When accuracy matters: Prevalence, incidence and mortality rate in an Agent Based model of dementia management

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ABSTRACT

An agent-based (AB) model of dementia management required that an accurate number of virtual patients be initialised at the beginning of the simulation, that new patients are added as time progresses and that some groups of patients are gradually removed from the simulation. This is the equivalent of prevalence, incidence and mortality in demographic analysis of the disease. We built a model in which these required parameters were taken from static look-up tables containing average data published in the literature. Our test results revealed that due to the probabilistic nature of the AB model it is difficult to accurately calibrate the model using average estimates of these three parameters over time. The proposed solution is based on implementation of a System Dynamics (SD) model that can drive the agent-based model. The possible benefits of such approach are further discussed and include the implementation of a feedback loop between the AB and SD parts of the model.

Keywords: Computer Modelling, Dementia Prevalence, Agent-Based Simulation.

INTRODUCTION

Background. The prevalence of dementia in Australia is estimated to increase from 172,000 in 2000 to 588,000 in 2050 [1][2]. Total health and aged care system costs for dementia in Australia in 2003 is conservatively estimated at $1.4billion of which 72.5% ($993 million) was for residential aged care according to the Australian Institute of Health and Welfare [3]. Indirect costs of dementia include loss of income of persons with dementