hospitalization. If the patient leaves hospital earlier than defined by the lower boundary, the LDF allowance is calculated as follows [13, 14]:

$$points/case = AC + \frac{DC \times (X+1)}{(BDUG+1)} \qquad (1)$$

AC: activity component
DC: day component
BDUG: lower border for duration of stay
X: duration of stay

In contrast, if the duration of stay exceeds the upper boundary defined by the system, a declining top-up is billed per day. This top-up (T_u) is determined as follows, but never gets smaller than half of the applicable day-component [13, 14]:

$$T_u(X) = \frac{DC \times BDOG}{X} \qquad (2)$$

DC: daily component
BDOG: upper border for duration of stay
X: duration of stay

Finally, the LDF-points as calculated above are converted to cost. Fig. 5 shows an example for the billed LDF-points as a function of the duration of hospitalization for a total hip arthroplasty. In this example, the daily component equals 3514 points and the activity component equals 3642 points. The boundaries for the duration of stay are 3 and 17 days, while the mean duration of stay is 11.6 days. Therefore the top-up never decreases below 151 points per day [14]. Therefore it can be seen from Fig. 5 that on the right hand side the line starts to continue with a linear trend.

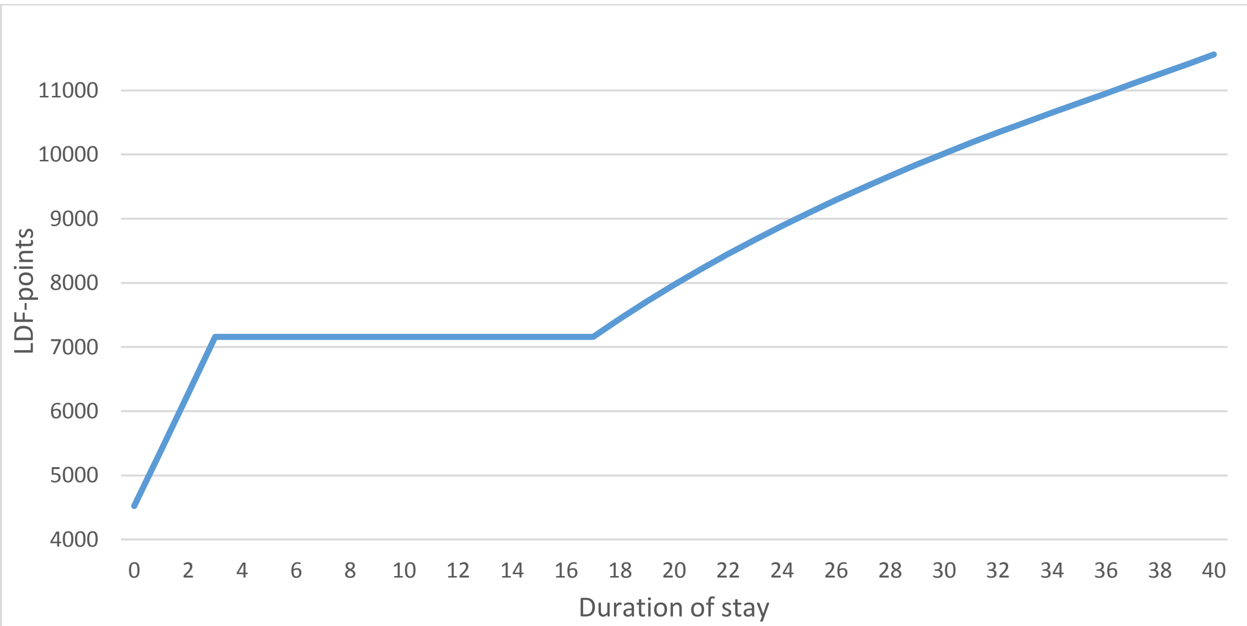

Fig. 5: Example for LDF-allowance depending on the duration of stay.

1.4 Thesis outline

This thesis is organized as follows. Chapter 2 describes the research goals and requirements. Chapter 3 points out the applied methods, including the choice of the simulation environment and modeling method, data retrieval and analysis, as well as the modifications and enhancements that have been integrated into the model. Chapter 4 gives results for a basic scenario, compares them to the baseline model, and points out the improvement in efficiency. These results are subsequently discussed in Chapter 5. Finally, Chapter 6 summarizes the conclusions of this study and further work that remains to be done.

2 Goals

The goal of this thesis work is to develop a model for estimating the costs that need to be covered by the Austrian public healthcare system due to hip replacement procedures. In detail this involves the following primary goals:

- Review of existing models for resource modeling of replacement procedures, in particular previous work at the Institute of Healthcare Engineering, TU Graz
- Choice of modeling system and software
- Implementation of the modeling system
- Review of present GUI (Graphical User Interface) and enhancements, if applicable
- Testing and development process validation
- Discussion and comparison to existing models

In terms of the model itself, the following requirements shall be met:

- During modeling, clinical data that has become available over the last years shall be considered
- Provision for special input parameters shall be made such as a limit to the benefit for certain groups of people (E.g. to give only 'low cost' prostheses to people over a certain age.).
- A dynamic simulation of population development shall be possible.

In parallel to this work, a model for cost estimation in the area of knee endoprostheses is currently being developed by A. Bleckenweger [15]. Throughout this work, it should be noted that some advantages can be gained by the possibility to fuse these two models.

3 Methods

3.1 Choice of simulation environment

The basic relations within the model are based on a baseline model [1], as mentioned in Chapter 1. This model was created using the **AnyLogic®** (XJ Technologies Company; St. Petersburg, Russia) version 6.1 programming environment. The overall performance of this model was found to be poor, and improvements were desired in its efficiency.

Additionally, major changes to the underlying software during the upgrade to AnyLogic® version 6.9 had rendered this model unusable without substantial modification. A model therefore needed to be developed that is compatible to the latest and future versions ad releases of AnyLogic®.

3.2 Simulation software

AnyLogic® 6.9 University License (XJ Technologies Company; St. Petersburg, Russia) was used to develop the presented model. AnyLogic® is an Eclipse-based (Eclipse Foundation, Inc.; Ottawa; Canada) programming and simulation environment, which supports most common modeling methods and their combinations. AnyLogic® provides a graphical user interface (GUI) for simple model creation. Pre-built blocks can be easily inserted by dragging and dropping, and AnyLogic® generates Java code according to the inserted blocks and their links. The user may also insert self-created Java code if desired.

3.3 Reference system

In order to obtain comparable results when testing the performance of different models, a reference system with the following specifications was used:

- **Operating system:** 64-bit Windows 7 Professional N Service Pack 1 (Microsoft Cooperation; Redmond; USA)
- **Central Processing Unit:** 3 GHz AMD Phenom ™ II X4 940 (AMD Microdevices Inc.; Sunnyvale; USA)
- **Random Access Memory:** 4 GB /1000 MHz (G.SKILL International Enterprise Co.; Taipei City, Taiwan)
- **Java:** 32-bit version 7 Update 25 (Oracle Corporation; Redwood Shores; USA)

- **AnyLogic®:** 64-bit Version 6.9 University License (XJ Technologies Company; St. Petersburg, Russia)

3.4 Modeling method

An improved modeling approach has been evaluated and implemented in order to increase the efficiency of the baseline model. All modeling methods described in Section 1.2 have their advantages and disadvantages. The following paragraphs will briefly discuss these, and explain the rationale behind the chosen modeling method.

Discrete event modeling

The main drawback of discrete event models is that a single entity cannot be traced during model run. Since system dynamics models, like the baseline model, also suffer from this shortcoming this would not be a knockout criterion. But since in a discrete event model there is no possibility to let an entity directly undergo the process of ageing, a model consisting of people (entities) raging up to the age of 95 would need at least 95 delay segments to represent the age of the persons. Additionally, the endoprosthesis also ages (up to 30 years), starting from the moment of implantation. This would add a second 'axis' to the model resulting in an array of approximately 95x30 delay elements.

To build a model with more than 2850 elements is considered unfeasible for performance reasons, and the effort to build this model would be of no reasonable relation to the advantages.

Agent-based modeling

The baseline model suffers from not being able to track a single patient through the treatment process. Therefore it cannot be evaluated if a patient undergoes his first implantation procedure or already has one prosthesis and receives another one for his other hip. As the ability of an agent-based model to track individuals is considered as the main advantage, several options of agent-based models were evaluated.

Since it was clear that a model consisting of 8 million agents, representing the whole population of Austria, would cause too much computational effort, several concepts of grouping patients with the same properties were developed.

- Option 1: Grouping people with same age

The main advantage of this option would be that ageing can be implemented very easily since it involves only changing one value within the agent. But since this option would mix males and females, as well as different fixation types and tribological pairings, a complex inner logic would be needed to calculate the number of revisions.

Considering that the youngest patients receiving hip replacement are about 35 years old, a period of 60 years has to be covered by the model. Also considering a prediction timespan of at least 40 years this would result in 2400 agents.

- Option 2: Grouping people with same age, sex, and prosthesis type

This option would result in the number of agents being increased to 48000 as there are five different types of prosthesis, two types of fixations and separate implementation for men and women.

- Option 3: One agent per year of simulation

This option would need a significantly lower number of agents, but requires an even more complex inner logic compared to Option 1. An inner logic that is very similar to a complete population model would be needed to take care of the ageing process of the people. Ageing of the implant can be implemented very easily as the year of implantation is known.

All options presented above share the drawback that in case of revision patients have to be transferred to another agent, which requires additional programming and computational effort.

To evaluate these options several test models have been built. Firstly the number of agents that can be simulated at reasonable computational effort has been determined by building a model consisting of agents that carry out a simple mathematical task (e.g. an addition and multiplication). Using the reference system described in Section 3.3 it was found to be unfeasible to simulate more than 10000 agents. As the complexity of the inner logic required for Option 1 is estimated to be four times higher than the one for the test model, Options 1 and 2 were discarded.

A test model for Option 3 that consisted of agents containing the population model [16] was also found to have very poor performance.

System dynamics

The baseline model was based on the system dynamics approach because the population model also was based on system dynamics [1]. In general the system dynamics method was found to be very efficient for this kind of problem, as the number of patients is a stock variable, and implantations and revisions are flow variables. Therefore the system dynamic approach was found to be the most suitable for the presented model, although the difficulties in combining the system dynamics population model with an implantation model that uses a different simulation method pointed out by [1] as a decisive reason have not been verified while creating the test systems for agent based modeling.

Besides the clear applicability of the system dynamics approach through the variables, a practical reason to continue with this modeling method was that arrays could be accessed easily by self-created Java code as well as by built-in AnyLogic® functions.

3.5 Data retrieval

There now exists an endoprostheses register in Austria that consists of data starting from the year 2008 and covers approximately 15% of the hip replacement procedures performed in Austria [17]. However, this data was not available at the time of creation of the baseline model [1], and currently has restricted availability. Since this data was not at disposal, the data for the creation of the improved model was therefore again obtained from the Swedish [9] and Australian [18] endoprostheses registers, which are publicly accessible. From these registers data on the lifetime and revision rate of hip endoprostheses made from different materials, and the revision rate for different fixations have been obtained. Furthermore the share of different materials for the tribological pairings has been filtered out.

Data for the determination of the implantation rate has been obtained from the Statistics Austria StatCube database [2]. The following queries were carried out:

<u>Number of hip replacement procedures</u>

- Region: Austria
- Year: 2002-2012 in 1-year divisions
- Age: up to 95 years in 1-year divisions
- Sex: male/female

- Medical procedure:
    - <4252> Hemiarthroplasty
    - <4262> Total hip arthroplasty
    - <NE080> Hemiarthroplasty
    - <NE120> Total hip arthroplasty
- ICD-10 Codes:
    - Arthrosis: M16-M19
    - Fracture of the hip: S70-S71

Duration of stay in hospital

- Region: Austria
- Year: 2002-2011
- Age: up to 95 years in 1-year divisions
- Sex: m/f
- Medical procedure:
    - <4252> Hemiarthroplasty and
    - <4262> Total hip arthroplasty
    - <NE080> Hemiarthroplasty and
    - <NE120> Total hip arthroplasty
- Care sector: acute
- Duration of stay:
    - Up to 40 days in daily divisions
    - Up to 20 weeks in weekly divisions

Population

- Region:
    - Austria
    - Styria
- Year: 2002-2011
- Age: up to 95 years in 1-year divisions
- Sex: male/female

<u>Number of hip replacement procedures distinguished by type of fixation</u>

- Region: Austria
- Year: 1997-2000 in 1-year divisions
- Age: up to 95 years in 5-year divisions
- Sex: male/female
- Medical procedure:
    - <4266> Hemiarthroplasty with cemented fixation
    - <4261> Total hip arthroplasty with cemented fixation
    - <4251> Hemiarthroplasty with cementless fixation
    - <4246> Total hip arthroplasty with cementless fixation
- ICD-10 Codes:
    - Arthrosis: M16-M19
    - Fracture of the hip: S70-S71

3.6 Data analysis

3.6.1 Implantation rate

Data provided by Statistics Austria (cf. Section 3.5 for retrieval procedure) have been used to calculate the implantation rate. For comparison purposes, this has been carried out as outlined in [1]; for every age, the total number of implantations per year and per indication was divided by the number of people at risk. This age-dissected, risk-weighted implantation number was determined with a one-year time resolution for the period 2002-2011. The arithmetic mean over this period (I_{mean}) is input into the model

$$I_{mean} = \frac{1}{10} \sum_{year=2002}^{2011} \frac{Implantations_{\,(age,\ sex,\ indication,\ year)}}{Population_{\,(age,\ sex,\ year)}} \qquad (3)$$

Although there is more historic data available from Statistics Austria ranging further back in time than 2002 [2], the averaging period had to be limited to ten years, as longer periods would cause a possible increase in the implementation rate over the past years to vanish. On the other hand the averaging period cannot be chosen to short as this would make the result prone to outliers.

In addition to this 10-year average implementation rate, 10-year minimum (I_{min}) and maximum (I_{max}) trends have been implemented by using the minimum and maximum values respectively for the implantation rate that occurred through the observed 10-year period. For this calculation the implantation rate has been determined as explained above, but with 5-year dissection of the age, as a single-year dissection would make the result prone to outliers again.

$$I_{\min(n,\ indication,\ sex,)} = \min\left(\frac{\sum_{5(n-1)}^{5n-1} Implantations_{(age,\ indication,\ sex,\ year)}}{\sum_{5(n-1)}^{5n-1} Population_{(age,\ sex,\ year)}}\right) \quad (4)$$

$$I_{\max(n,\ indication,\ sex,)} = \max\left(\frac{\sum_{5(n-1)}^{5n-1} Implantations_{(age,\ indication,\ sex,\ year)}}{\sum_{5(n-1)}^{5n-1} Population_{(age,\ sex,\ year)}}\right) \quad (5)$$

n….Index for age groups (e.g. n=1… age 0 to 4)

Fig. 6 and Fig. 7 show the 10-year average implantation rates (2002-2011) related to the age of the patient. Since Fig. 8 shows a clear difference between males and females in the rate of total hip endoprostheses, all values were considered for males and females separately. In contrast the difference concerning partial hip endoprostheses is very small. This might be due to the fact that women are more likely to suffer from arthrosis and other bone-degrading diseases at advanced ages.

Implantation rates for arthrosis decrease for people aged over 75, whereas rates for the fracture of the hip still increase. This might be due to occurring comorbidities contraindications, as arthrosis is slowly progressing, implantation can be omitted. In contrast there is no other admissible option than to treat fracture of the femur neck immediately. Since elderly people are more likely to fall down, implantation rates increase with age.

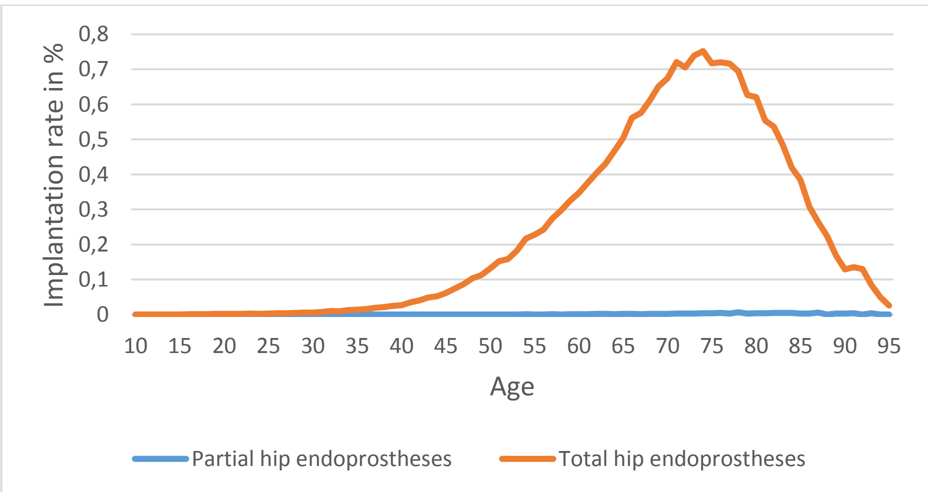

Fig. 6: 10-year average implantation rate per year, indicated by arthrosis for males and females combined

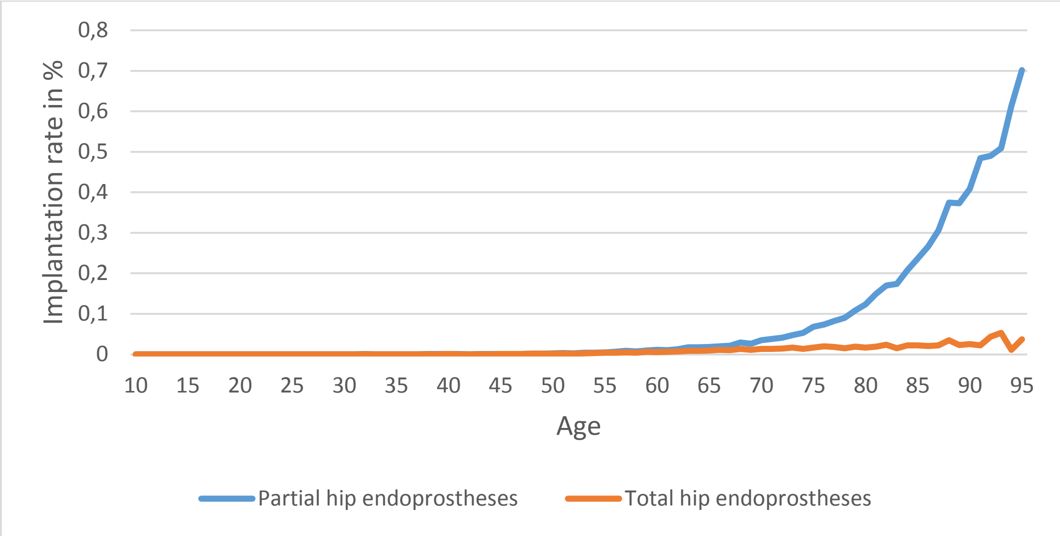

Fig. 7: 10-year average implantation rate per year, indicated by hip fracture for males and females combined

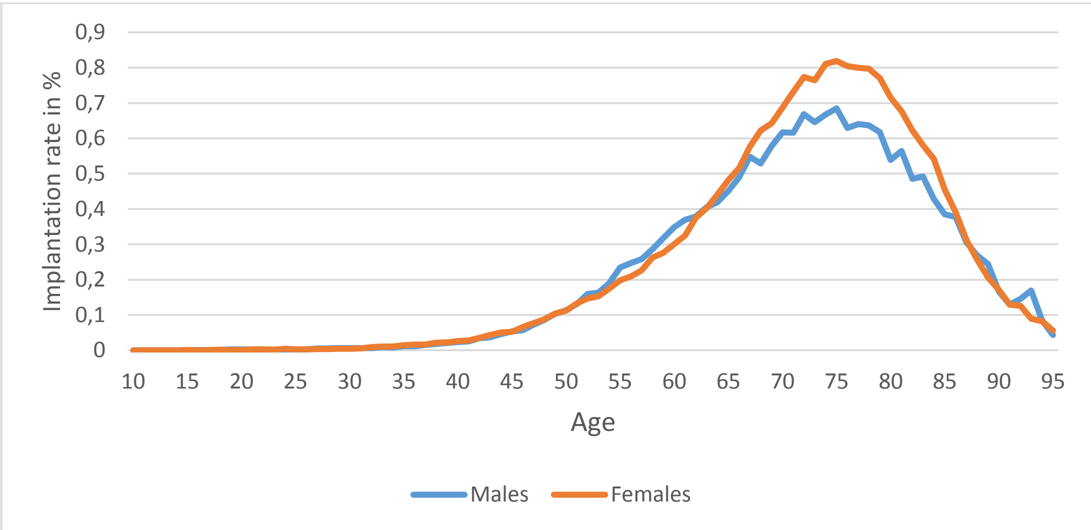

Fig. 8: 10-year average implantation rate per year, for total hip endoprostheses, comparison between males and females

3.6.2 Revision rate

Statistics Austria provides data on the number of reoperations and revisions performed in Austria. Since the total number of patients with hip implants is unknown due to lack of data in the Austrian prostheses register (cf. Section 3.5), no reliable revision rate can be derived from this data.

Data has therefore been obtained from the Australian [18] and Swedish [9] hip endoprostheses registers. From the Australian register, the most recent dataset has been retrieved. In the Swedish register, the methodology of reporting was changed in 2009 to only give values for the ten-year outcome (i.e. if there has been a hip revision surgery within ten years after the original implantation). As the average lifetime of prostheses is likely to be more than 15 years [1], data from 2009 have been used because they report on a timespan of up to 30 years after original implantation. Further to obtaining the raw revision rate, the Australian register [18] data has been used to calculate an age dependent factor of the change in revison rate (cf. Section 3.7.4).

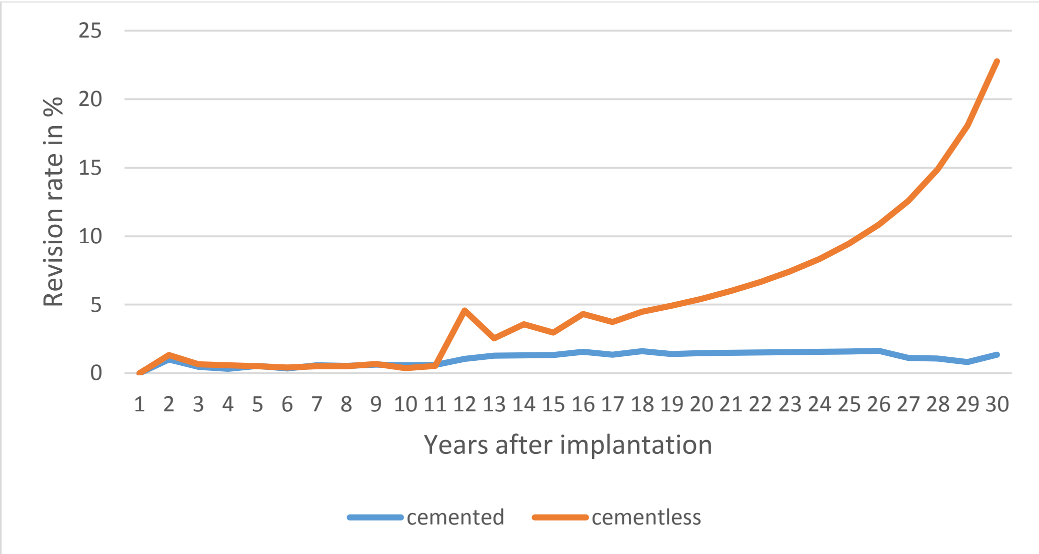

Fig. 9: Revision rates for cemented and cement-less fixation depending on the years since implantation

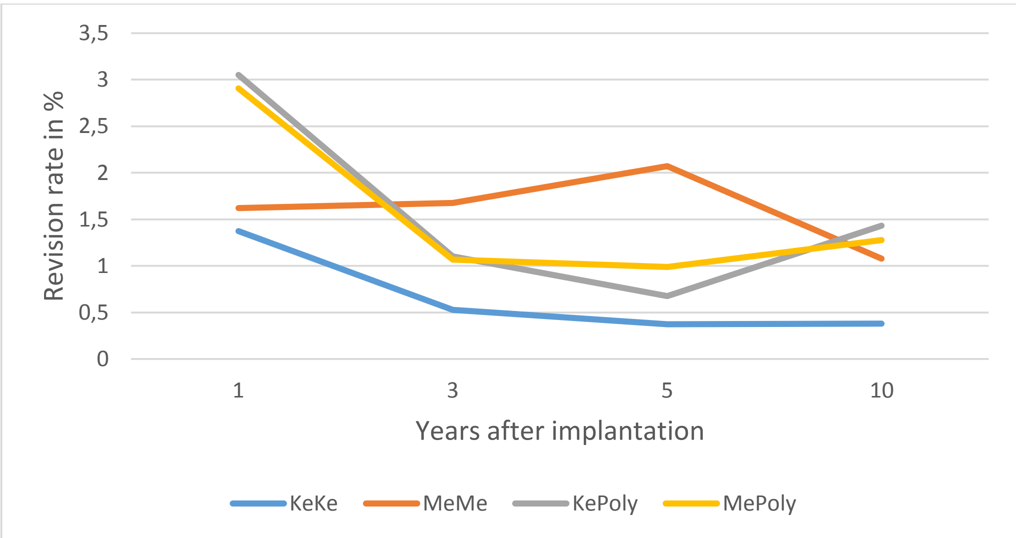

Fig. 10: Revision rates for different tribological pairings as a function of years since implantation

Fig. 9 and Fig. 10 illustrate the revision rates implemented in the model. As expected cemented fixation techniques show longer durability than implants fixed in a cement-less way. The sudden increase after ten years is due to the fact that the documentation in [9] was restarted ten years ago to obtain more recent data, as lifetime of prostheses might have increased due to engineering progress. It can also be observed that KeKe (ceramic head/ceramic inlay) implants have a longer lifetime (lower revision rate) than other tribological pairings. MeMe (metal head/metal inlay) implants do not match the trend in Fig. 10, but are less important than the other pairs since they are hardly used anymore (<1% of the total implantations [9]). The higher rates during the first two years might be due to poorly performed implantation procedures.

The model calculates the revision rate for every combination of implant and type of tribological pairing by building their respective arithmetic means.

3.7 Improvements of the model

So far the basic data analysis has been discussed. This straightforward analysis was carried out in a similar way to [1]. The main difference is that instead of grouping the people by age into 20 groups (e.g. 40-44 years old) a one-year dissection was used if appropriate data was available. More recent data has been used if available.

3.7.1 Distribution of tribological pairings

Tribological pairings on primary implantation are now distributed according to statistical data instead of being equally distributed. Moreover the graphical user interface allows to define a custom distribution with a 5-year age dissection. In this way also a scenario that only gives low-cost prostheses to people above a certain age can be built.

Table 1: Percentage of tribological parings on primary implantation [9]

Tribological pairing	Fraction
MeMe	1%
MePoly	85%
KeKe	1%
KePoly	13%

3.7.2 Type of fixation

The preexisting model did not contain any data distinguishing the type of fixation. As Statistics Austria does not discern the type of fixation anymore, historic data from the years 1997 to 2000 has been used to determine the fraction of the different fixation types. This is done by dividing the number of cement-less fixed prostheses by the total number of implanted prostheses for a specific age group. Table 2 shows the determined values. Due to the lack of more recent data it was assumed that these fractions did not change over the last years.

Table 2: Fraction of cement-less fixed implants (THR: total hip replacement, PHR: partial hip replacement)

Age	THR	PHR
0 - 39	97.73%	84.00%
40 - 44	97.85%	47.06%
45 - 49	98.41%	50.00%
50 - 54	97.65%	57.14%
55 - 59	97.98%	46.81%
60 - 64	96.90%	39.71%
65 - 69	95.00%	38.71%
70 - 74	91.68%	34.22%
75 - 79	88.21%	34.13%
80 - 84	82.27%	32.41%
85 - 89	72.36%	32.60%
90 - 94	62.24%	32.03%
95+	56.67%	32.71%

3.7.3 Type change on revision

In the baseline model [1] a patient undergoing revision operation will be supplied with the same type of prosthesis again, as well as the same fixation method. This fact was found to be a major shortcoming, because in reality the type of new prosthesis and fixation method is chosen based on medical indications. As can be seen in Table 2, older patients are more likely to get cemented fixation, as regeneration might be faster due to the fact that there is no need to wait for natural osteointegration. In contrast younger patients are mostly provided with cement-less fixation methods as this procedure preserves most of the remaining bone [8, 1]. This becomes important if the patient has to undergo revision procedure as there will be enough bone left for another implant.

For this reason a possibility to simulate the change on revision, for the type of prosthesis, the tribological pairing and the fixation method, has been implemented in the model. To start with, the total number of patients that need revision is determined. These patients are then distributed according to the age-dependent setting that also applies to primary implantation. However one has to take into account certain limitations for this process. Firstly, a change from cemented to cementless fixation is impossible, as there will hardly be enough bone left for the latter method. Secondly, after total hip arthroplasty there is no more possibility to perform hemiarthroplasty. Fig. 11 shows a flow chart for the change of prosthesis type on revision.

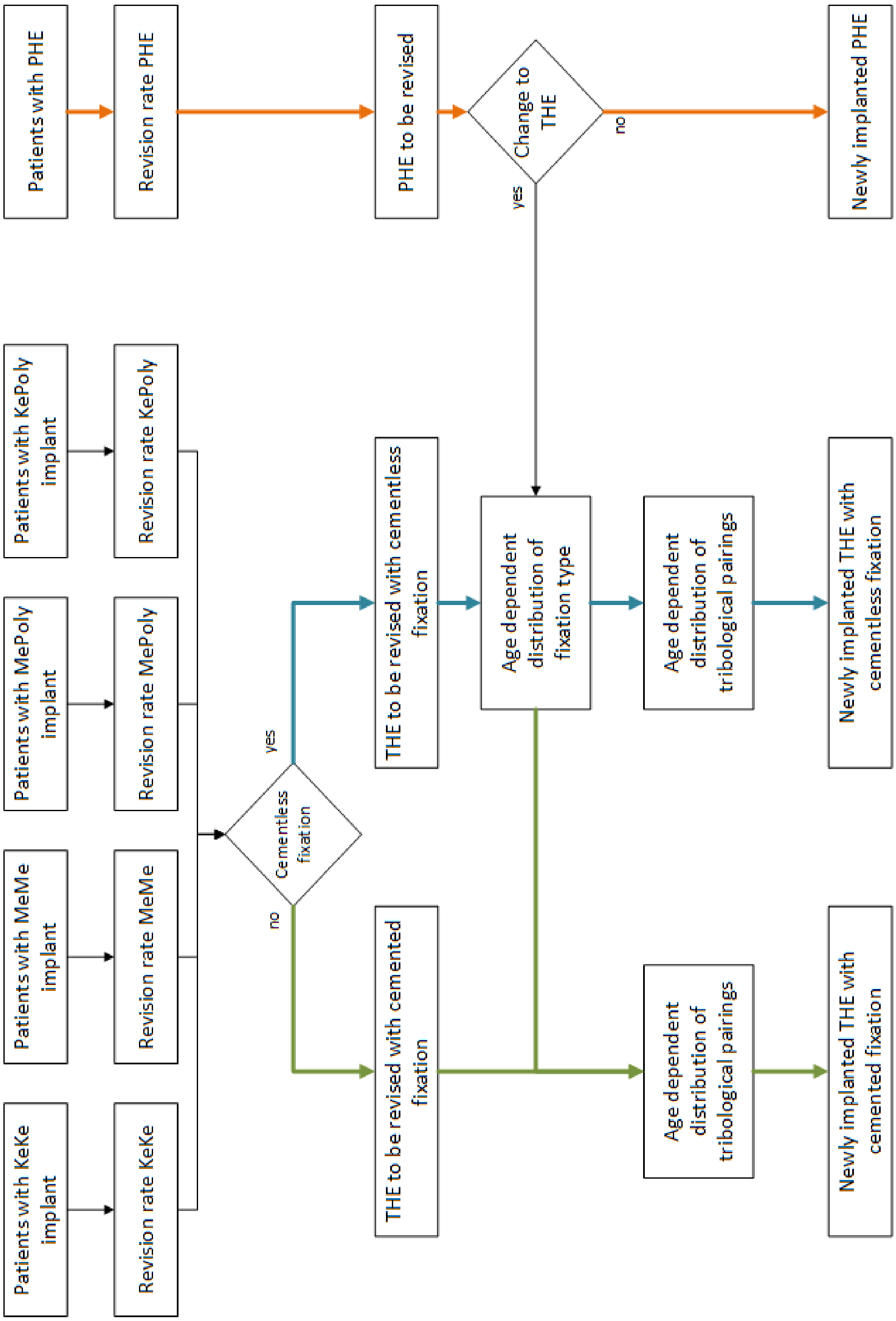

Fig. 11: Flow chart for change of prosthesis type on revision. Orange lines indicate partial hip endoprostheses (PHR), green lines indicate total hip endoprostheses (THR) with cemented fixation, while blue lines indicate THR with cement-less fixation.

3.7.4 Dynamic calculation of the revision rate

The method of determining the initial values for the revision rate has been explained in Section 3.6.2. The possibilities for the user to modify these values at runtime have been extended.

The baseline model [1] includes a parameter called 'Engineering Progress', which should represent the extension of the implants lifetime due to newly discovered technologies. During code analysis it was found that the way this parameter was integrated does not match its intended function, as it affects all implants regardless of the year of implantation. Once implanted a prosthesis can no longer benefit from engineering progress, and therefore its lifetime must not be affected by this progress anymore.

For this reason a function performing a stepwise update of the revision rate has been implemented in the presented model. In this way only patients, who received their implant after the engineering progress has been made, are affected. Moreover this parameter can now be set separately for the type of fixation and the tribological pairing.

A new parameter to cut the benefit for the insurant has been introduced. This parameter delays the revision for a period of time specified by the user. In addition the Body Mass Index can now be set separately for males and females.

An age-dependent factor was derived from the Australian prostheses register [18] data, as abrasion is related to the degree of activity of the patient. As activity is likely to be lower in older patients, the revision rate is also slightly lower, as shown in Table 3.

Table 3: Age dependency factor for the revision rate (1 = no change due to age)

Age	Males	Females
40 - 54	1.00657058	1.01846907
55 - 64	1.00207715	1.00591900
65 - 74	0.98902077	0.98971963
>75	0.9998587	0.98976413

3.7.5 Cost sharing

The options for cost sharing have been increased. Now it is possible to define progressive cost sharing models containing up to three steps that specify different amounts to be paid depending on the age of the patient. The user has the possibility to specify a total amount or a percentage of the total costs with upper and lower limits.

Cost sharing discount for the socially-disadvantaged

Austrian public healthcare system provides at least basic service to every person, regardless of his/her financial situation. Since the model contains cost sharing elements as explained above, one also must take into account that not every person is capable of paying these fees. Therefore, in the optimized model, the percentage of non-paying people can be specified by the user (cf. Fig. 12), and discounts ranging from 25% to 75% can be applied.

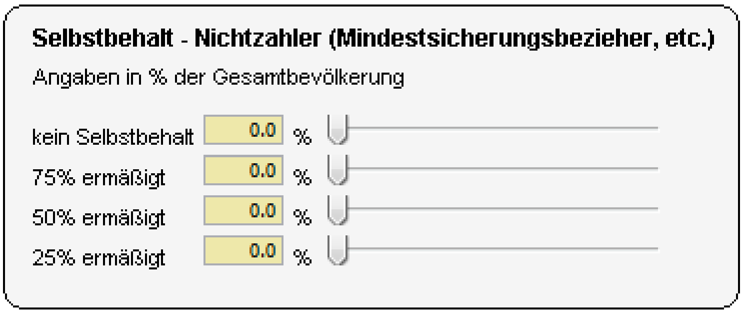

Fig. 12: GUI to set discounts for the socially-disadvantaged

3.7.6 Cost sharing for risk groups

The idea of cost sharing for risk groups has been introduced in [1]. However, the calculation of the used coefficients has not been documented adequately in the implementation. Because patients from both indications, arthrosis and fracture, are affected by these coefficients, the original idea of cost sharing for people who have higher risk due to performing dangerous sports might not be addressed.

In the improved model, the relative fraction of sports accidents within the total number of accidents resulting in the fracture of the femur has been calculated, based on values obtained from [19]. The values integrated into the model are shown in Fig. 13. A decrease for elderly people can justified by the lower likelihood of elderly persons performing high-risk sport activities, as well the increase in accidents occurring at home.

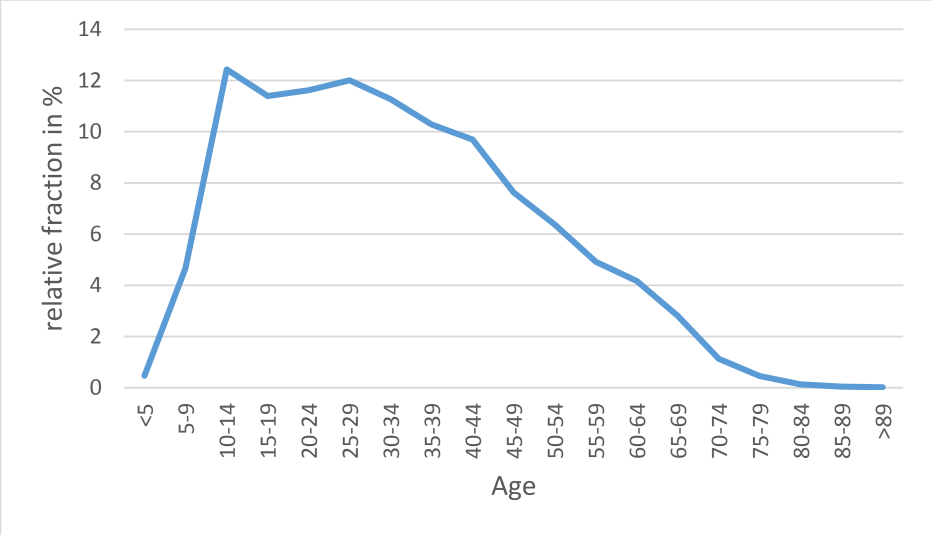

Fig. 13: Relative fraction of sports accidents related to the total accidents resulting in femur fracture.

The values obtained in this way now represent only the fraction of sports accidents based on the total number of accidents and therefore are only multiplied with the number of implants due to hip fracture. This contrasts with the baseline model which multiplied the total number of implantations with a parameter for cost sharing.

3.7.7 Cost increase

The baseline model [1] integrated a parameter that defines the percentage of costs due to staff, to be able to simulate cost increases in this area. It was assumed by [1] that the costs due to staff equal 40% of the total costs. A second hardcoded parameter (60%) equals the fraction of costs that are not due to staff. The result is obtained by multiplying with the factor built of these two parameters. If no cost change is specified by the user, the sum of the parameters is 100% and the final result does not change. If the user prompts a different value for the staff costs, for example 50%, the sum equals 110% and the final result changes accordingly.

In the new model this section of the program has been modified in a way that allows it to simulate any change of costs. In addition to yearly inflation the user can specify a percentage for cost change. There is no longer any need for the cost change to be related to staff.

3.7.8 Cost adjustment due to the duration of stay

The calculation of the costs due to arthroplasty was found to be a major shortcoming in the baseline model. As explained in Section 1.3, billing in the Austrian public healthcare system is based on the LKF-system that involves cutting or top-up due to the duration of stay in hospital.

Since the baseline model [1] did not retrieve any data for the duration of stay in hospital, the billed amount of LKF points was mainly influenced by a user-specified parameter representing the average period of stay in hospital. On the one hand the assumption that this data follows normal distribution may not be valid, which would make the use of arithmetic mean incorrect. On the other hand, even if the assumption of normal distribution holds, the LDF points will not be awarded properly as their trend is not linear (cf. Fig. 5). For this reason the patients on one side of the bell-shaped Gaussian curve do not outweigh their symmetric counterparts on the other side.

Fig. 14 shows the main problem of the application of mean values for the duration of stay. In case A for all patients the standardized LDF-allowance would be billed, whereas in case B for every patient a top-up would apply. It is clear that neither the former nor the latter case occur in reality.

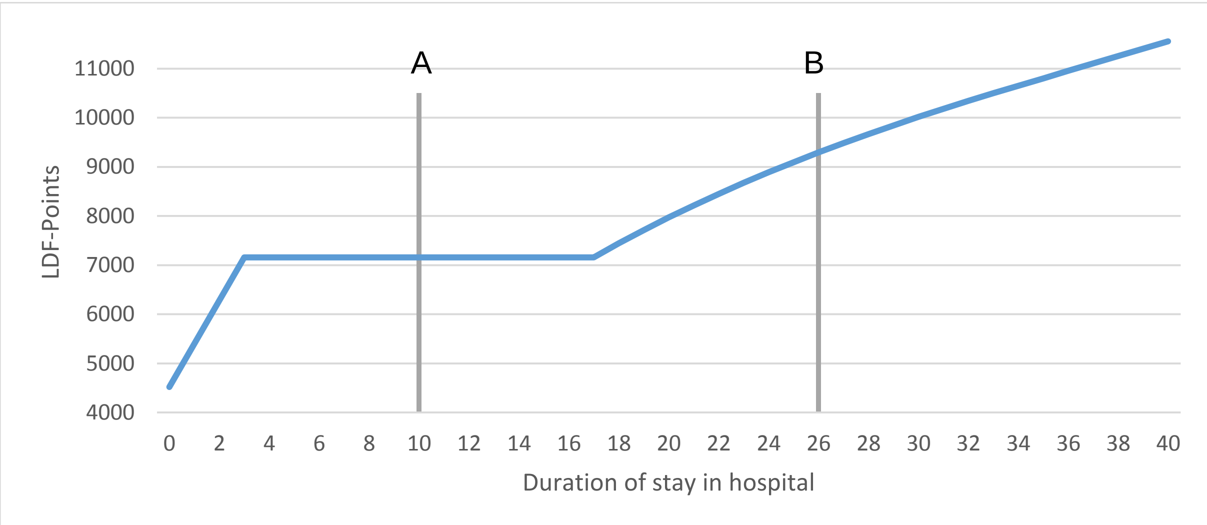

Fig. 14: LDF-points related to the duration of stay in hospital for total hip arthroplasty

Fig. 15 shows an example of how the duration of stay is actually distributed. The data has been obtained from Statistics Austria [2] for the years 2002 to 2011 divided by age, gender and performed medical procedure. For the data analysis, stays up to 49 days (or 7 weeks) were considered. Longer stays were neglected as more than 95% of the stays were covered by the stated period of time. Longer stays can be highly related to the presence of comorbidities and are therefore considered out of the scope of the presented model. The retrieved data was subsequently averaged over the ten-year period to make the result less prone to outliers.

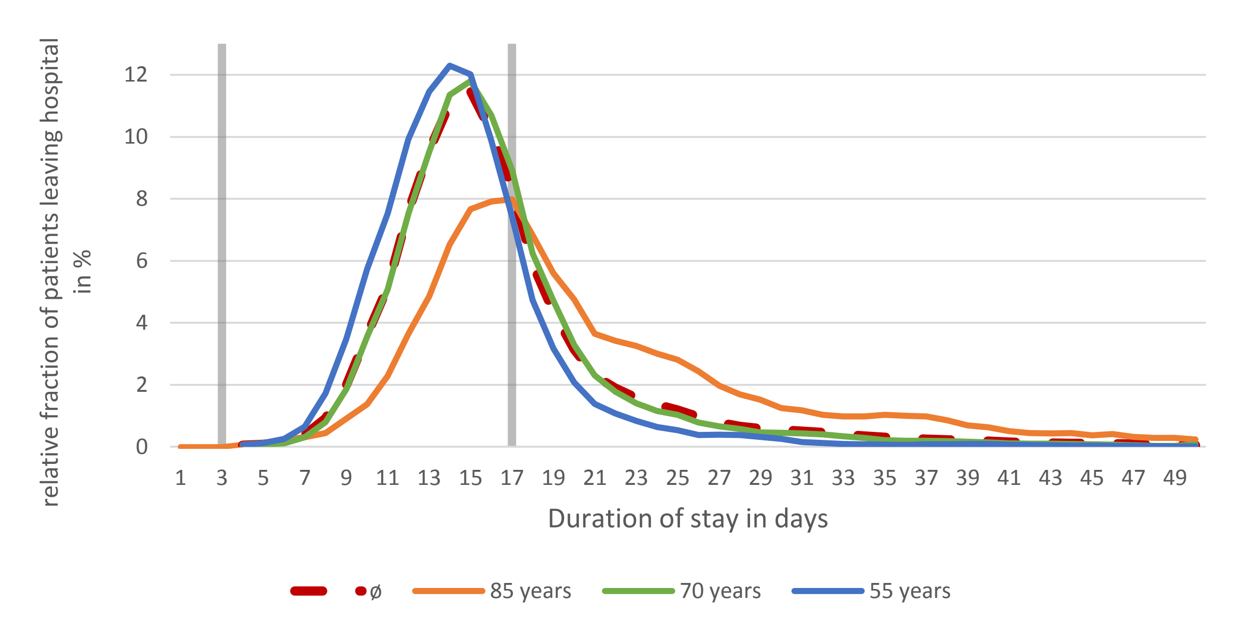

Fig. 15: Duration of stay in hospital for patients of different age undergoing total hip arthroplasty.

It can be observed in Fig. 15 that the duration of stay tends to increase with age. The fact that elderly people are more likely to get cemented implants (cf. Section 3.7.2) that are supposed to allow faster recovery as there is no need to wait for natural osteointegration, seems to be outweighed by the general decrease of the ability for fast recovery with age and also may be affected by the presence of comorbidities.

Keeping in mind the amount of awarded LDF-points depending on the duration of stay, it is clear that for the distribution highlighted in Fig. 15 a considerable number of top-up points will apply. The corresponding limits for the duration of stay that triggers either top-up or point deduction are indicated by the grey lines.

Fig. 16 points out how the duration of stay of patients undergoing hemiarthroplasty is distributed. For this procedure the expected extension of time spent in hospital has not been verified. This can be reasoned as follows: the total number of procedures within the evaluated ten-year period is only about 30000, while the number of total hip arthroplasty procedures is higher than 150000. Broken down per age, the quality of data for hemiarthroplasty becomes quite poor because of the small sample size. As an example, the blue line indicating the fraction of 55-year old patients shows considerable steps. On the other hand, extending the ten-year period might result in disguising possible decreases in the general duration of stay due to new operation techniques and medical progress.

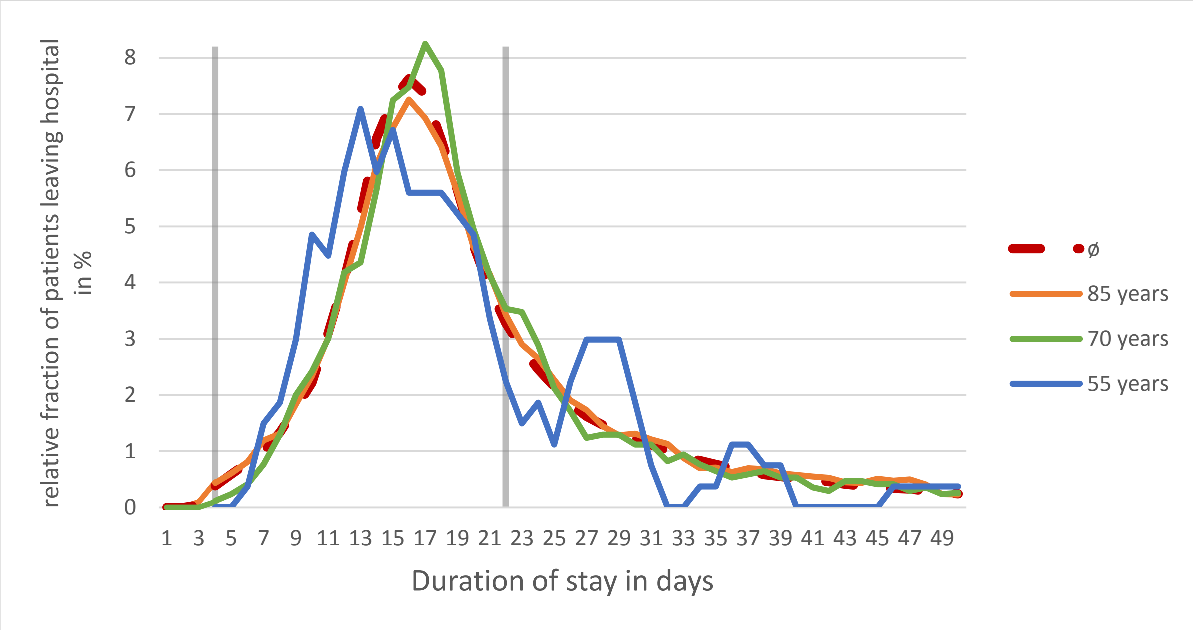

Fig. 16: Duration of stay in hospital for patients of different age undergoing hemi arthroplasty.

Finally the data was integrated separately for men and women, since a stay in hospital tends to be slightly longer for women as can be seen in Fig. 17.

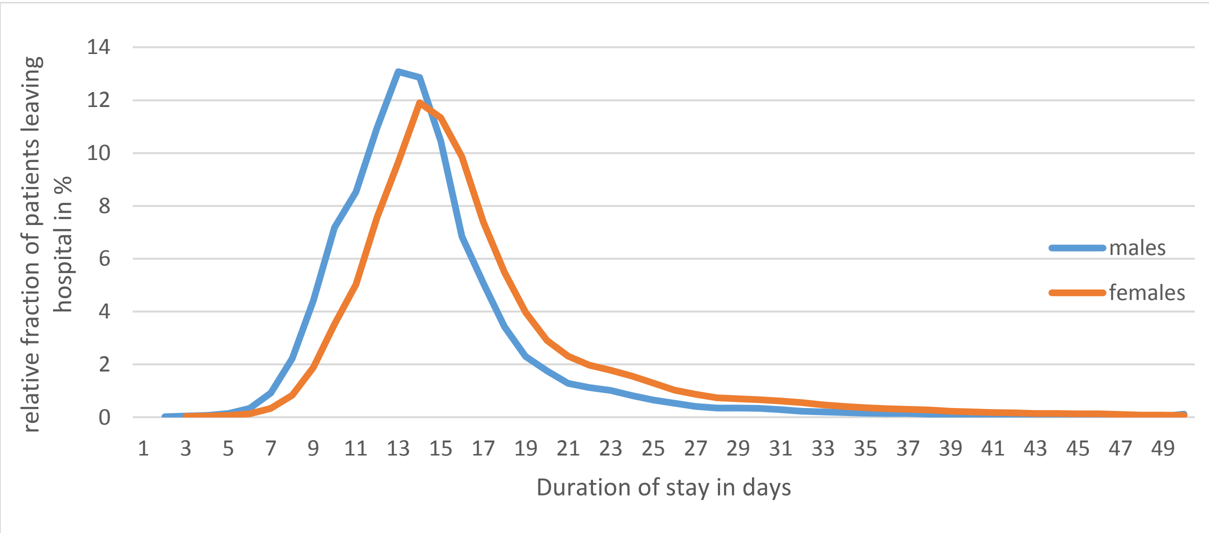

Fig. 17: Duration of stay in hospital for patients undergoing total arthroplasty grouped by sex.

From the implementation point of view, the data were saved in an array variable instead of implementing a fitted distribution function. This approach was chosen to allow custom modification of the distribution at runtime, and for performance reasons. A graphical user interface is provided, which enables shifting the implemented distribution along the time axis with respect to user-defined minimum values. Since the duration of stay will never exceed 49 days, no patients are dropped from the distribution table but accumulation on day 49 takes place (e.g., if the user specifies an increase of 50 days, the probability for day 49 will be set to 100% when accumulation takes place).

It has also been found to be more efficient to calculate the expected value ($E_{(x)}$) for the LDF-points corresponding to the implemented distribution once at the beginning of a simulation run, rather than applying the distribution function for every time step. In this way the calculation of the total number of LDF-points is reduced to a single multiplication of the number of implantations per year, gender, age and prosthesis type, with the expected value of the LDF-points. The expected value itself is calculated as follows:

$$E_{(x)} = \sum LDF_{(x)} \times p_{(x)} \qquad (6)$$

E(x): expected value
X: day of discharge from hospital
$LDF_{(x)}$: amount of LDF-points billed if patients is discharged on day x
$p_{(x)}$: probability that patient leaves hospital on day x

Costs of implantations and revisions based on LKF

The costs of revisions are approximately 22% percent higher than those for primary implantation [20, 1]. Based on this, the baseline model implemented a factor that increases the costs for revisions by 22%. Since the LKF-System contains separate values for revision operations, these values have been integrated as additional points are added in case of revision, if the activity component is higher than for primary implantation. However, this increase of LDF points is very small and does not cover the 22% stated above. Therefore the option of using a custom multiplier specified through the graphical user interface is also retained.

The LDF-allowance for the different medical procedures was retrieved from the Austrian Ministry of Health [14] as follows:

- Re-implantation of a partial hip endoprosthesis < NE 100>
    - Activity component: 2727
    - Day component: 5437
    - Limits for duration of stay: 4 – 22
    - Mean duration of stay: 14.7

- Implantation of a partial hip endoprosthesis < NE 080>
  - Activity component: 2845
  - Day component: 5443
  - Limits for duration of stay: 4 – 22
  - Mean duration of stay: 14.7
- Re-implantation of a total hip endoprosthesis < NE 100>
  - Activity component: 4190
  - Day component: 3513
  - Limits for duration of stay: 3 – 17
  - Mean duration of stay: 11.6
- Implantation of a total hip endoprosthesis < NE 080>
  - Activity component: 3642
  - Day component: 3514
  - Limits for duration of stay: 3 – 17
  - Mean duration of stay: 11.6

3.7.9 Measures to enhance precision

Age division

The given population model provides the number of people per gender and age in one-year divisions. However, in the baseline prosthesis model, patients were grouped by age into 20 age-groups, each covering 5 years. This grouping may have had some benefits for the performance of the baseline model, but raised a major problem. When people were growing older, the number of people to be transferred to another age group could not be determined exactly due to lack of information on the age-distribution within the age group. Therefore every year one-fifth of the patients were transferred to the next group. This approach tends to delay and camouflage trends in the population forecast. More importantly, the resulting imprecision accumulates over time.

To prevent this, the new model retains the one-year divisions provided by the population model, although the computational effort increases five-fold. Additionally, implantation rates for the main scenario were updated to values with one-year divisions.

Monitoring period

So far patients have been monitored for 25 years after undergoing arthroplasty. After the end of this period they were no longer included in the model. This was found to be another drawback of the baseline model, since implantation rate significantly increases at the age of 40. These patients would only be monitored until the age of 65, but life expectancy in Austria is above 80 years [2]. Therefore the baseline model is likely to underestimate the number of revision procedures.

Now, in the new model, the monitoring period is extended to 30 years after implantation. Additionally, patients are not omitted at the end of this period. Patients not undergoing revision within 30 years are kept static at year 30 after implantation. The revision rate would of course tend to further increase, but the Swedish hip prosthesis register [9], which has existed for a little more than 30 years and is the oldest register available, does not so far provide values for revision rates after more than 30 years. Therefore the new model still tends to underestimate the total number of revisions, but delivers better results than the baseline model.

General mortality

The included population model not only consists of actual demographic indicators, but also predicts several parameters such as mortality. So far changes in mortality did not affect the prosthesis model. The new prosthesis model also considers the change in mortality predicted by the population model.

Delay of implantation

The baseline model [1] contains a possibility to limit the benefit on the healthcare insurance in a way that implantation or revision is postponed for a specified period of time. This can be a suitable solution for patients suffering from arthrosis, but is considered not practicable for people with fracture of the femur. Therefore, in the new model, this option is limited to primary implantations due to arthrosis.

Custom parameters

The graphical user interface provides the possibility to influence the model at runtime by specifying custom parameters. In the baseline user interface these options were limited as age divisions were mostly set to 20 or 25 years. Now the following custom values can be prompted with 5-year divisions:

- Body Mass Index
- Distribution of the type of tribological pairing
- Distribution of the type of fixation

In addition the Body Mass Index can now be defined separately for males and females. The unisex option is also available.

Third revision

Mean prosthesis lifetime is assumed to be approximately 15 years [1]. Since implantation rate increases significantly for people older than 40 years, and life expectancy is more than 80 years [2], it is likely that a third revision will occur, as second revision prostheses on average may be broken at the age of 85 when the patient received primary hip replacement very early. As the Australian prostheses register also states values for revision 3+, the possibility to monitor 3+ revision was integrated into the new model. 3+ means that patients may also undergo further revisions, but are afterwards again added to the 3+ stock variables. However, since a system dynamics model does not allow tracking individuals, the number of people undergoing more than 3 revisions cannot be resolved.

3.7.10 Simulation scenarios

For enhancing the capability to simulate different scenarios some additional parameters can be customized in the new model. As pointed out in Chapter 3.6 scenarios for three different implantation rates are already built in. The main scenario is based on the ten-year average of the implantation rate. Further scenarios based on the maximum and minimum values that occurred during the last ten years are provided. A combined scenario, which starts with the average implantation rate for a user-specified period of time and then switches to high or low implantation rate, is also available. Additionally, the average scenario can be adjusted by a user-specified percentage.

If all the built-in scenarios do not meet the user's needs an arbitrary scenario may be loaded from a csv file. In this way any desired simulation can be performed.

3.7.11 Dynamic population model

Despite the recent modification and update of the population model by Trausnitz [16], some further optimization potential was discovered.

So far the population model was available for either Styria or Austria. In the presented model, these two models have been fused and the user may choose from the graphical user interface whether to include data from the whole of Austria or only from Styria.

The simulations so far always started in the year 1996. To simulate history (i.e. before 2012 in this case) can be useful for validation purposes, but does not meet the requirements for daily use. One can now choose whether to start in the year 1996 or 2012. If the simulation start is set to 1996, deviations occurring until 2012 are corrected by setting population values retrieved from Statistics Austria [2] for the year 2012.

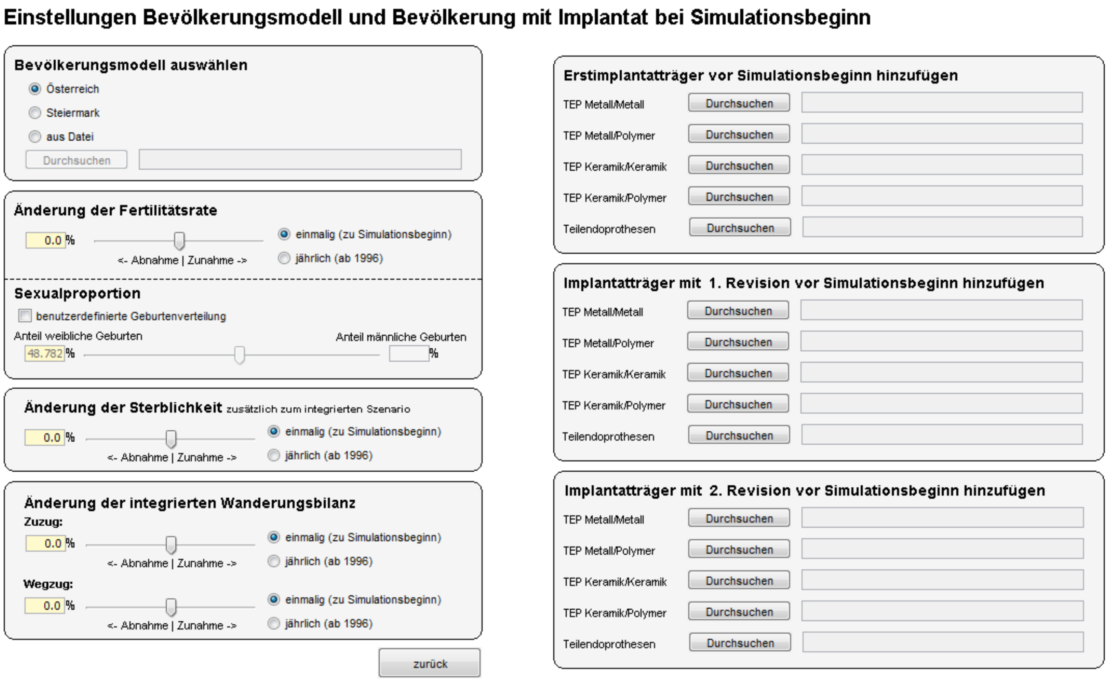

Fig. 18: Graphical user interface of the population model module.

The population model can now be modified at runtime. The following parameters may be influenced by the user through a new graphical user interface (see Fig. 18):

- Sex ratio
- total fertility rate
- mortality
- immigration and emigration

Since it is crucial for obtaining correct simulation results to know the number of people with prostheses at the simulation start, these values can be loaded into the model from a csv file provided by the user.

Additionally, all parameters included in the population model can be loaded from csv files. In this way the model can be used to simulate the population for any desired country.

3.7.12 Combination with knee endoprostheses model

There is currently research ongoing to develop a model for knee endoprostheses by Bleckenweger [15]. Since the final goal is to obtain a single model for knee and hip implants, compatibility with this knee implant model was ensured during this thesis work.

For this reason a modular composition was chosen whenever possible, instead of mixing different types of prostheses in one array. The main part of the new hip prostheses model now consists of five identical modules, one for each tribological pairing and an additional one for partial endoprostheses. New modules can be added easily, and a fusion with the knee prostheses model can be done with low effort, since parameters that possibly influence knee arthroplasty but do not influence hip arthroplasty are already integrated in the model with neutral values (e.g. Body Mass Index for primary implantation) [15, 1].

3.7.13 Adapting the model for AnyLogic® 6.9

An objective for this work was also to adapt the baseline model such that it works with the newest AnyLogic® version, since major changes in this software between versions 6.1 and 6.4 rendered the model inoperative. A change within the syntax for HyperArrays caused nearly 2500 runtime errors with the baseline model.

AnyLogic® is an Eclipse-based programming and simulation environment, and is therefore intrinsically Java-based. AnyLogic® provides a graphical user interface for simple model creation that allows to insert prebuilt blocks by dragging and dropping, and generates Java code according to the inserted blocks and their links.

A solution more robust to future changes within the underlying AnyLogic® software has been developed and implemented. Java is a widespread programing language used in numerous applications in the world wide web, and therefore compatibility between different Java versions is likely over a longer period of time. Therefore the new model was created with focus on Java code rather than built-in functions of AnyLogic®.

3.7.14 Validation

Crucial for the success of a model is proper validation, to ensure that one can rely on the results obtained and that the model meets the original requirements. Reliable results are important especially in the area of cost estimation, since this is often the basis for decision-making in the public healthcare system. For validation, the V-model for software development was applied (Fig. 19).

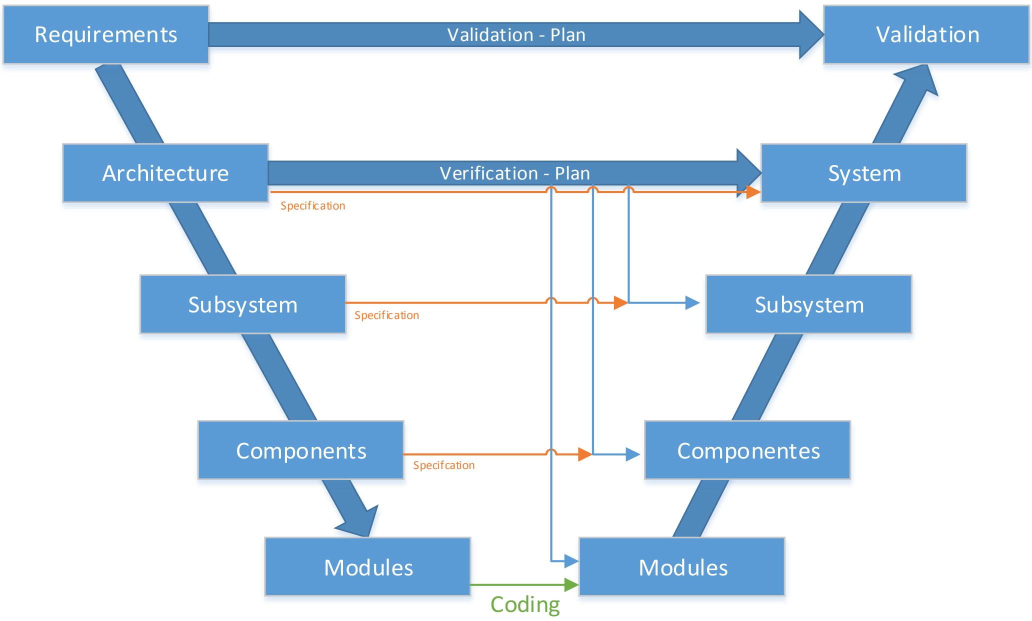

Fig. 19: V-model for software development. Adapted from [21]

The V-model describes the process of software development from the requirements specification to the determination of system architecture, and subsequently down to the development of single modules that can be easily coded and reviewed. These modules can be integrated stepwise into components after being verified. The components thus formed are assembled to a subsystem and so on until the whole system can be validated according to the validation plan [21].

3.7.15 The graphical user interface

Parameter input

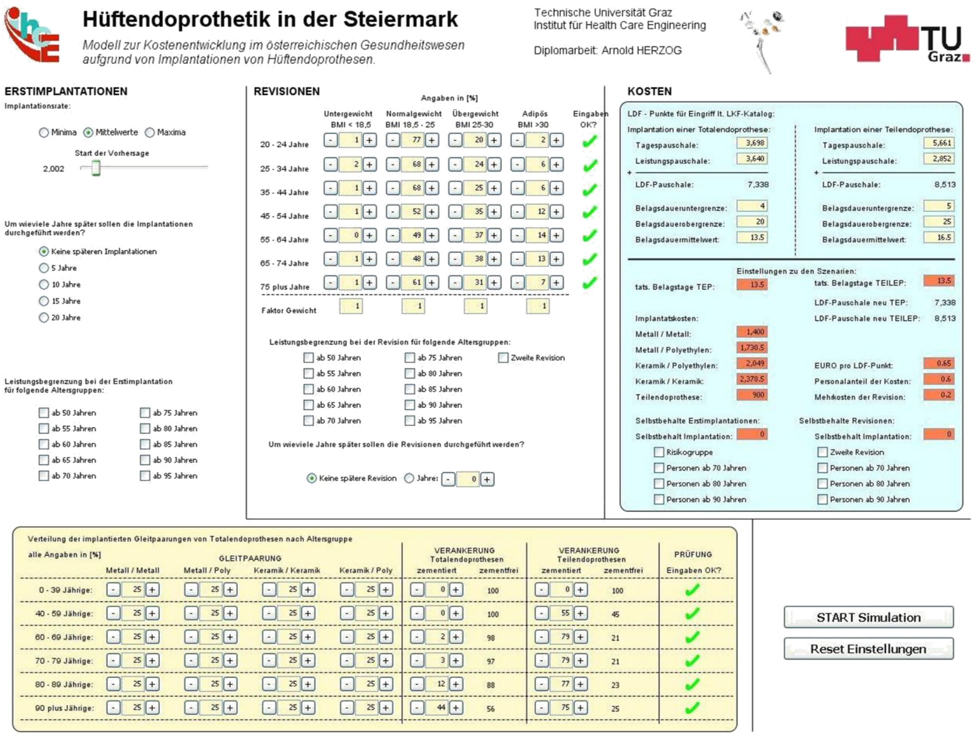

Fig. 20: GUI of the baseline prostheses model [1]

The goal of enhancing the usability of the model resulted in a newly-designed graphical user interface. Fig. 20 shows the baseline GUI that had a very compact design. Since the new user interface needed to contain more adjustable parameters, a compact design would have made the interface much less user-friendly. Therefore a modular user interface was created that divides the GUI into 8 parts, enabling different properties to be set as follows:

- Main GUI (cf. Fig. 21)
    - Provide access to the other modules
    - Set implantation rate
    - Set start time for simulation
- Population model GUI
    - Choose between Austria and Styria
    - Set parameters listed in Section 3.7.11
- Total hip prostheses GUI
    - Set distribution of tribological pairings

    - Set distribution of fixation type
- Partial hip prostheses GUI
    - Set distribution of fixation type
- Engineering progress GUI
    - Set increase in lifetime of prostheses, separated by fixation and tribological pairing
- Body Mass Index GUI
    - Set distribution of BMI separately for males and females, or unisex values
    - Set influence factor for different ranges of the BMI
- Costs GUI
    - Set parameters given by the LKF-System
    - Set material costs for the different types of prostheses
    - Influence the distribution of the duration of stay in hospital
    - Set inflation and yearly cost change
- Cap on the benefit GUI
    - Set a delay for implantations and revisions
    - Introduce a cost share
    - Define discount for socially disadvantaged people

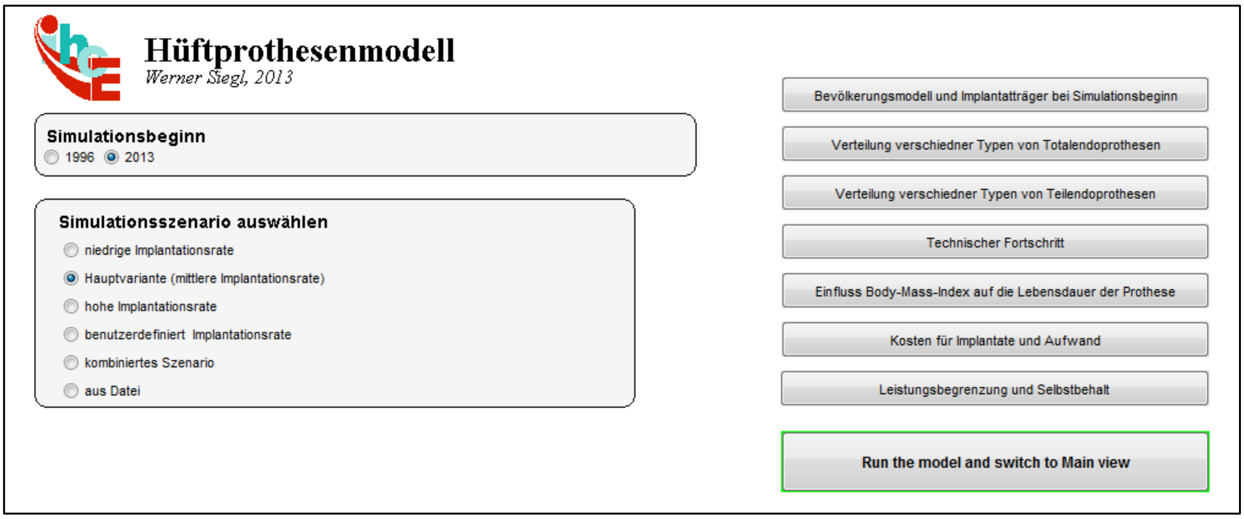

Fig. 21: Main GUI of the new model

Fig. 21 shows the main user interface of the new model. On the right hand side the 7 sub-modules can be accessed to set different properties. Besides the modular structure, the main difference in comparison with the old graphical user interface is the option to set age-dependent values with five-year divisions instead of ten-year divisions.

All values specified by the user are checked for validity. For example, the distribution of tribological pairings must equal 100%. A warning indicator pops up if the check conditions are not met. The model does not start the simulation until all input values are valid.

Results output

The output interface is kept simple and contains three graphs:

- Costs divided into primary implantation and revisions
- Costs divided into primary implantation and revisions after subtraction of the cost share
- Number of primary implantations and revisions

The output interface is kept simple to achieve maximum performance, since graphical output slows down the system enormously. The implemented output options are considered sufficient also because the new model provides the option to easily copy data after the end of the simulation from integrated datasets into third-party software (e.g. Microsoft Excel or MATLAB) which are more powerful tools for data analysis.

4 Results

4.1 Model design overview

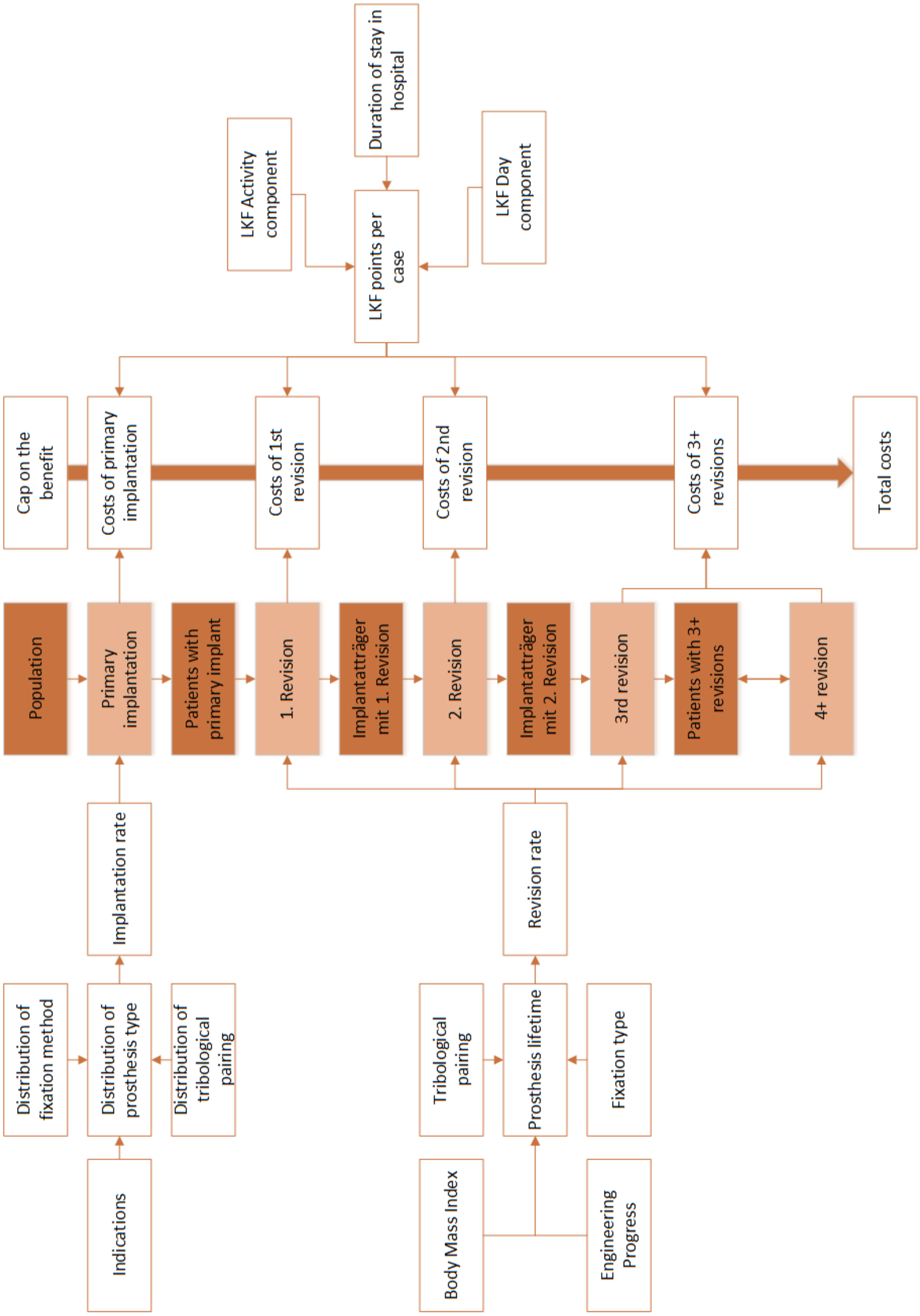

Fig. 22: Simplified overview of the relations, stock variables (dark brown) and flow variables (light brown) within the new model.

Fig. 22 illustrates the basic relations within the new model and points out the different stock and flow variables. The clear improvements compared to the baseline model are the more detailed calculation of costs, and the consideration of the 3+ and 4+ revisions. Additionally, the distribution of different fixation types, tribological pairings and prosthesis types is now considered by default.

4.2 Population model

Since the population model was extended to be able to simulate the population in Austria as well as in Styria, the whole model was reviewed and re-implemented in the Java programming language.

Duration of a simulation

The duration for a single run spanning a 60-year period was decreased from 60 seconds to ~3 seconds.

Verification

As mentioned before, the underlying data for the population model was retrieved from Statistics Austria [2]. Therefore, the main population forecast published by Statistics Austria as well as the output of the baseline population model were chosen as references for verifying the new model.

Fig. 23 and Fig. 24 illustrate the result of the simulation used to compare the model, for Austria as well as for Styria. The vertical line indicates the present time (the year 2013). Up to this year statistical data provided by Statistics Austria [2] was used as reference value.

In comparison to the baseline model, the cumulative deviation using the new model was decreased by 1.8% for a simulation of the Austrian population, and by 45% for a simulation of the Styrian population, within a 60-year period starting from 1996. For population simulation in Styria and in the whole of Austria, deviation for a single year never exceeded 0.5% when compared to the Statistics Austria [2] data (cf. Table 4 and Table 5).

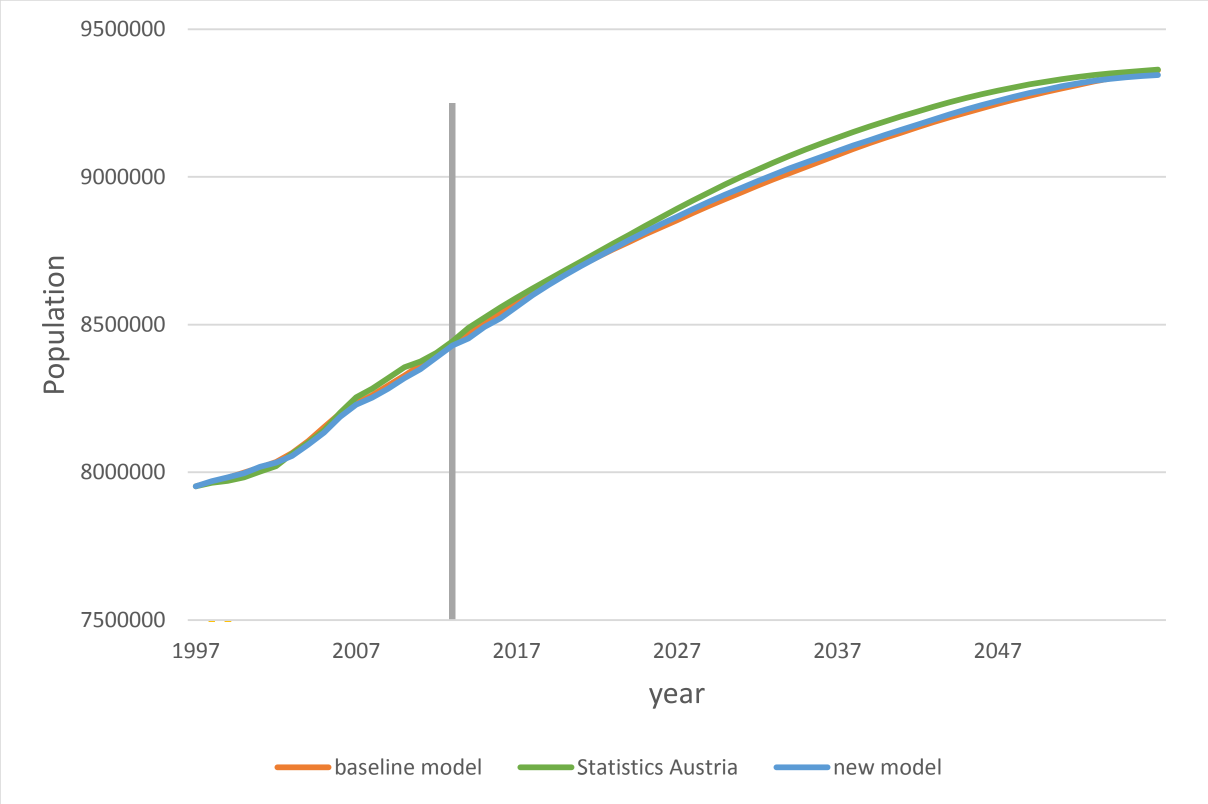

Fig. 23: Output of the new population model for Austria compared to reference values.

Table 4: Absolute and relative deviation of the population model output from the total population compared to Statistics Austria data [2], when simulated for the whole of Austria.

Year	Model output	Statistics Austria		Deviation	
		real data	forecast	absolute	relative
1997	7,953,067	7,953,067	-	0	0.00%
2000	7,997,474	7,982,461	-	15,013	0.19%
2005	8,134,601	8,142,573	-	-7,972	-0.10%
2010	8,318,614	8,355,260	-	-36,646	-0.44%
2015	8,481,924	-	8,523,323	-41,399	-0.49%
2020	8,666,470	-	8,683,212	-16,742	-0.19%
2025	8,813,076	-	8,833,521	-20,445	-0.23%
2030	8,939,415	-	8,974,391	-34,976	-0.39%
2035	9,048,348	-	9,092,436	-44,088	-0.48%
2040	9,142,133	-	9,188,485	-46,352	-0.50%
2045	9,228,201	-	9,266,791	-38,590	-0.42%
2050	9,295,543	-	9,322,592	-27,049	-0.29%
2055	9,337,914	-	9,354,982	-17,068	-0.18%

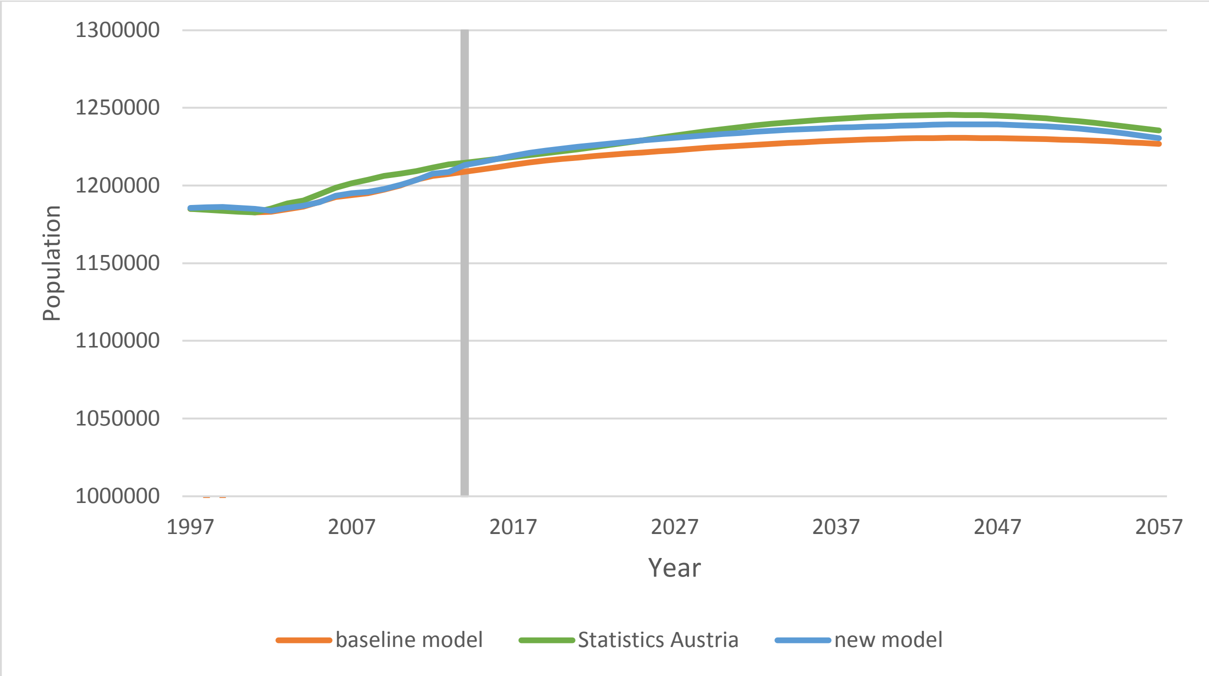

Fig. 24: Output of the population model for Styria compared to reference values.

Table 5: Absolute and relative deviation of the population model output from the total population compared to Statistics Austria data [2], when simulated for Styria.

Year	Model output	Statistics Austria		Deviation	
		real data	forecast	absolute	relative
1996	1,185,066	1,185,066	-	0	0.00%
2000	1,185,649	1,183,146	-	2,503	0.21%
2005	1,189,242	1,194,368	-	-5,126	-0.43%
2010	1,200,525	1,207,588	-	-7,063	-0.58%
2015	1,215,160	-	1,215,813	-653	-0.05%
2020	1,223,728	-	1,222,019	1,709	0.14%
2025	1,229,019	-	1,229,122	-103	-0.01%
2030	1,233,130	-	1,236,343	-3,213	-0.26%
2035	1,236,289	-	1,241,505	-5,216	-0.42%
2040	1,238,224	-	1,244,548	-6,324	-0.50%
2045	1,239,462	-	1,245,447	-5,985	-0.48%
2050	1,238,078	-	1,243,203	-5,125	-0.41%

4.3 Duration of a simulation

4.3.1 Analysis of the baseline model

A major shortcoming of the baseline model [1] was the long computation time it required. Due to the high complexity of the model, a single simulation run took about 45 to 60 minutes. Thorough analysis of the code revealed that changing the architecture of the model could improve the performance significantly.

AnyLogic® is a Java-based system and is therefore based on the object-oriented programming paradigm. This paradigm is a programming approach that makes use of classes and objects that contain data fields and functions. The principle is to keep entities that belong together within classes. A class itself can be seen as a template for the creation of an object, and an object is only an instance of a class. The main advantage of this paradigm is that one can create several instances of a single class. All these instances can have different values for their variables [22].

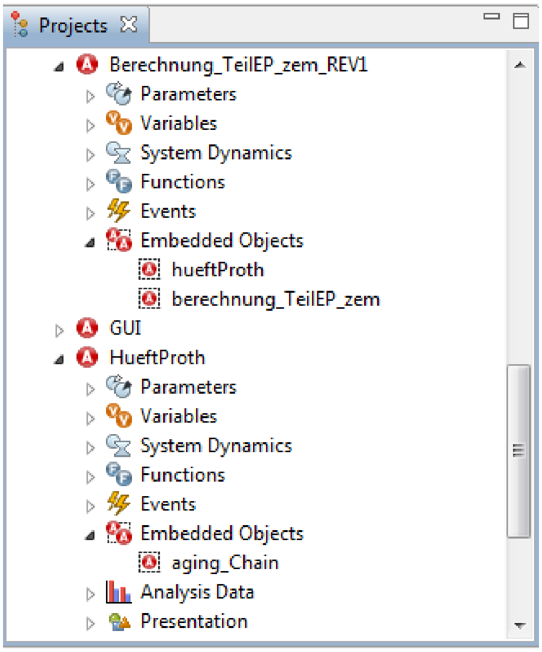

Fig. 25: AnyLogic® screenshot showing the architecture of the baseline model.

As can be seen in Fig. 25, the baseline model consists of several active object classes. The main class in this model is the class hueftProth. It contains the implantation and revision rates and calculates the primary implantations. For these computations it needs the results of the population model and therefore has the embedded object Aging_Chain. hueftProth itself is an embedded class in 20, as there are 20 possible combinations of fixation, type of prosthesis and number of revisions, other classes that calculate the revisions (cf. Fig. 26).

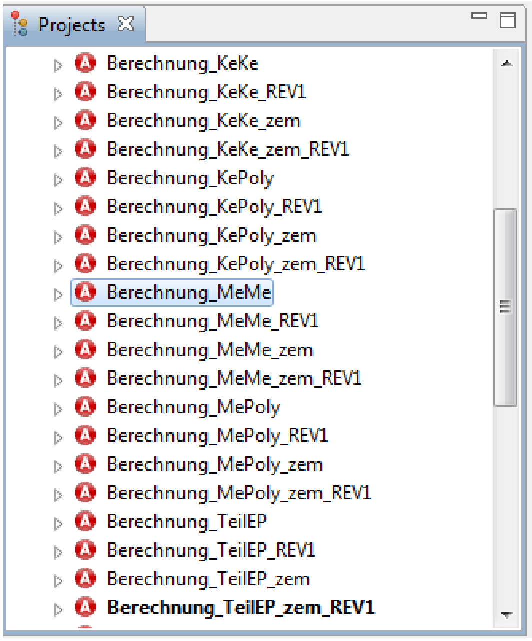

Fig. 26: Another AnyLogic® screenshot showing the architecture of the baseline model.

The primary reason for splitting the model into many active object classes is the performance of the AnyLogic® programing environment. When more and more pre-built blocks are added to the object, the underlying code grows rapidly and can render AnyLogic® slow and unstable, as detailed in [23].

Splitting the model in several smaller classes is a feasible way to overcome this limitation. However, the method of splitting objects in the baseline model necessitated the use of many embedded objects. Since all of the 20 active object classes have the same structure, a better approach for the prostheses model is to have one class as a template, and to subsequently create 20 instances out of it with different values for their variables, corresponding to the data for the different prostheses types.

This suggestion alone cannot increase the performance of the program, as long as the template makes use of the embedded classes hueftProth and Aging_Chain. The core problem is that through the use of embedded objects, there are 30 instances of the classes hueftProth and Aging_Chain at runtime, but these instances are to a large extent unnecessary as they all work with the same values for their variables. Therefore the model actually benefit from the advantages of object-oriented programing. In contrast, the model is slowed down extremely, since the same calculations are repeated several times.

4.3.2 Design of the new model

For the new model the architecture has been optimized in a way that the Aging_chain object is only used once. Also, the calculation for all different types of prostheses is done within one instance of the new object 'Main'. Therefore the overall number of active object classes could be reduced to 4, thereby enhancing the clarity, logic and ultimately the runtime performance of the model structure. The root object 'Costs' covers the costs, and the object RevisionRate performs the dynamic calculation of the revision rate (cf. Section 3.7.4). The architecture was designed in a way that only one instance of every object is created during the simulation run (cf. Fig. 27).

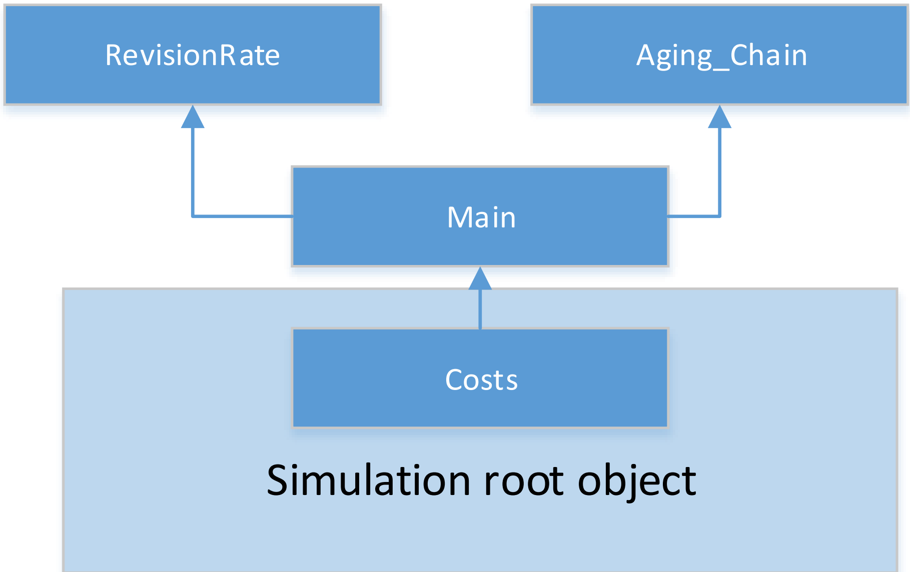

Fig. 27: Architecture of the newly-developed model.

The new model has significantly better performance than [1]. The duration of a single simulation run for a period of 65 years is reduced from 50 minutes to 15 minutes.

4.4 Complexity

The model extensions presented in Chapter 3 result in a vast increase in model complexity. Table 6 shows the quantifiable complexity changes between the new and baseline models. Overall the complexity has increased by a factor of 9. It should also be noted that for a large number of enhancements explained in Section 3, the change in computational effort cannot be quantified owing to the lack of comparable functions in the baseline model.

Table 6: Overview of quantifiable complexity change.

	Baseline Model (Herzog [1])	New Model (Siegl)	Complexity change
Age dissection	20 groups of 5 years	Yearly	x 5
Number of revisions monitored	2	3	x 1.5
Number of years after revision monitored	25	30	x 1.2

4.5 Verification of the implantation rate

Since the underlying data for the calculation of the implantation rate as well as for the population model were obtained from Statistics Austria [2], the number of primary implantations per year recorded by Statistics Austria [2] was chosen as reference value for the verification of the calculation of primary implantations. Fig. 28 shows the comparison of the model output for the total number of implantations in Austria with the database data. The grey line indicates the year 2002, as only data dating back to the year from 2011 to 2002 was integrated in the model. Fig. 29 illustrates data obtained from the default scenario (cf. Section 4.6) for Styria.

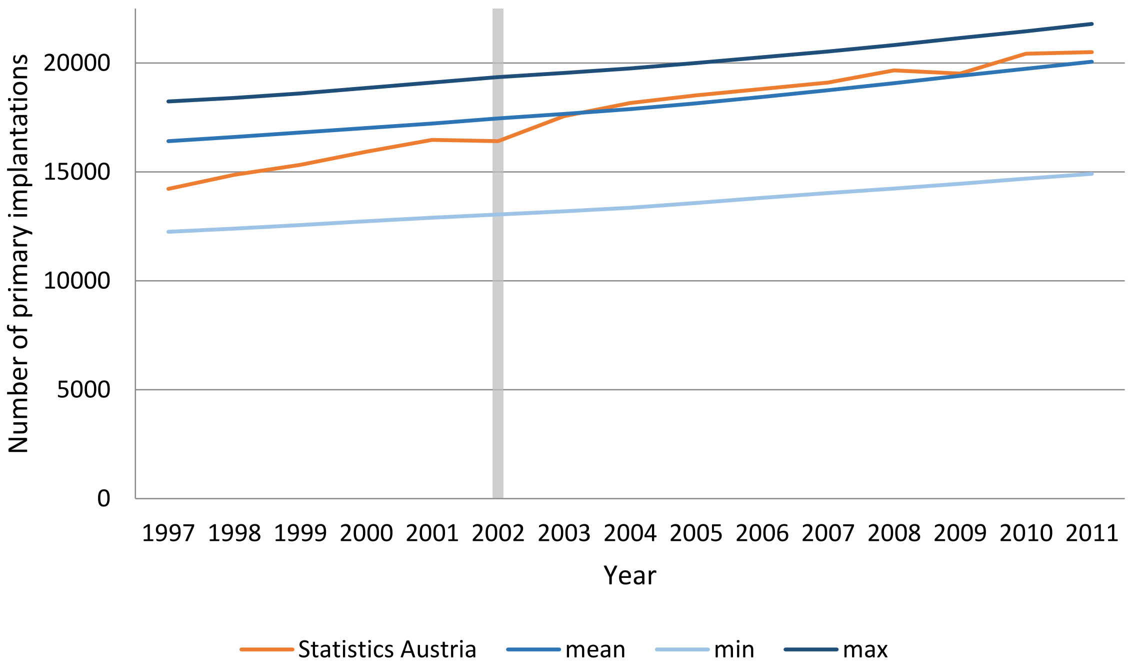

Fig. 28: Comparison of data from Statistics Austria and the model output for primary implantations in Austria.

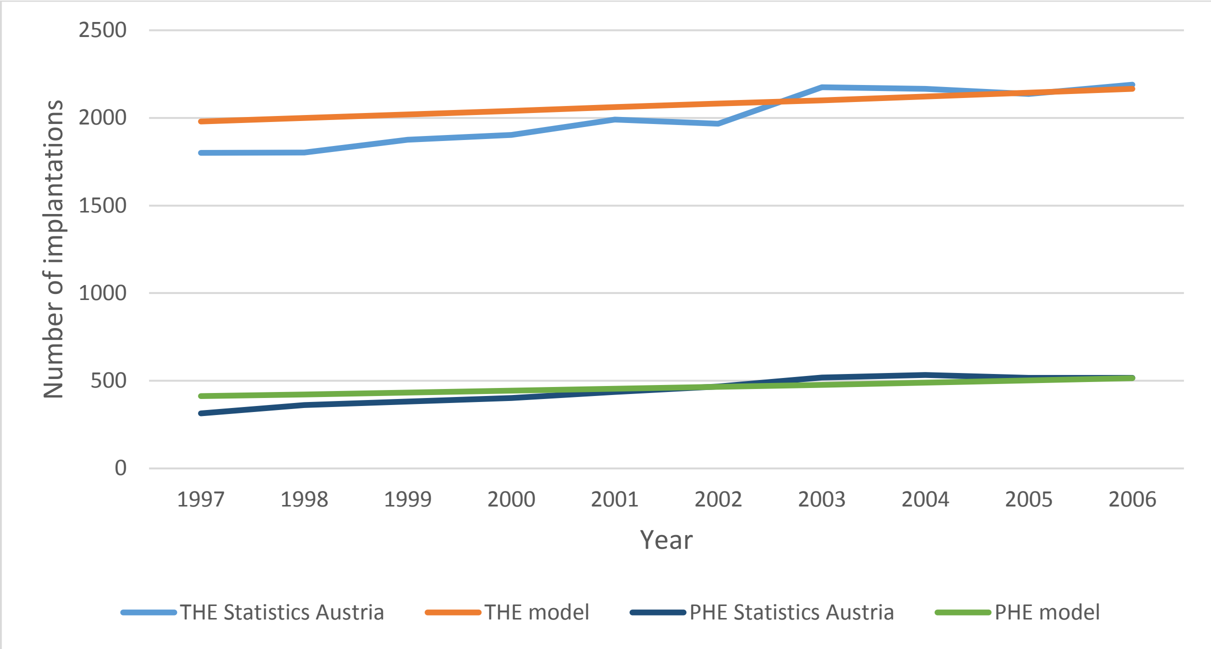

Fig. 29: Number of implantations of THR and PHR in Styria.

Major changes were made towards optimizing above the baseline model [1], and therefore the output of this model cannot be used as reference value for further validation of the new model. Due to a lack of statistics regarding costs related to hip endoprostheses, the remaining part of the model was verified by manual calculation and plausibility check, strictly following the V-Model presented in Section 3.7.14. The computation of revisions was also treated with this approach, as essential data containing the number of patients with implant or revised implant on simulation startup are not available.

4.6 Comparison of results to the baseline model – default scenario

In the thesis of Herzog [1], a base scenario for the period 2002 to 2040 with default values was defined. This scenario now can serve as reference for comparison.

A similar scenario was performed with the new model. The main difference to the scenario used by [1] is that the tribological pairings are not equally distributed as by now a distribution based on data retrieved from Statistics Austria [2] has been integrated and is used as default parameter. Inflation is a dynamic input variable to the new model and can be user-defined. Since in [1] inflation is statically predefined as 2.3%, this value was employed for comparison purposes.

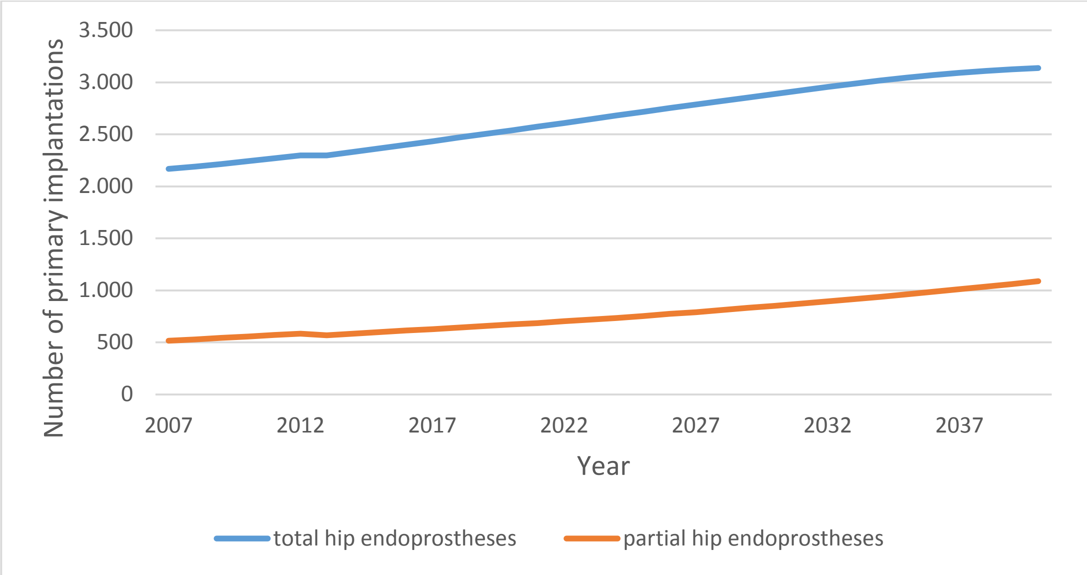

Fig. 30: Number of primary implantations in Styria calculated by the new model using the default scenario.

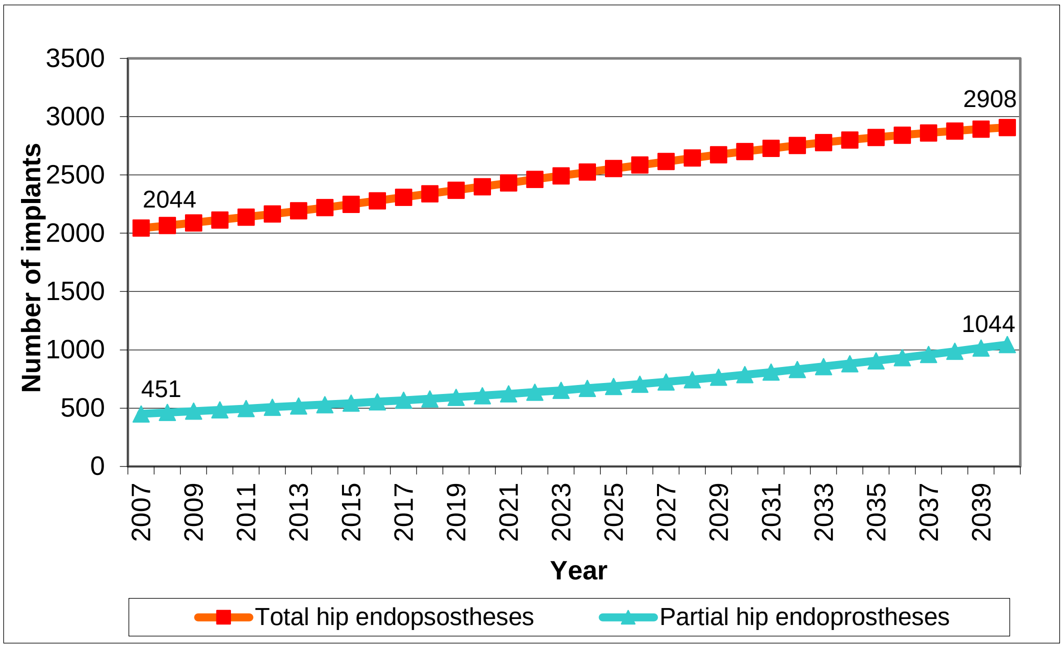

Fig. 31: Number of primary implantations in Styria calculated by the baseline model using the default scenario as taken from [1]

Fig. 30 and Fig. 31 illustrate the output for the new and the baseline model, respectively. A general trend of increasing implantation numbers is obvious from both figures, but overall the total number of implantations tends to be higher in the new model. While the baseline model predicts 3952 hip replacement procedures the newly developed model gives a value of 4222, i.e. a 6.8% deviation.

The increase during the observed period was given by [1] as 45.7% for total hip endoprostheses and 131.4% for partial hip prostheses. In comparison the values from the new model are 44.7% and 110.9%.

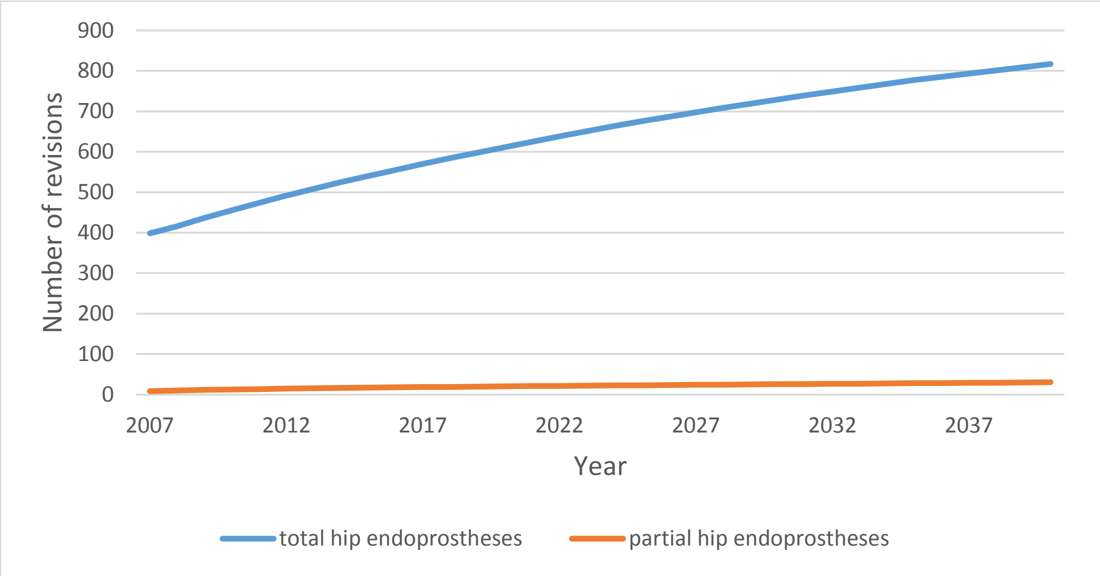

Fig. 32: Number of revisions in Styria calculated by the base scenario using default values.

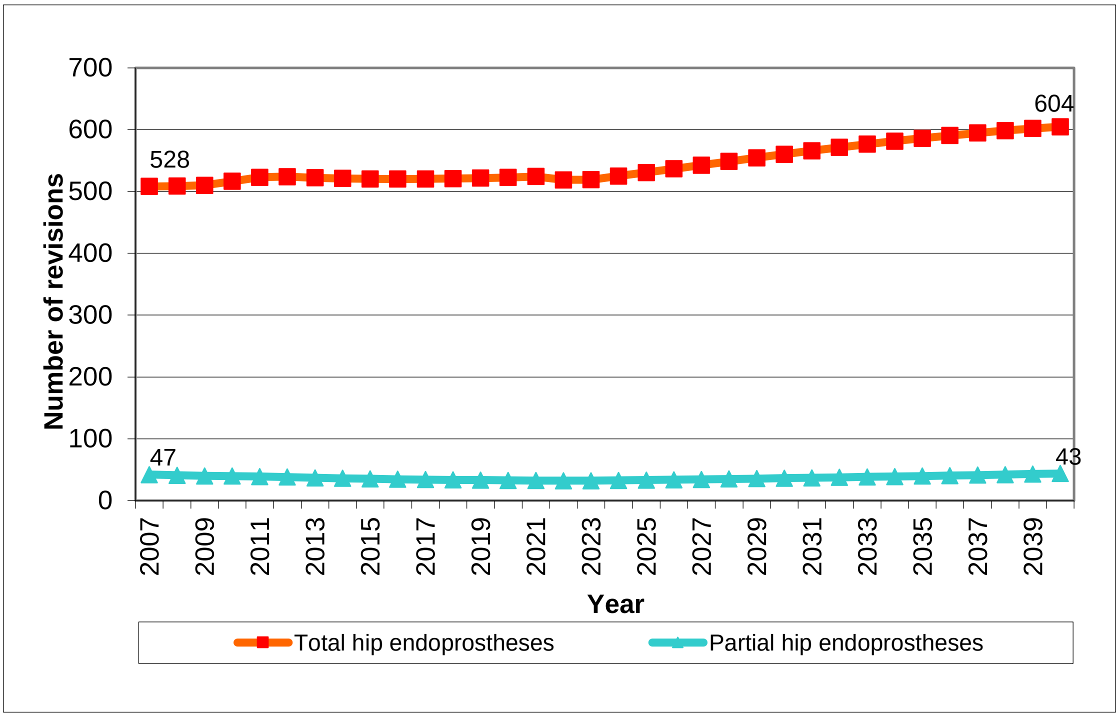

Fig. 33: Number of revisions in Styria calculated by the baseline model using the default scenario as provided from [1].

Fig. 32 and Fig. 33 contain the number of revisions for total and partial hip endoprostheses. While the baseline model [1] predicts a nearly constant behavior over time, the new model shows lower values at the beginning as well as a significant rise for total hip endoprostheses. The total number of revisions is 846 by the year 2040 while the baseline model only predicts 647. This means the new model shows an increase of 30.7% in comparison to the old one.

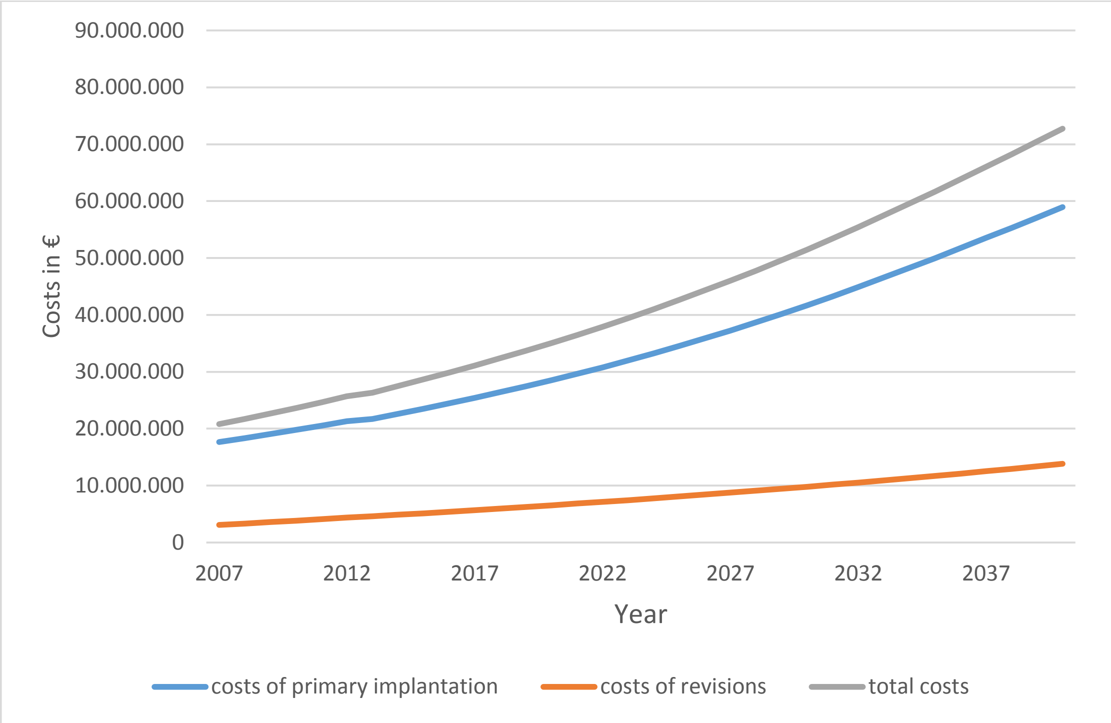

Fig. 34: Costs due to hip replacement procedures in Styria calculated by the newly developed model.

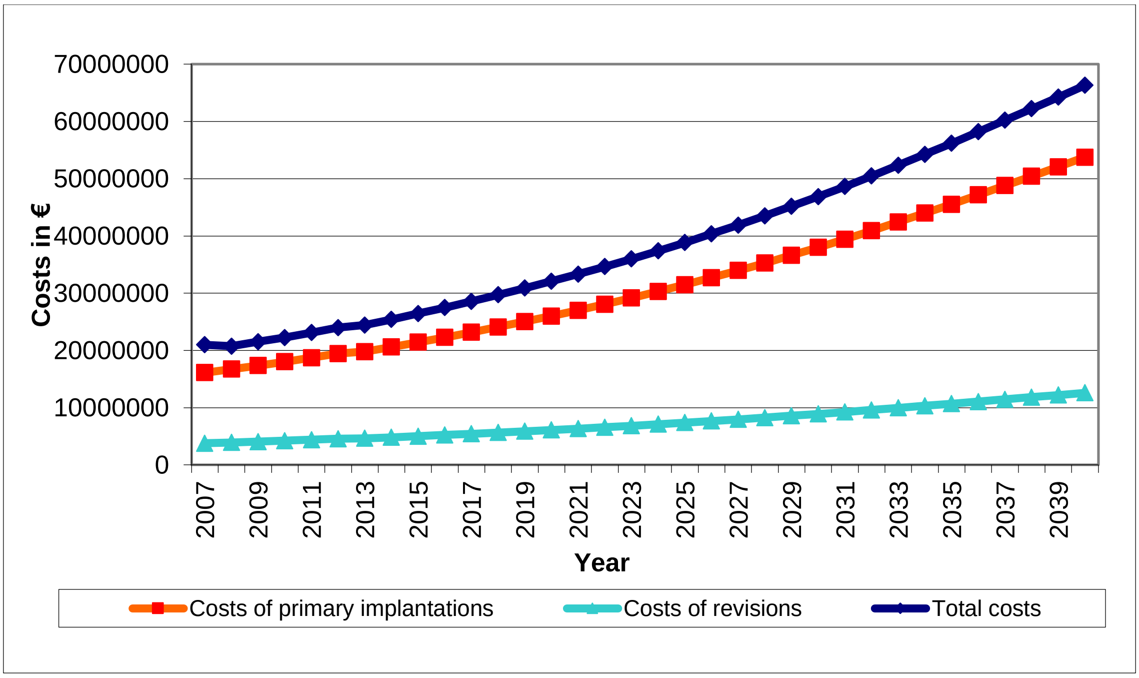

Fig. 35: Costs due to hip replacement procedures in Styria. Copied from [1].

Fig. 34 and Fig. 35 show the costs due to hip replacement procedures in Styria for the new as well as the baseline model. The costs for revision in the year 2040 was stated by [1] to be

12.61 million €. As pointed out above the total number of revisions is 30.7% higher when using the new model, but cost due to revisions only increase by 9.5% to 13.81 million €. Total costs increased by 9.8% from 66.31 million € [1] to 72.8 million € as well as costs for primary implantation increased from 53.7 million € [1] to 58.95 million € respectively by 9.8%.

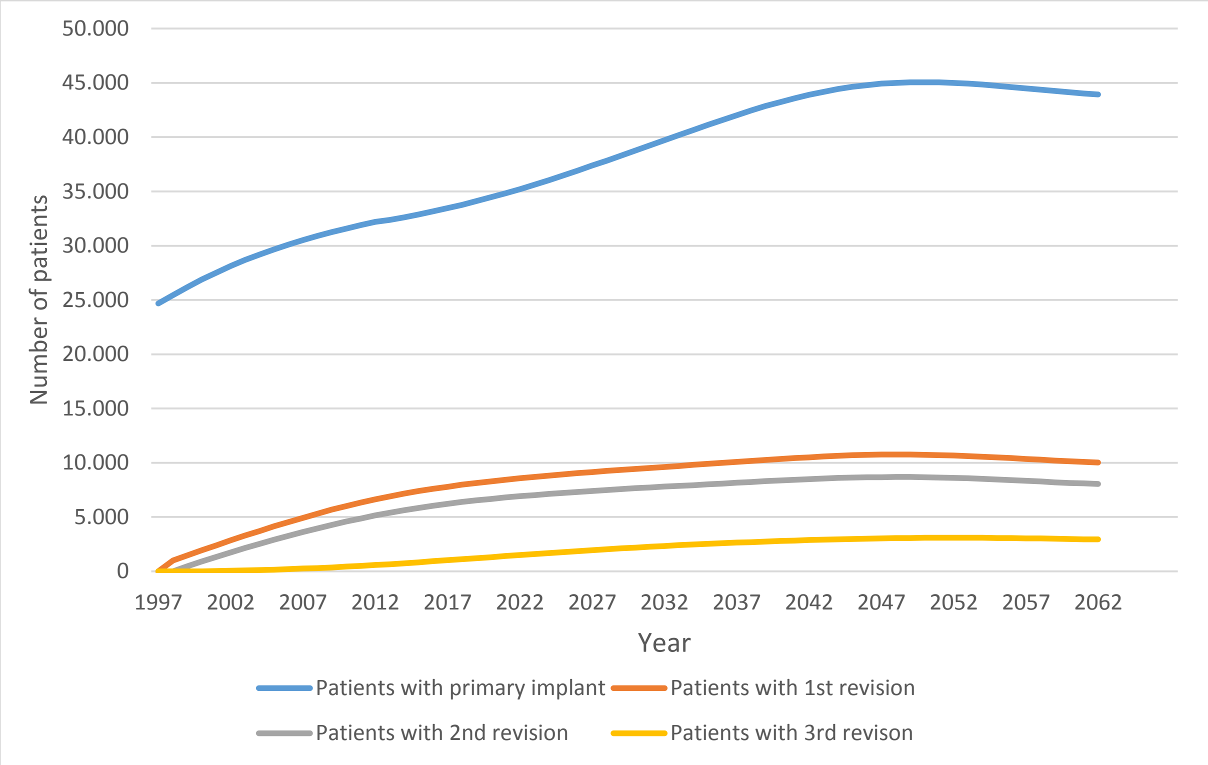

Fig. 36: Total number of patients with implants in Styria - results from the newly built model.

Fig. 36 illustrates the total number of patients with implants in Styria, separated by primary implants and the number of carried out revisions, as the new model allows this evaluation. All three curves follow a similar trend, to increase until the year 2050, while afterwards a slight fall is predicted.

The total number of patients with revised implant is zero in the year 1997, as no statistical data was available. The amount of people with primary prosthesis was estimated by [1].

Fig. 37 indicates the revision load, defined as the ratio between primary implantations and revisions. The revisions load is zero until 1998 for the reason stated above. Afterwards it increases from 10.5% to 20% by the year 2040. The actual value for 2013 is 18.3%. Revision rate drawn from the Herzog [1] model is 23% for the year 2007 respectively 16.3% for the year 2040.

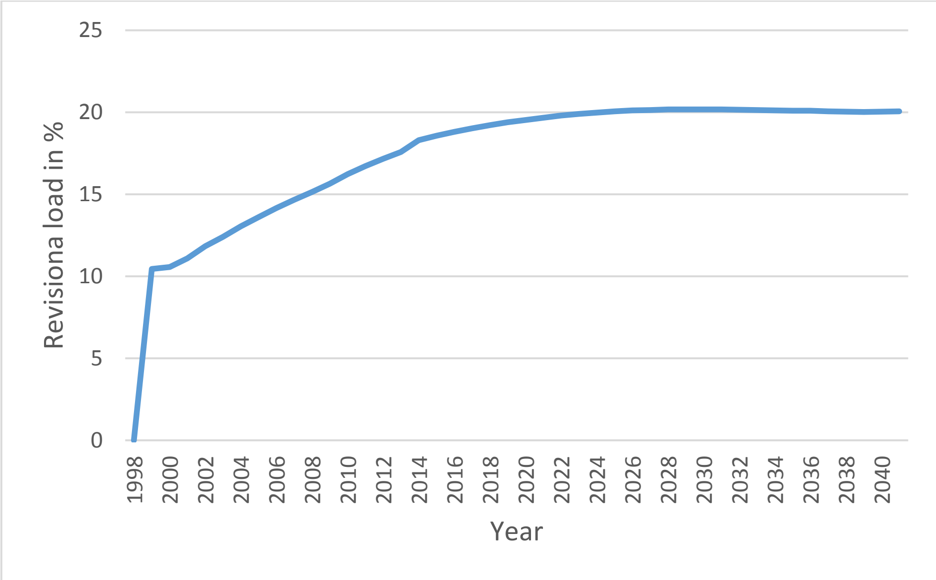

Fig. 37: Revision load calculated by the new model for the base scenario.

4.7 Maximum and minimum scenario

Since Section 4.2 showed that the default mean scenario slightly underestimates the number of implantations, maximum and minimum scenarios were defined. These scenarios indicated a bandwidth of the cost to be expected in future. Fig. 38 shows the number of primary implantations for all three scenarios. For further comparison, the total number of patients with implant is given by Fig. 39 as well as the total costs are shown in Fig. 40.

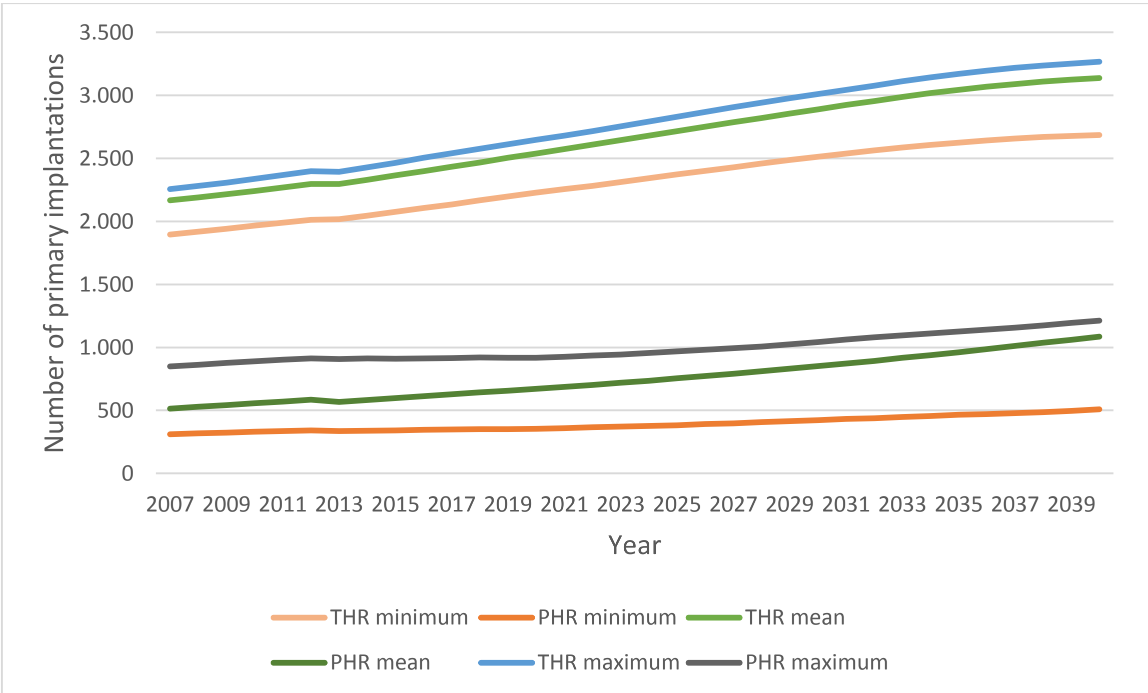

Fig. 38: Comparison of primary implantations between the minimum, mean and maximum scenario.

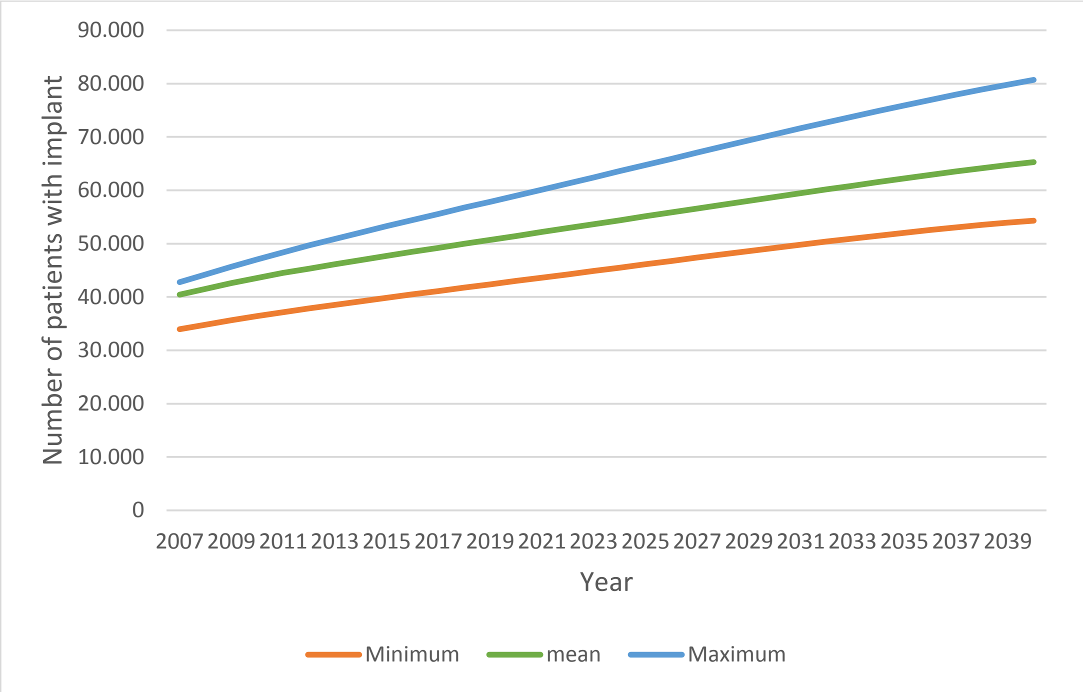

Fig. 39: Comparison of the number of patients with implant between the minimum, mean and maximum scenario.

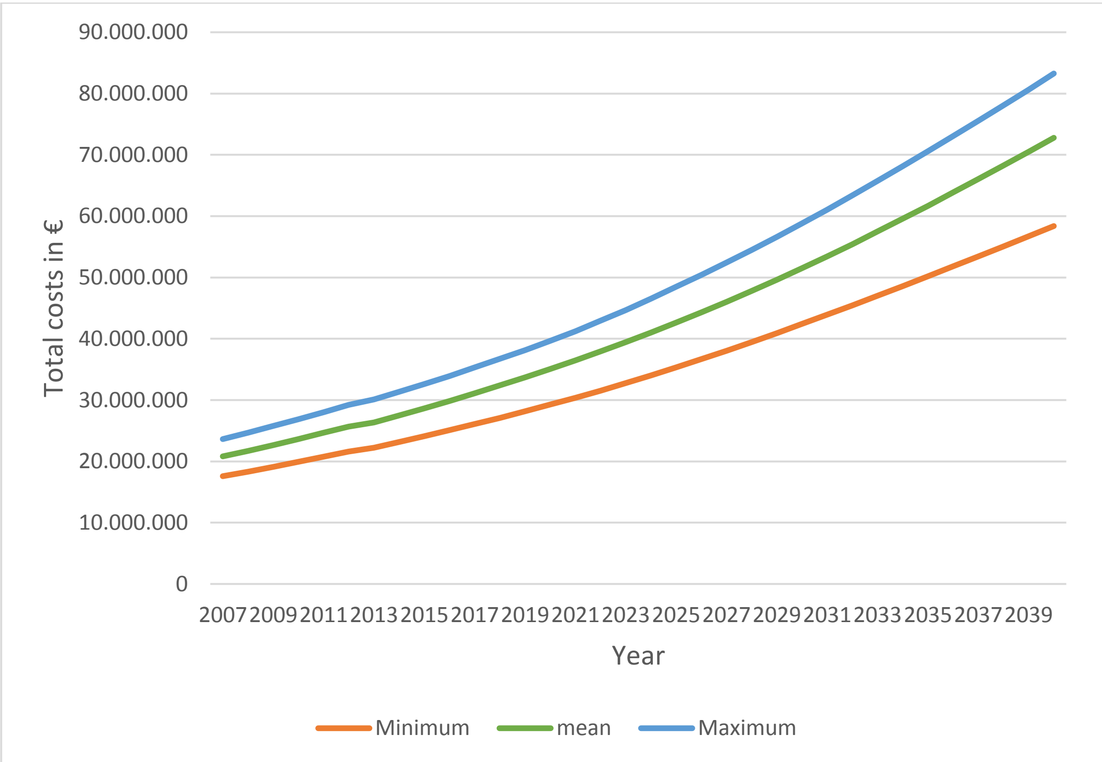

Fig. 40: Comparison of the total costs due to hip replacement between the minimum, mean and maximum scenario.

5 Discussion

5.1 Population model

Fig. 23 shows that although the cumulative deviation has been lowered by 1.8%, the population model still underestimates the total population development for Austria in comparison to the Statistics Austria [2] forecast. For this reason the overall hip prostheses model might underestimate the total costs. This fact should be kept in mind when interpreting results. Similar conclusions can be drawn for the population forecast for Styria (cf. Fig. 24).

Since the population model was recently updated by Trausnitz [16], the underlying data itself are up to date. Further improvement therefore might need to build a more sophisticated model structure that includes more parameters as well as improving the forecast for single parameters (e.g.: mortality).

The vast decrease in simulation duration indicates the potential of Java code programming in comparison to built in AnyLogic® functions, especially as there are, in contrast to the whole hip endoprostheses model, no new functionalities added to the population model that have influence on the duration of a simulation.

5.2 Duration of a simulation

It was pointed out in sections 4.3 and 4.4 that the duration of a simulation run was reduced by a factor of 0.3 while complexity increased by a factor of nine. The overall efficiency of the new model therefore is at least 30 times higher than the efficiency of the baseline model.

It cannot be exactly determined what fraction of the increase in efficiency is due to the new class architecture and what fraction is caused by the reorientation to Java coding. On the one hand side 30 instances of the Aging_Chain class would approximately cause 30 minutes simulation time. On the other hand side in Section 5.1 the vast optimization potential of Java code is pointed out.

Moreover the real increase in efficiency is likely to be higher than stated above, because new functionalities that are not comparable to the baseline model, but cause computational effort, were introduced (cf. 3.7).

5.3 Verification

5.3.1 Primary implantations

From Fig. 28 it can be seen that the total number of primary implantations per year, calculated by the mean variant of the presented model, follows the general trend of an increase, but matches the reference data only to a limited extend.

For the period 1996 to 2002, the number of implants is far overestimated. Since the model is based on data collected between 2002 and 2011 this can be explained by a general increase in the implantation rate over the past years. The same phenomenon can be seen in Fig. 29, that gives data for Styria.

The value for the year 2002 in Fig. 28 seems to be an outlier as it does not match the overall trend. Since the implantation rate implemented in the model is also affected by this value, this might explain the underestimation of the number of implantations in the succeeding years. In general, a 10-year averaging interval has been applied to make the result less prone to outliers. But in this case a shorter averaging period could make sense, as it maybe would also better reflect the general trend of an increasing implantation rate.

Another possible reason is that the underlying population model also tends to underestimate the population, thereby also affecting the number of implantations.

Fig. 28 also shows two additional scenarios implemented in the model. The minimum and maximum scenario use the respective corresponding values from the implantation rate data over the last 10 years. To avoid building a scenario out of outliers only, for these scenarios the values for the implantation rate were divided and averaged into five years age divisions.

The minimum scenario is far from matching the chosen reference data. In contrast the maximum scenario only overestimates the reference data slightly. As pointed out above the mean scenario will tend to underestimate primary implantations and therefore the resulting costs. For that very reason it would be reasonable to use the maximum scenario if simulations for budget planning are performed. In that way one is likely not to exceed the planned costs.

Alternatively one might use the possibility to dynamically modify the implantation rate at runtime. Since the average deviation of the mean scenario in the time period 2002 to 2011 was found to be 2.4%, it is possible to readjust the values for the implantation rate using the graphical user interface. As the outlier in 2002 is still likely to cause underestimation, correcting the maximum deviation of 4% might also be indicated.

5.3.2 Revisions

The number of revisions could only be calculated by comparison with manual calculations and plausibility checks, since there is a lack of data suitable as a reference. Although Statistics Austria [2] provides the number of revision procedures per year, the model output cannot be compared to these values, as revisions depend on the number of people already carrying primary prosthesis. As values for the patients with primary prosthesis at the simulation start are not available yet, the number of revision operations will not match any reference data. Therefore the former method of verification was chosen.

5.4 Comparison of results to the baseline model

Primary implantation

As stated above in Section 4.6, the newly built model predicts a 6.8% higher number of primary implantations. This behavior is most likely caused by generally increased implantation rates since [1] used data from the years 1996 to 2008 and the new model uses data from 2002 to 2011. The simulation used to validate the model also indicates this behavior (cf. 5.3.1).

The values for partial endoprostheses show good conformity while the number of total hip replacements is slightly above the values of the baseline model and therefore causes most of the 6.8% deviation

Revisions

Concerning the revisions it is obvious that the revisions at total arthroplasty occur more often than predicted by the baseline model (Fig. 32 and Fig. 33). This can have several reasons. Firstly, as pointed out above, the number of primary total hip replacements is increased in comparison to the baseline model. Therefore, with some delay, also the number of revision starts to grow. Secondly, the monitoring period after implantation has been extended to infinity, as patients will stay in year 30 after implantation instead of being released from the model. Therefore they contribute to the total number of revisions at least with the 30 years revision rate whereas their real probability for revision is actually higher.Furthermore the model now also includes the 3rd revision, that can be distinguished, as well as any further revision after the third one (cf. 3.7.9). For this reason the total number of revisions is further elevated. Finally the revision rates have been updated with data from the available prostheses registers during the model development and especially long-term results are higher than the values implemented [1].

The revision load, the ratio of revisions to primary implants, grows up to about 20% by the year 2040. Compared to the baseline model that states 23% revision load for 2007 the new model gives 15.2% what corresponds very well to international statistics, which give values between 10 and 18% [24].

Patients with implants

A major shortcoming of predictions by all models can be noticed from Fig. 36. The total number of patients with revised implants at simulation startup is unknown. The number of people with a primary implant also has to be based on estimation (cf. [1]). The error due to these unknowns decreases over time, but in return forecast-uncertainty rises.

Costs

Fig. 34 and Fig. 35 show a similar trend for the costs. The curves show a slightly exponential tendency, which may be caused by considering inflation, as the underlying data for implantations and revisions is not at all exponential. Costs for primary implantations increase by 9.8% while the number of implantations only increases by 6.8%. In contrast the total number of revisions rises by 30.7% while costs only increase by 9.5%

The given ratios point out that the change in the number of procedures does not equal the change in costs. This behavior results from several modifications in the cost calculation algorithm, as well as the calculation of implantations and revisions itself.

Firstly, the costs are now affected by the duration of stay in hospital. As Herzog [1] used default values, only the LDF-Allowance was charged. The new model uses the expected value for the costs due to de distribution of the duration of stay in hospital (see 3.7.8). This may justify the cost increase in primary implantations.

Secondly, when a patient undergoes revision, the new model supplies him with a type of prosthesis, tribological pairing and fixation, determined by the statistical data that is also used for determination of primary implantations. Formerly the patients were supplied with the same prosthesis again. Moreover it was assumed by [1] that prostheses types are equally distributed on primary implantation. Now statistic data for this distribution is integrated in the model. It can be seen from Table 7 that cheaper prostheses are used more often. This may be the reason that costs for revisions rise less than the total number of revisions.

Table 7: Percentage of tribological parings on primary implantation and their costs.

Tribological pairing	**Fraction** [9]	**Material costs** [1]
MeMe	1%	1,498.83 €
MePoly	85%	1,852.67 €
KeKe	1%	2,546.42 €
KePoly	13%	2,193.66 €

5.5 Minimum and maximum scenario

Fig. 38 shows the trend for primary implants for all three built-in scenarios. For total hip replacement all scenarios show the same trend, but of course a different number of implantations according to their underlying implantation rate. In contrast for partial hip replacements the number of the average scenario at first is closer to the minimum scenario, but approaches to the maximum scenario during the observation period.

A possible reason for this different trend is due to the increasing part of elderly people in the population: Since implantation rate for partial hip replacement significantly increases with age, the earlier increase of the maximum scenario is likely to be triggered by the higher implantation rate for people above the age of 50, while the average scenario shows the first significant increase at the age of 75 (cf. Fig. 7). The 5 years age dissection for the minimum and maximum scenarios should also be kept in mind, as it also introduces a slight shift of the implantation rate to earlier implantation. Therefore the max scenario will show increasing implantation number about 25 years before the mean scenario and is already strongly affected by the baby-boomer generation (born in the 1950s and 60s).The mean scenario then catches up with some delay.

Fig. 39 illustrates the total number of patients with implants in Styria. It is clearly visible that the lines tend to spread up over the simulation period. This is a direct reason of the difference in the number of primary implantations that accumulates over time. However even if the number of implantations of partial hip endoprostheses from the mean scenario approaches the maximum scenario as pointed out above, the mean scenarios output tend to stick closer to the minimum values here. This might be reasoned as the expected lifetime of people receiving a partial hip endoprosthesis is likely to be lower than those of patients with total endoprosthesis when comparing the implantation rates (cf. Fig. 6 and Fig. 7). Therefore the number of people with implants is governed mainly by the total hip replacement implantation rate.

Furthermore the three scenarios do not spread too much here, as the life expectancy of patients is crucial for the total number of people with implant. The higher number of implantations in the maximum scenario does not necessarily lead to a vast increase of people with implants, as only the increase of young patients affects the long term results, while older patients are likely to die soon.

Finally Fig. 40 shows the total costs to be expected. The mean scenario here follows approximately the average of the minimum and maximum scenario and therefore behaves as expected.

5.6 Suggested improvements and further work

Although numerous improvements have been realized as part of this work, there are opportunities for further enhancements. The presented model was updated with the most recent available data, but still misses some important statistics since access to the Austrian prostheses register [17] is not available. Especially data concerning the number of patients that already carry an implant at the simulation startup would be a major improvement, as it affects the computation of revisions.

Secondly, data concerning the specific reason for a revision would be useful, as the LKF-System also states an allowance for procedures other than implantation and re-implantation, which might apply in some cases.

Finally the implantation rate is based on historical data, but is likely to change in the future. Retrieval of a drift in implantation rate by long-term data analysis and including a prediction function in the model would be another huge enhancement.

6 Conclusions

The main objective of creating a hip implant model was fulfilled with AnyLogic® 6.9 as the modeling environment. Compared to the baseline model a vast increase in efficiency has been achieved, allowing further and more detailed development, as limitations due to computational effort no longer apply.

Prior to model development, the complex functional relationships regarding hip replacement statistics have been analyzed thoroughly. The presented model then tries to find a feasible compromise between level of detail and skipping (sufficiently) irrelevant aspects during model development (cf. 1.2). The availability of statistics data has been found to be a driver in this regard: For some model aspects that would be worth for further investigation, the required statistical input data are not available. This lack of data has become one of the major challenges during model development and therefore gaining access to obtaining data from the Austrian prostheses register would be a major breakthrough.

Model validation has been performed against accessible statistical data where possible. In addition, applying the V-Model for software development has been employed to proof the functionality and validity of the model.

Finally it should be kept in mind that a model relying on the extrapolation of historical data never represents the real world, which is subject to constant changes in the economic, legislative and technical domain. Ideally however, the presented model can be used to shape these changes: with its increased functionality, it is applicable to a wide range of different scenarios and can be used as input to decision making on different levels of the Austrian public healthcare system.

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8 Figures

9 Tables

10 Appendix

Appendix 1: Screenshots of the input GUI

Appendix 2: Distribution of the duration of stay in hospital

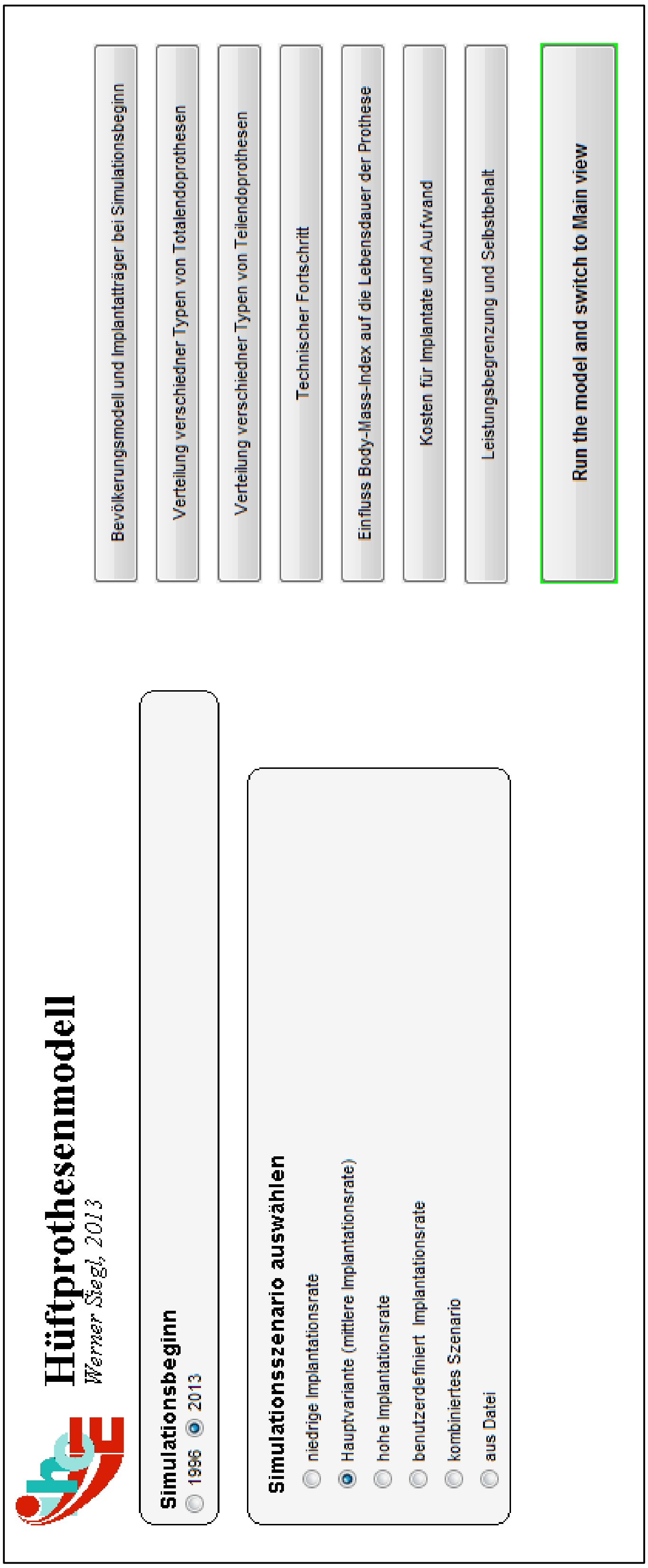
Appendix 3: Default output of the population model for Styria and Austria

Appendix 4: Results default scenario

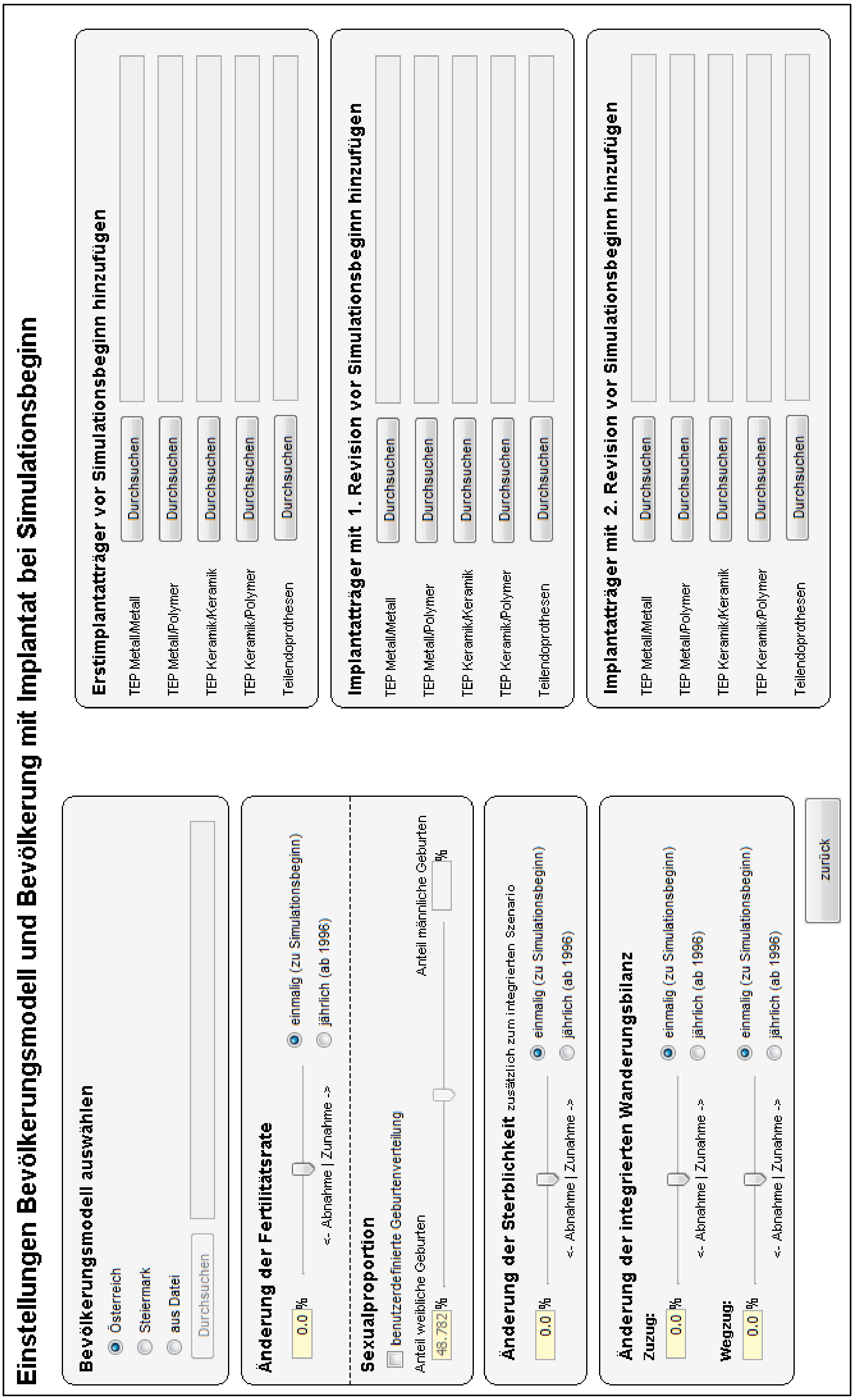
Appendix 5: Output of the minimum and maximum scenario

Appendix 1

Main GUI



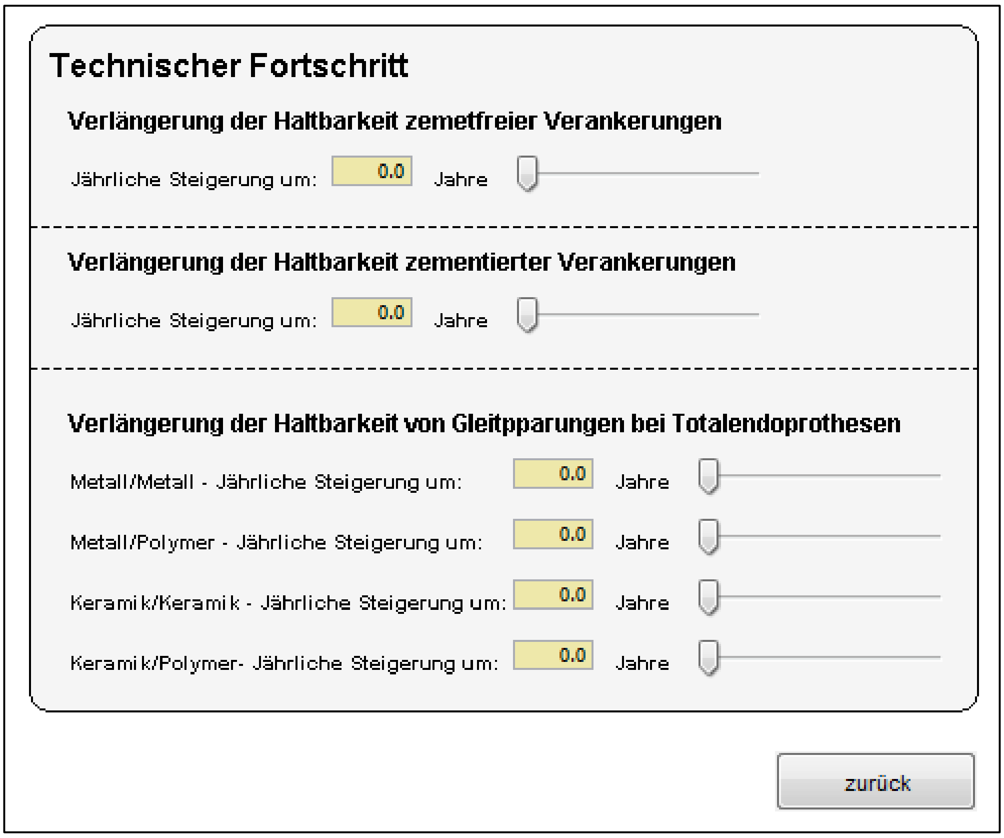
Population model GUI



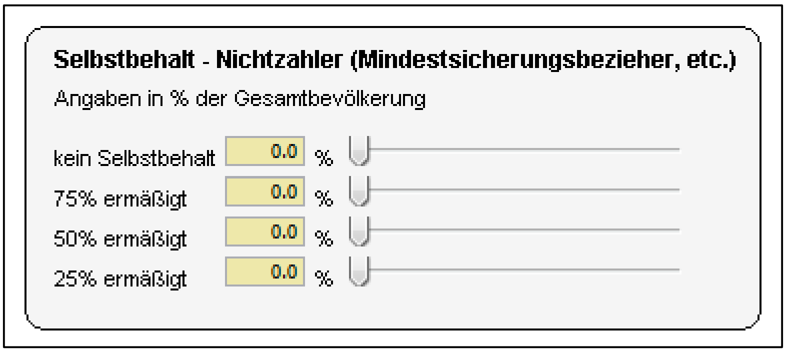
Total hip replacement GUI

Partial hip replacement GUI

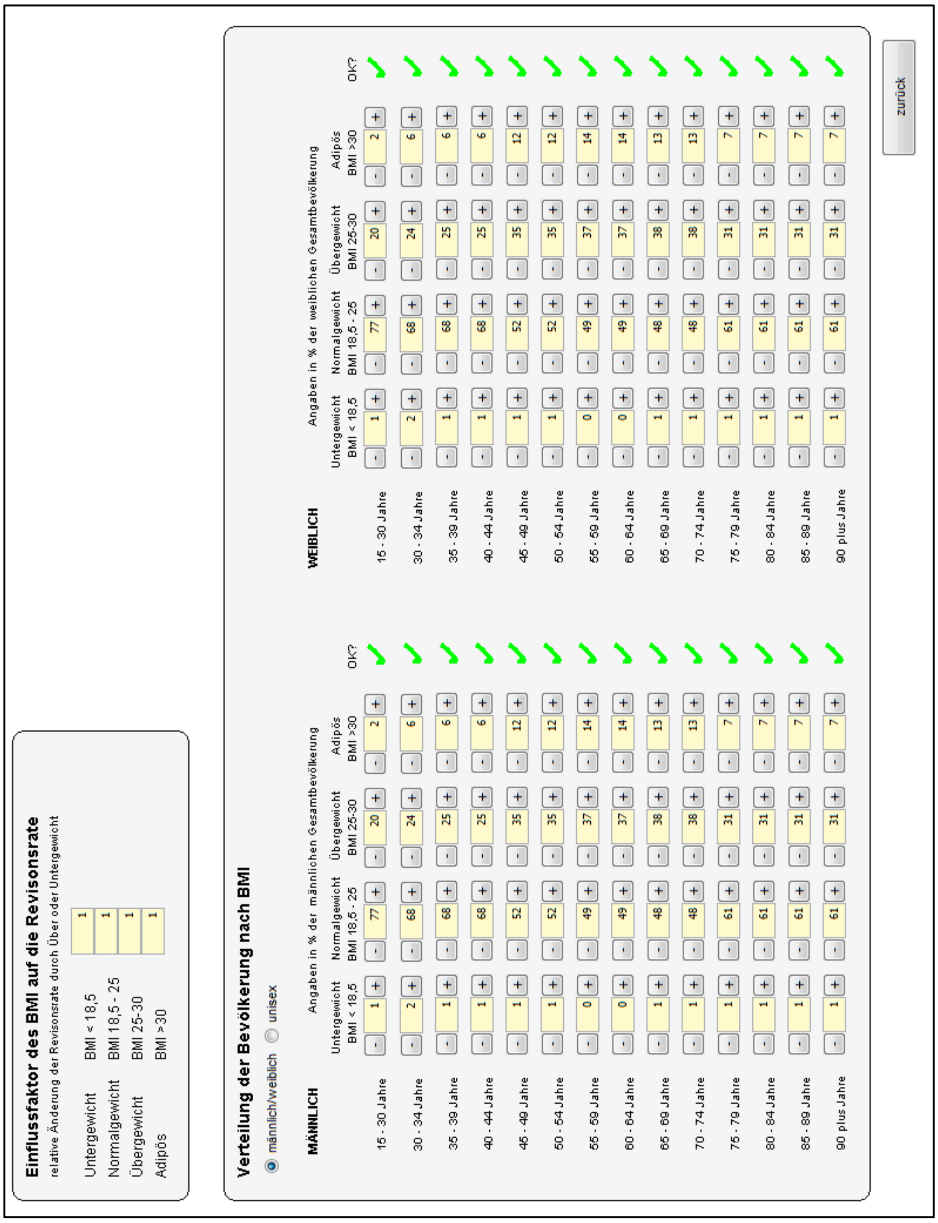
Engineering progress GUI



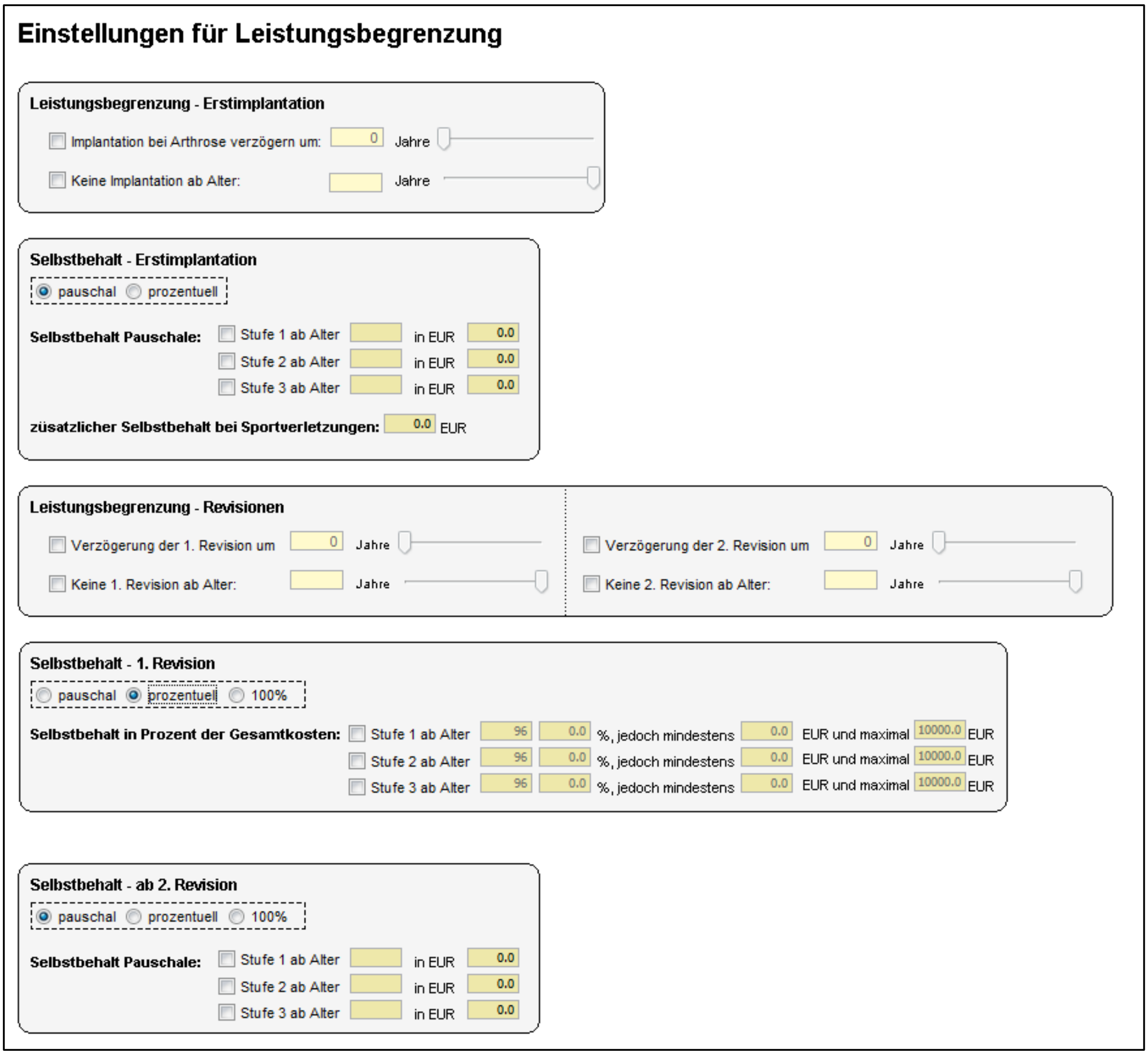
Discount for the social disadvantaged - GUI



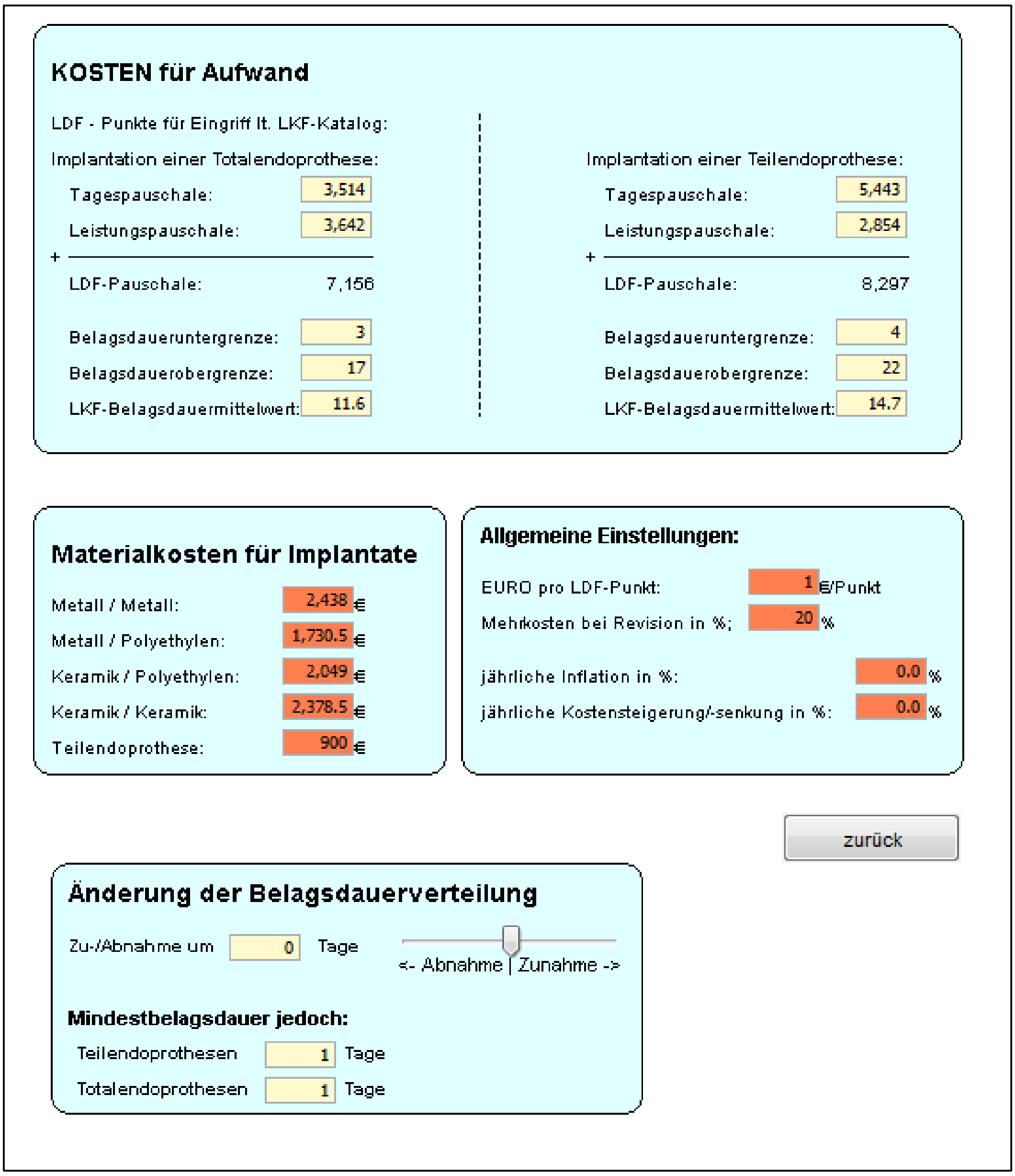
Body Mass Index GUI



Cut of benefit GUI



Costs and duration of stay GUI



Appendix 2

Distribution of the duration of stay in hospital

Duration of stay in days	Relative fraction in %	
	Males	Females
0	0	0
1	0.0441	0.0445
2	0.0489	0.0525
3	0.1056	0.0593
4	0.1718	0.1175
5	0.4966	0.2214
6	1.3542	0.6881
7	3.1026	1.5862
8	5.7307	3.4052
9	8.6331	5.5768
10	8.4235	6.0880
11	13.4857	11.0486
12	12.6675	11.8258
13	13.0585	12.8368
14	7.8496	9.3232
15	5.8300	7.4141
16	4.3134	5.4171
17	2.5335	3.6117
18	2.0700	2.8837
19	1.4315	2.2161
20	1.1351	1.8544
21	1.1225	1.8487
22	0.9223	1.6410
23	0.7173	1.2096
24	0.5880	1.0487
25	0.4793	0.8376
26	0.3390	0.7315
27	0.3658	0.6539
28	0.3468	0.7018
29	0.3374	0.6288
30	0.2491	0.5341
31	0.2113	0.4941
32	0.1986	0.3960
33	0.1718	0.3401
34	0.1529	0.3332
35	0.1435	0.3127
36	0.1340	0.2762
37	0.1167	0.2362
38	0.1056	0.1894
39	0.1025	0.1951
40	0.0568	0.1483

	41	0.0599	0.1563
	42	0.0741	0.1290
	43	0.0804	0.1449
	44	0.0489	0.1392
	45	0.0615	0.0993
	46	0.0378	0.0959
	47	0.0410	0.0708
	48	0.0268	0.0810
	49	0.2223	0.0556

Appendix 3

Default output of the population model

Year	Population Styria	Population Austria
1997	1,185,538	7953067
1998	1,186,022	7969845.443
1999	1,186,264	7983275.52
2000	1,185,649	7997474.196
2001	1,184,899	8018800.353
2002	1,183,734	8033202.535
2003	1,185,608	8055511.384
2004	1,187,056	8093978.013
2005	1,189,242	8134601.169
2006	1,193,367	8187554.501
2007	1,195,175	8228611.792
2008	1,195,920	8252958.967
2009	1,197,721	8283605.16
2010	1,200,525	8318614.205
2011	1,203,486	8349537.513
2012	1,207,740	8389108.781
2013	1,208,699	8419944.086
2014	1,213,255	8443018
2015	1,215,160	8481924.454
2016	1,217,079	8521155.43
2017	1,219,114	8560740.708
2018	1,220,970	8599216.167
2019	1,222,441	8634098.217
2020	1,223,728	8666469.948
2021	1,224,882	8697894.356
2022	1,225,990	8727846.103
2023	1,227,065	8757257.095
2024	1,228,084	8785574.675
2025	1,229,019	8813075.988
2026	1,229,883	8839640.664
2027	1,230,725	8865144.469
2028	1,231,565	8891013.435
2029	1,232,401	8915757.565
2030	1,233,130	8939415.171
2031	1,233,838	8962462.648
2032	1,234,557	8985417.582
2033	1,235,198	9007283.943
2034	1,235,781	9028242.659
2035	1,236,289	9048347.986
2036	1,236,715	9067491.637
2037	1,237,234	9087554.915

2038	1,237,619	9106419.111
2039	1,237,943	9124541.37
2040	1,238,224	9142133.107
2041	1,238,496	9159393.188
2042	1,238,829	9177322.532
2043	1,239,128	9194952.505
2044	1,239,363	9212103.213
2045	1,239,462	9228200.765
2046	1,239,404	9243029.902
2047	1,239,294	9257758.421
2048	1,239,036	9271443.629
2049	1,238,627	9284059.16
2050	1,238,078	9295542.983
2051	1,237,472	9306785.753
2052	1,236,711	9316732.074
2053	1,235,777	9325259.122
2054	1,234,665	9332313.877
2055	1,233,383	9337913.959
2056	1,231,970	9342276.359
2057	1,230,458	9345533.637
2058	1,228,874	9347782.135
2059	1,227,238	9349167.488
2060	1,225,560	9349824.37
2061	1,223,876	9349989.653
2062	1,222,213	9349890.139
2063	1,220,618	9349832.118
2064	1,219,130	9350085.714
2065	1,217,761	9350786.829
2066	1,216,516	9351990.613
2067	1,215,397	9353828.215

Appendix 4

Results default scenario

Year	Primary implantations		Revisions	
	THE	PHE	THE	PHE
1997	1957.564	401.726	0	0
1998	1979.165	411.59	247.562	2.262
1999	1999.733	421.363	252.616	3.276
2000	2019.898	431.781	268.198	4.093
2001	2040.178	442.717	288.962	4.823
2002	2062.39	454.575	307.073	5.365
2003	2081.191	464.935	326.342	5.979
2004	2100.743	476.279	344.21	6.523
2005	2121.327	488.354	362.468	7.134
2006	2144.733	501.577	380.553	7.547
2007	2166.671	515.033	398.137	8.007
2008	2189.852	529.077	415.466	10.01
2009	2214.541	542.877	436.356	11.137
2010	2240.552	556.855	455.266	12.425
2011	2269.085	570.885	473.931	13.434
2012	2295.861	583.984	491.416	14.601
2013	2297.083	566.992	508.662	15.519
2014	2330.817	582.549	525.213	16.272
2015	2365.185	598.011	540.121	17.041
2016	2398.756	613.017	555.433	17.74
2017	2433.295	627.741	570.046	18.375
2018	2468.215	642.361	584.212	18.982
2019	2504.536	657.246	598.051	19.56
2020	2538.661	671.767	611.514	20.13
2021	2573.104	686.192	624.828	20.689
2022	2609.285	702.163	637.829	21.261
2023	2645.658	718.58	650.703	21.816
2024	2681.377	735.251	663.279	22.324
2025	2716.854	753.948	675.223	22.834
2026	2752.495	773.219	686.772	23.345
2027	2786.605	790.956	697.842	23.863
2028	2820.973	810.876	708.579	24.362
2029	2855.178	832.452	719.002	24.871
2030	2889.286	851.54	729.292	25.393
2031	2922.91	871.41	739.34	25.896
2032	2955.768	893.187	749.097	26.377
2033	2987.604	917.069	758.578	26.853
2034	3017.707	938.104	767.886	27.331
2035	3044.21	960.348	777.038	27.779
2036	3068.608	987.351	785.598	28.181
2037	3090.344	1011.999	793.309	28.637

2038	3108.592	1036.065	800.918	29.142
2039	3123.88	1059.786	808.691	29.705
2040	3136.181	1086.6	816.593	30.29
2041	3145.287	1115.134	823.994	30.891
2042	3150.089	1142.616	830.69	31.554
2043	3151.696	1173.884	837.046	32.176
2044	3149.767	1207.164	842.047	32.794
2045	3144.915	1239.362	845.758	33.424
2046	3138.088	1270.721	848.446	34.054
2047	3129.171	1301.875	850.17	34.665
2048	3118.696	1332.025	850.838	35.26
2049	3106.811	1361.453	850.544	35.811
2050	3094.49	1389.518	849.216	36.315
2051	3081.755	1416.158	846.85	36.759
2052	3068.844	1440.25	843.479	37.138
2053	3056.6	1463.276	839.186	37.438
2054	3044.951	1483.094	834.023	37.681
2055	3034.186	1498.912	828.369	37.867
2056	3024.604	1512.785	822.466	37.978
2057	3015.802	1523.601	816.352	38.033
2058	3008.378	1532.805	810.22	38.026
2059	3001.996	1538.681	804.105	37.973
2060	2996.378	1542.788	798.193	37.873
2061	2991.811	1545.266	792.577	37.75
2062	2987.887	1545.182	787.4	37.619
2063	3030.806	1544.575	782.825	37.474
2064	3025.517	1544.062	778.802	37.332
2065	3022.028	1543.743	775.276	37.194
2066	3018.638	1543.107	772.133	37.081
2067	3017.359	1542.057	769.441	36.997

Year	Costs in €		
	primary implantation	revisions	total
1997	12,348,503.58	0.00	12,348,503.58
1998	12,806,197.24	1,556,992.61	14,363,189.85
1999	13,272,429.69	1,632,093.63	14,904,523.32
2000	13,754,636.50	1,777,402.48	15,532,038.97
2001	14,255,708.69	1,962,733.43	16,218,442.12
2002	14,789,310.23	2,136,411.99	16,925,722.22
2003	15,310,795.12	2,325,764.61	17,636,559.73
2004	15,859,101.77	2,512,342.53	18,371,444.30
2005	16,435,719.60	2,709,739.66	19,145,459.25
2006	17,056,146.21	2,912,327.20	19,968,473.41
2007	17,688,330.77	3,119,432.80	20,807,763.57
2008	18,353,067.07	3,344,259.18	21,697,326.25
2009	19,048,161.12	3,599,885.70	22,648,046.82

2010	19,776,458.25	3,850,647.93	23,627,106.18
2011	20,547,320.00	4,106,902.14	24,654,222.14
2012	21,323,784.59	4,364,195.55	25,687,980.14
2013	21,713,229.17	4,627,098.24	26,340,327.41
2014	22,601,408.67	4,891,743.97	27,493,152.64
2015	23,513,554.97	5,148,988.94	28,662,543.91
2016	24,445,741.10	5,418,674.22	29,864,415.33
2017	25,414,334.99	5,690,695.71	31,105,030.70
2018	26,417,059.62	5,967,664.49	32,384,724.11
2019	27,466,949.17	6,250,766.51	33,717,715.68
2020	28,528,376.09	6,539,755.19	35,068,131.28
2021	29,626,322.43	6,837,044.78	36,463,367.21
2022	30,789,691.78	7,141,297.37	37,930,989.16
2023	31,996,708.52	7,454,334.18	39,451,042.70
2024	33,238,845.57	7,774,106.61	41,012,952.18
2025	34,538,001.26	8,097,317.34	42,635,318.60
2026	35,886,548.29	8,426,607.18	44,313,155.47
2027	37,247,611.83	8,761,021.26	46,008,633.09
2028	38,677,096.40	9,101,991.63	47,779,088.03
2029	40,167,944.42	9,450,137.79	49,618,082.21
2030	41,679,254.82	9,807,890.45	51,487,145.27
2031	43,241,723.38	10,173,641.26	53,415,364.64
2032	44,866,251.38	10,546,808.15	55,413,059.53
2033	46,553,789.31	10,927,846.89	57,481,636.19
2034	48,241,088.15	11,318,378.50	59,559,466.64
2035	49,949,952.79	11,718,349.46	61,668,302.26
2036	51,742,256.45	12,121,239.03	63,863,495.48
2037	53,526,095.73	12,524,330.59	66,050,426.32
2038	55,310,441.42	12,938,758.83	68,249,200.25
2039	57,103,144.65	13,369,114.94	70,472,259.59
2040	58,947,347.23	13,814,833.83	72,762,181.06
2041	60,823,649.18	14,265,891.23	75,089,540.41
2042	62,676,318.80	14,719,352.27	77,395,671.06
2043	64,586,865.66	15,179,405.68	79,766,271.34
2044	66,526,470.06	15,628,520.40	82,154,990.46
2045	68,458,533.81	16,066,889.50	84,525,423.31
2046	70,399,268.88	16,497,994.91	86,897,263.79
2047	72,354,970.66	16,921,602.33	89,276,572.99
2048	74,320,844.06	17,335,005.06	91,655,849.13
2049	76,302,338.43	17,738,310.55	94,040,648.98
2050	78,304,986.94	18,128,863.46	96,433,850.39
2051	80,327,523.75	18,505,012.50	98,832,536.25
2052	82,353,378.11	18,865,929.56	101,219,307.66
2053	84,423,723.55	19,211,787.65	103,635,511.21
2054	86,498,729.00	19,542,818.36	106,041,547.35
2055	88,567,332.73	37,929,774.92	126,497,107.65
2056	90,672,645.50	38,553,509.32	129,226,154.82

2057	92,784,235.17	39,175,105.48	131,959,340.65
2058	94,942,266.75	39,800,247.53	134,742,514.28
2059	97,105,293.34	40,432,516.76	137,537,810.11
2060	99,297,814.59	41,078,229.41	140,376,043.99
2061	100,277,480.07	41,745,545.30	142,023,025.37
2062	102,490,792.15	42,441,818.18	144,932,610.33
2063	104,748,749.13	43,175,639.13	147,924,388.26
2064	107,073,441.41	43,949,764.84	151,023,206.25
2065	109,454,670.85	44,763,260.91	154,217,931.76
2066	111,881,459.14	45,614,418.75	157,495,877.89
2067	114,347,860.31	46,505,921.44	160,853,781.75

Year	Number of patients with implant			
	primary implantation	1st revision	2nd revision	3rd revision
1996	24,808	0	0	0
1997	24,682	0	0	0
1998	25,454	999	0	0
1999	26,189	1,466	461	0
2000	26,878	1,926	911	0
2001	27,521	2,388	1,331	22
2002	28,124	2,838	1,736	46
2003	28,676	3,284	2,134	76
2004	29,188	3,715	2,521	110
2005	29,662	4,134	2,898	149
2006	30,108	4,539	3,263	193
2007	30,521	4,926	3,615	241
2008	30,898	5,302	3,951	294
2009	31,252	5,670	4,267	349
2010	31,585	6,009	4,580	418
2011	31,903	6,329	4,870	490
2012	32,200	6,625	5,143	568
2013	32,373	6,901	5,393	650
2014	32,623	7,154	5,627	738
2015	32,888	7,384	5,840	827
2016	33,165	7,596	6,035	920
2017	33,459	7,790	6,214	1,014
2018	33,771	7,968	6,377	1,109
2019	34,106	8,133	6,527	1,205
2020	34,456	8,285	6,665	1,301
2021	34,824	8,428	6,793	1,396
2022	35,213	8,562	6,912	1,491
2023	35,620	8,688	7,023	1,585
2024	36,041	8,808	7,127	1,678
2025	36,477	8,921	7,225	1,769
2026	36,927	9,030	7,317	1,858

2027	37,381	9,135	7,405	1,944
2028	37,845	9,236	7,488	2,028
2029	38,315	9,335	7,568	2,108
2030	38,785	9,431	7,645	2,186
2031	39,255	9,524	7,719	2,260
2032	39,727	9,617	7,792	2,330
2033	40,200	9,708	7,863	2,398
2034	40,665	9,799	7,934	2,461
2035	41,125	9,890	8,005	2,522
2036	41,586	9,982	8,078	2,580
2037	42,033	10,074	8,151	2,635
2038	42,460	10,165	8,223	2,686
2039	42,862	10,256	8,293	2,735
2040	43,241	10,344	8,362	2,782
2041	43,591	10,427	8,428	2,827
2042	43,902	10,504	8,488	2,870
2043	44,182	10,573	8,542	2,909
2044	44,429	10,633	8,589	2,946
2045	44,636	10,681	8,628	2,979
2046	44,801	10,718	8,656	3,008
2047	44,926	10,742	8,674	3,033
2048	45,011	10,753	8,681	3,054
2049	45,058	10,750	8,677	3,070
2050	45,070	10,735	8,662	3,081
2051	45,051	10,706	8,637	3,088
2052	45,003	10,666	8,602	3,091
2053	44,935	10,616	8,558	3,088
2054	44,847	10,558	8,508	3,081
2055	44,742	10,492	8,451	3,070
2056	44,627	10,423	8,391	3,055
2057	44,505	10,350	8,328	3,038
2058	44,382	10,277	8,265	3,018
2059	44,260	10,205	8,203	2,996
2060	44,141	10,136	8,143	2,973
2061	44,029	10,070	8,087	2,950
2062	43,922	10,010	8,034	2,926

Appendix 5

Primary implantations

Year	Minimum scenario		Maximum scenario	
	THR	PHR	THR	PHR
1997	1701.519	258.291	2038.183	752.766
1998	1721.112	262.616	2057.48	761.674
1999	1739.342	267.503	2075.756	772.264
2000	1757.995	274.404	2096.325	787.601
2001	1774.121	280.58	2116.371	806.192
2002	1793.298	285.523	2139.866	816.081
2003	1809.747	288.533	2160.034	821.252
2004	1827.425	292.246	2181.664	825.586
2005	1851.306	297.653	2206.52	832.289
2006	1874.135	304.644	2230.876	843.199
2007	1896.495	311.643	2255.747	849.035
2008	1918.325	317.926	2281.632	862.138
2009	1941.056	323.576	2308.175	878.309
2010	1966.584	329.975	2337.358	889.091
2011	1989.092	336.434	2366.978	902.333
2012	2013.397	341.049	2397.38	911.623
2013	2016.495	335.367	2393.02	907.364
2014	2044.892	338.794	2428.904	912.949
2015	2074.594	341.814	2465.556	910.806
2016	2105.773	345.912	2504	912.337
2017	2135.464	348.978	2540.061	915.515
2018	2166.056	350.379	2576.548	920.236
2019	2197.092	351.595	2612.758	916.764
2020	2228.126	353.407	2647.779	918.62
2021	2255.01	360.176	2681.283	924.721
2022	2281.493	365.541	2715.077	934.257
2023	2310.907	371.86	2752.702	942.859
2024	2342.451	376.425	2792.386	956.762
2025	2373.361	381.909	2831.328	967.688
2026	2400.551	391.326	2868.17	980.353
2027	2429.852	398.292	2905.672	993.538
2028	2458.263	406.672	2941.556	1007.404
2029	2486.517	414.224	2976.421	1024.422
2030	2513.874	422.591	3010.528	1042.269
2031	2538.725	431.634	3043.587	1061.69
2032	2563.202	438.306	3077.681	1079.336
2033	2585.358	446.677	3111.079	1095.104
2034	2605.459	455.688	3142.422	1110.313
2035	2624.239	464.455	3171.391	1125.267
2036	2641.15	471.02	3197.112	1141.281
2037	2656.344	477.692	3219.397	1157.169

2038	2668.903	486.357	3237.067	1174.699
2039	2678.631	496.595	3252.267	1193.463
2040	2685.345	507.603	3266.857	1212.134
2041	2690.211	518.781	3279.425	1231.635
2042	2692.457	531.668	3291.14	1250.847
2043	2691.748	544.098	3300.878	1270.6
2044	2688.981	555.691	3308.667	1289.854
2045	2684.346	567.498	3314.899	1309.277
2046	2679.125	579.027	3319.149	1328.911
2047	2673.294	589.707	3323.053	1347.534
2048	2666.587	600.322	3325.281	1365.581
2049	2658.523	610.205	3327.03	1381.55
2050	2648.604	619.687	3328.616	1396.563
2051	2638.902	627.9	3330.082	1409.455
2052	2629.907	633.913	3332.297	1420.637
2053	2621.316	638.162	3333.585	1429.917
2054	2612.822	641.163	3334.206	1436.971
2055	2604.466	643.115	3334.605	1442.018
2056	2596.453	644.343	3334.811	1444.953
2057	2589.711	644.182	3335.195	1446.118
2058	2584.075	642.94	3335.073	1445.848
2059	2579.104	640.483	3333.807	1444.262
2060	2574.532	636.616	3331.593	1441.536
2061	2569.598	633.376	3328.684	1437.598
2062	2564.905	630.496	3325.072	1433.14
2063	2560.733	628.088	3321.459	1428.635
2064	2557.386	625.37	3317.704	1424.415
2065	2554.895	622.196	3313.844	1420.6
2066	2552.308	620.047	3309.447	1417.55
2067	2549.84	618.99	3304.683	1415.263

Revisions

Year	Minimum scenario		Maximum scenario	
	THR	PHR	THR	PHR
1997	0	0	0	0
1998	0	0	0	0
1999	247.696	1.37	248.543	3.63
2000	247.759	1.979	255.724	5.131
2001	260.481	2.437	272.782	6.295
2002	279.504	2.834	294.713	7.289
2003	295.978	3.127	313.98	7.966
2004	313.847	3.455	334.492	8.719
2005	330.243	3.737	353.658	9.376
2006	347.142	4.051	373.483	10.133
2007	363.771	4.257	392.861	10.605

2008	380.285	4.5	412.015	11.134
2009	397.336	5.556	436.522	14.129
2010	415.755	6.127	463.399	15.753
2011	433.563	6.77	489.125	17.65
2012	450.761	7.264	514.456	19.122
2013	467.516	7.831	540.462	20.89
2014	483.655	8.253	566.017	22.22
2015	499.669	8.599	591.715	23.464
2016	514.283	8.913	616.502	24.599
2017	529.519	9.173	642.455	25.614
2018	544.389	9.396	668.523	26.542
2019	559.115	9.587	694.845	27.419
2020	573.748	9.752	721.85	28.217
2021	588.235	9.903	749.565	29.024
2022	602.775	10.055	778.157	29.836
2023	617.301	10.229	807.753	30.663
2024	631.601	10.403	837.024	31.435
2025	645.607	10.566	865.843	32.144
2026	658.962	10.721	893.484	32.817
2027	671.954	10.872	920.315	33.456
2028	684.443	11.061	946.191	34.077
2029	696.523	11.24	971.373	34.681
2030	708.269	11.432	995.848	35.296
2031	719.856	11.618	1019.728	35.917
2032	731.146	11.803	1043.146	36.527
2033	742.125	11.995	1066.041	37.109
2034	752.724	12.163	1088.532	37.661
2035	763.088	12.335	1110.687	38.193
2036	773.193	12.502	1132.68	38.674
2037	782.666	12.648	1153.842	39.063
2038	791.365	12.806	1173.793	39.508
2039	799.833	12.986	1193.323	40.055
2040	808.247	13.214	1212.744	40.715
2041	816.57	13.464	1232.092	41.4
2042	824.291	13.729	1250.667	42.098
2043	831.264	14.029	1268.249	42.88
2044	837.737	14.32	1285.354	43.575
2045	842.979	14.611	1300.761	44.219
2046	847.064	14.905	1314.526	44.853
2047	850.199	15.206	1326.976	45.476
2048	852.43	15.5	1338.215	46.063
2049	853.708	15.785	1348.043	46.619
2050	854.122	16.053	1356.597	47.1
2051	853.644	16.296	1363.684	47.5
2052	852.268	16.514	1369.289	47.803
2053	849.991	16.698	1373.445	48.003
2054	846.945	16.836	1376.14	48.121

2055	843.192	16.939	1377.386	48.195
2056	839.041	17.006	1377.526	48.225
2057	834.669	17.038	1376.836	48.203
2058	830.103	17.039	1375.249	48.174
2059	825.492	17.005	1373.034	48.063
2060	820.876	16.944	1370.2	47.892
2061	816.415	16.855	1366.941	47.667
2062	812.171	16.748	1363.34	47.426
2063	808.228	16.64	1359.519	47.211
2064	804.678	16.532	1355.766	46.989
2065	801.488	16.43	1352.033	46.77
2066	798.62	16.327	1348.307	46.545
2067	795.993	16.233	1344.459	46.358
2068	793.667	16.157	1340.654	46.215

Costs

Year	Minimum scenario costs in €		
	primary implantation	revisions	total
1997	10,282,807.30	0.00	10,282,807.30
1998	10,652,905.48	1,552,520.33	12,205,425.81
1999	11,030,134.58	1,593,189.94	12,623,324.52
2000	11,432,324.26	1,716,659.82	13,148,984.09
2001	11,828,726.89	1,886,794.18	13,715,521.06
2002	12,248,657.69	2,045,854.77	14,294,512.46
2003	12,654,124.68	2,221,359.56	14,875,484.24
2004	13,083,693.88	2,393,126.94	15,476,820.82
2005	13,576,167.63	2,575,667.81	16,151,835.45
2006	14,087,432.37	2,762,678.43	16,850,110.79
2007	14,612,153.01	2,956,438.81	17,568,591.82
2008	15,145,559.83	3,168,119.27	18,313,679.11
2009	15,698,093.96	3,395,422.71	19,093,516.67
2010	16,293,277.25	3,627,204.08	19,920,481.33
2011	16,886,011.27	3,861,669.33	20,747,680.60
2012	17,498,100.65	4,101,932.27	21,600,032.92
2013	17,893,099.88	4,344,695.70	22,237,795.58
2014	18,560,521.86	4,594,351.61	23,154,873.47
2015	19,248,662.54	4,838,019.93	24,086,682.47
2016	19,979,196.91	5,095,865.33	25,075,062.24
2017	20,712,523.84	5,359,143.56	26,071,667.40
2018	21,463,410.51	5,630,111.71	27,093,522.22
2019	22,240,196.65	5,909,495.36	28,149,692.01
2020	23,046,420.86	6,197,101.51	29,243,522.37
2021	23,882,638.16	6,495,400.07	30,378,038.23
2022	24,728,871.39	6,804,211.78	31,533,083.17
2023	25,638,259.88	7,121,278.23	32,759,538.10

2024	26,581,154.39	7,445,884.72	34,027,039.11
2025	27,556,176.69	7,774,013.08	35,330,189.77
2026	28,561,671.63	8,108,929.61	36,670,601.23
2027	29,597,005.56	8,449,467.77	38,046,473.33
2028	30,669,486.24	8,796,179.42	39,465,665.66
2029	31,765,253.25	9,150,262.42	40,915,515.67
2030	32,893,518.99	9,513,848.95	42,407,367.94
2031	34,035,191.79	9,885,326.68	43,920,518.47
2032	35,181,509.75	10,264,745.07	45,446,254.82
2033	36,353,435.16	10,650,784.41	47,004,219.56
2034	37,542,940.34	11,045,832.79	48,588,773.12
2035	38,748,306.80	11,449,534.97	50,197,841.76
2036	39,938,433.15	11,856,255.71	51,794,688.85
2037	41,141,399.39	12,263,995.35	53,405,394.74
2038	42,367,981.42	12,680,973.47	55,048,954.89
2039	43,610,547.92	13,110,510.81	56,721,058.74
2040	44,855,124.59	13,551,938.00	58,407,062.59
2041	46,109,449.16	13,996,920.22	60,106,369.38
2042	47,382,454.58	14,442,988.52	61,825,443.10
2043	48,638,286.51	14,893,237.99	63,531,524.51
2044	49,882,660.10	15,334,514.67	65,217,174.76
2045	51,131,995.00	15,767,088.74	66,899,083.74
2046	52,398,549.14	16,193,786.31	68,592,335.45
2047	53,672,863.83	16,614,332.87	70,287,196.70
2048	54,962,023.29	17,026,827.22	71,988,850.51
2049	56,246,582.43	17,431,853.68	73,678,436.10
2050	57,521,320.44	17,827,708.90	75,349,029.34
2051	58,807,262.72	18,213,187.08	77,020,449.79
2052	60,096,623.57	18,586,921.99	78,683,545.55
2053	61,390,353.96	18,950,375.91	80,340,729.87
2054	62,690,954.33	19,304,111.41	81,995,065.74
2055	64,001,994.60	19,654,175.37	83,656,169.97
2056	65,333,556.35	20,004,144.34	85,337,700.68
2057	66,691,837.50	20,354,413.27	87,046,250.78
2058	68,080,071.32	20,708,319.32	88,788,390.63
2059	69,486,597.01	21,066,943.42	90,553,540.43
2060	70,901,306.43	21,434,435.41	92,335,741.84
2061	72,349,597.09	21,812,955.07	94,162,552.16
2062	73,840,641.17	22,205,637.12	96,046,278.29
2063	75,385,135.66	22,615,694.37	98,000,830.03
2064	76,974,655.69	23,043,146.08	100,017,801.77
2065	78,608,263.46	23,487,552.21	102,095,815.67
2066	80,298,423.41	23,947,608.83	104,246,032.24
2067	82,054,893.82	24,426,015.89	106,480,909.72

Year	Maximum scenario costs in €		
	primary implantation	revisions	total
1997	14,516,092.23	0.00	14,516,092.23
1998	15,007,560.09	1,571,263.38	16,578,823.47
1999	15,517,271.39	1,663,242.74	17,180,514.12
2000	16,080,916.27	1,821,095.06	17,902,011.33
2001	16,677,250.76	2,016,944.12	18,694,194.88
2002	17,264,477.26	2,200,694.88	19,465,172.14
2003	17,822,778.08	2,401,199.62	20,223,977.70
2004	18,402,099.76	2,599,624.75	21,001,724.51
2005	19,033,673.71	2,811,607.88	21,845,281.59
2006	19,707,379.11	3,026,722.06	22,734,101.17
2007	20,373,791.10	3,249,097.42	23,622,888.51
2008	21,114,341.28	3,540,911.65	24,655,252.93
2009	21,903,240.39	3,853,207.51	25,756,447.89
2010	22,700,121.82	4,170,908.25	26,871,030.07
2011	23,542,414.94	4,494,682.49	28,037,097.43
2012	24,389,870.46	4,839,647.13	29,229,517.59
2013	24,900,572.97	5,190,677.13	30,091,250.10
2014	25,806,917.46	5,555,526.43	31,362,443.89
2015	26,678,370.78	5,922,698.13	32,601,068.92
2016	27,619,424.07	6,313,788.98	33,933,213.05
2017	28,582,688.82	6,720,055.88	35,302,744.70
2018	29,592,001.85	7,143,682.83	36,735,684.69
2019	30,562,270.94	7,589,414.01	38,151,684.95
2020	31,595,930.33	8,059,317.56	39,655,247.89
2021	32,683,827.63	8,556,171.84	41,239,999.48
2022	33,838,204.72	9,082,667.89	42,920,872.61
2023	35,056,783.95	9,624,683.68	44,681,467.63
2024	36,382,882.52	10,181,014.26	46,563,896.78
2025	37,715,676.29	10,743,749.04	48,459,425.33
2026	39,085,801.37	11,316,980.82	50,402,782.18
2027	40,511,346.80	11,899,081.56	52,410,428.36
2028	41,971,036.66	12,493,144.88	54,464,181.54
2029	43,497,740.70	13,099,359.10	56,597,099.80
2030	45,072,423.13	13,719,175.11	58,791,598.24
2031	46,701,424.96	14,354,281.89	61,055,706.85
2032	48,374,562.85	15,003,887.60	63,378,450.45
2033	50,069,745.80	15,669,745.46	65,739,491.26
2034	51,785,763.29	16,353,214.27	68,138,977.56
2035	53,521,002.65	17,056,716.26	70,577,718.91
2036	55,279,680.36	17,770,242.10	73,049,922.46
2037	57,043,953.53	18,489,923.04	75,533,876.57
2038	58,818,135.73	19,228,302.05	78,046,437.78
2039	60,625,882.08	19,990,851.51	80,616,733.59
2040	62,475,442.73	20,777,480.94	83,252,923.67
2041	64,360,078.27	21,577,000.87	85,889,113.74

2042	66,281,342.30	22,386,713.33	88,525,303.82
2043	68,234,562.73	23,212,387.55	91,161,493.90
2044	70,204,943.83	24,032,928.72	93,797,683.98
2045	72,207,562.07	24,848,753.33	96,433,874.05
2046	74,236,039.90	25,664,550.04	99,070,064.13
2047	76,297,970.28	26,480,863.51	101,706,254.21
2048	78,377,629.66	27,292,917.05	104,342,444.28
2049	80,470,350.51	28,101,324.94	106,978,634.36
2050	82,598,854.47	28,900,786.53	109,614,824.44
2051	84,744,228.97	29,689,114.65	112,251,014.51
2052	86,928,589.35	30,465,172.96	114,887,204.59
2053	89,116,883.44	31,227,428.76	117,523,394.67
2054	91,306,316.67	31,975,183.45	120,159,584.75
2055	93,507,362.25	32,714,428.74	122,795,774.82
2056	95,717,324.69	33,450,102.46	125,431,964.90
2057	97,948,546.15	34,180,576.56	128,068,154.98
2058	100,192,273.29	34,909,603.36	130,704,345.05
2059	102,435,609.80	35,637,038.82	133,340,535.13
2060	104,684,295.78	36,367,181.72	135,976,725.21
2061	106,940,692.22	37,102,702.52	138,612,915.28
2062	109,217,788.94	37,847,595.50	141,249,105.36
2063	111,542,165.67	38,608,792.85	143,885,295.44
2064	113,918,715.53	39,385,599.50	146,521,485.52
2065	116,352,709.23	40,177,757.79	149,157,675.59
2066	118,842,982.23	40,983,030.11	151,793,865.67
2067	121,395,833.17	41,806,697.93	154,430,055.75

Number of patients with implant

Year	Minimum scenario				
	Primary implant	**1st revision**	**2nd revision**	**3rd revision**	**Total**
1996	24808	0	0	0	24808
1997	24130.093	0	0	0	24130.093
1998	24763.445	498.133	0	0	25261.578
1999	25382.166	731.147	230.52	0	26343.833
2000	25982.235	965.568	451.598	0	27399.40104
2001	26551.196	1205.453	663.403	5.53	28425.582
2002	27094.97	1443.72	872.492	11.397	29422.579
2003	27602.078	1683.16	1080.42	18.708	30384.366
2004	28081.421	1919.35	1287.073	26.988	31314.832
2005	28547.256	2153.449	1491.68	36.679	32229.064
2006	28992.886	2383.931	1693.535	47.558	33117.91
2007	29417.785	2610.189	1892.186	59.763	33979.923
2008	29817.053	2835.285	2086.514	72.898	34811.75
2009	30198.168	3057.431	2275.985	87.09	35618.674

2010	30568.03	3269.95	2464.919	104.806	36407.705
2011	30917.883	3476.241	2646.359	123.602	37164.085
2012	31251.148	3674.573	2822.075	144.4	37892.196
2013	31509.621	3864.833	2990.275	166.384	38531.113
2014	31802.821	4046.661	3152.3	190.149	39191.931
2015	32098.868	4219.445	3307.024	214.806	39840.143
2016	32402.919	4385.547	3454.825	240.688	40483.979
2017	32709.079	4544.415	3596.164	267.48	41117.138
2018	33021.143	4696.618	3731.4	295.077	41744.238
2019	33341.65	4843.035	3861.231	323.351	42369.267
2020	33671.56	4984.082	3986.28	352.261	42994.183
2021	34011.373	5120.714	4107.071	381.758	43620.916
2022	34355.603	5253.42	4223.979	411.751	44244.753
2023	34712.685	5381.978	4337.269	442.172	44874.104
2024	35077.957	5506.503	4447.183	472.932	45504.575
2025	35450.025	5626.499	4553.666	503.896	46134.086
2026	35828.477	5742.856	4656.646	534.864	46762.843
2027	36210.732	5855.551	4756.365	565.733	47388.381
2028	36596.39	5964.44	4852.599	596.388	48009.817
2029	36980.712	6069.695	4945.436	626.707	48622.55
2030	37363.728	6171.587	5035.169	656.731	49227.215
2031	37741.028	6270.152	5121.901	686.387	49819.468
2032	38108.279	6365.586	5205.805	715.609	50395.279
2033	38466.489	6457.644	5286.861	744.37	50955.364
2034	38815.414	6546.928	5365.319	772.595	51500.256
2035	39155.718	6633.729	5441.889	800.456	52031.792
2036	39479.946	6717.821	5516.581	827.915	52542.263
2037	39788.096	6798.958	5588.941	854.827	53030.822
2038	40078.453	6877.151	5658.356	881.284	53495.244
2039	40347.487	6952.217	5724.598	907.315	53931.617
2040	40588.711	7023.418	5787.468	933.119	54332.716
2041	40799.84	7089.352	5846.039	958.595	54693.826
2042	40980.646	7149.252	5899.502	983.573	55012.973
2043	41126.269	7202.774	5947.305	1008.045	55284.393
2044	41235.528	7248.505	5989.132	1031.824	55504.989
2045	41308.831	7285.974	6024.12	1054.754	55673.679
2046	41348.045	7314.908	6051.696	1076.767	55791.416
2047	41353.426	7335.044	6071.688	1097.816	55857.974
2048	41327.544	7346.103	6083.878	1117.831	55875.356
2049	41270.504	7348.288	6088.265	1136.689	55843.746
2050	41184.579	7341.71	6085.194	1154.37	55765.853
2051	41074.666	7327.009	6075.068	1170.809	55647.552
2052	40944.447	7304.729	6058.461	1185.993	55493.63
2053	40797.424	7275.847	6036.12	1199.931	55309.322
2054	40638.105	7241.184	6008.759	1212.615	55100.663
2055	40471.149	7202.167	5977.337	1224.085	54874.738
2056	40300.748	7160.16	5943.068	1234.447	54638.423

2057	40131.238	7116.058	5906.858	1243.806	54397.96
2058	39966.076	7071.181	5869.693	1252.147	54159.097
2059	39807.177	7026.396	5832.492	1259.553	53925.618
2060	39655.602	6982.797	5796.038	1266.063	53700.5
2061	39513.483	6941.208	5761.14	1271.769	53487.6
2062	39382.658	6902.155	5728.163	1276.719	53289.695

Year	Maximum scenario				
	Primary implant	1st revision	2nd revision	3rd revision	Total
1996	24808	0	0	0	24808
1997	25792.37	0	0	0	25792.37
1998	27219.844	504.346	0	0	27724.19
1999	28600.155	756.315	231.372	0	29587.842
2000	29940.207	1011.111	459.998	0	31411.3161
2001	31236.412	1272.203	683.216	5.552	33197.383
2002	32476.255	1533.245	905.775	11.611	34926.886
2003	33649.53	1797.157	1128.899	19.235	36594.821
2004	34767.581	2059.689	1352.317	27.946	38207.533
2005	35842.322	2322.285	1575.328	38.188	39778.123
2006	36877.568	2582.355	1797.337	49.755	41307.015
2007	37862.299	2839.376	2017.622	62.801	42782.098
2008	38805.631	3109.35	2234.885	76.95	44226.816
2009	39717.888	3383.796	2453.242	92.326	45647.252
2010	40587.903	3654.556	2677.691	111.438	47031.588
2011	41426.002	3924.47	2900.488	132.101	48383.061
2012	42220.574	4194.317	3122.864	155.228	49692.983
2013	42885.1	4461.929	3343.832	180.06	50870.921
2014	43583.329	4727.157	3564.471	207.226	52082.183
2015	44251.948	4989.55	3783.632	235.938	53261.068
2016	44910.542	5251.747	4001.823	266.566	54430.678
2017	45554.628	5513.311	4219.837	298.878	55586.654
2018	46192.165	5774.909	4438.206	332.824	56738.104
2019	46806.203	6038.049	4657.671	368.365	57870.288
2020	47413.278	6303.546	4879.478	405.706	59002.008
2021	48013.722	6572.603	5104.228	444.87	60135.423
2022	48610.5	6846.201	5332.59	485.939	61275.23
2023	49205.37	7122.177	5565.127	528.944	62421.618
2024	49809.661	7399.613	5801.522	574.029	63584.825
2025	50407.613	7676.68	6040.841	621.168	64746.302
2026	51001.983	7953.203	6281.872	670.332	65907.39
2027	51594.679	8228.201	6523.875	721.529	67068.284
2028	52180.534	8500.904	6765.689	774.8	68221.927
2029	52761.754	8770.361	7006.433	830.159	69368.707
2030	53335.822	9035.847	7245.462	887.754	70504.885
2031	53902.614	9296.98	7482.048	947.666	71629.308

2032	54458.718	9553.088	7715.595	1009.965	72737.366
2033	54998.661	9803.588	7945.36	1074.766	73822.375
2034	55523.519	10048.585	8171.244	1142.146	74885.494
2035	56035.667	10288.733	8393.777	1212.396	75930.573
2036	56532.248	10522.772	8612.496	1285.653	76953.169
2037	57007.057	10749.558	8825.979	1361.731	77944.325
2038	57455.991	10969.053	9033.062	1440.758	78898.864
2039	57877.505	11180.816	9233.008	1522.845	79814.174
2040	58267.389	11383.427	9424.933	1608.239	80683.988
2041	58621.536	11574.8	9607.392	1696.72	81500.448
2042	58938.457	11753.856	9778.97	1787.936	82259.219
2043	59216.662	11920.08	9938.797	1881.785	82957.324
2044	59452.804	12070.846	10086.071	1977.844	83587.565
2045	59646.078	12205.372	10219.365	2075.59	84146.405
2046	59795.102	12323.26	10337.716	2174.665	84630.743
2047	59900.832	12424.265	10440.878	2274.74	85040.715
2048	59962.275	12507.549	10528.28	2375.486	85373.59
2049	59979.646	12573.276	10599.68	2476.224	85628.826
2050	59958.312	12621.536	10655.594	2576.422	85811.864
2051	59900.267	12653.182	10696.545	2675.65	85925.644
2052	59812.663	12668.872	10723.185	2773.589	85978.309
2053	59696.776	12669.618	10736.322	2869.677	85972.393
2054	59556.492	12656.437	10736.731	2963.2	85912.86
2055	59397.768	12631.522	10725.883	3053.355	85808.528
2056	59224.278	12596.6	10705.226	3139.885	85665.989
2057	59042.046	12553.226	10676.259	3222.091	85493.622
2058	58854.977	12503.372	10640.461	3299.474	85298.284
2059	58666.314	12448.626	10599.472	3371.568	85085.98
2060	58479.665	12390.768	10554.726	3437.974	84863.133
2061	58296.107	12331.277	10507.607	3498.308	84633.299
2062	58118.422	12271.432	10459.084	3552.167	84401.105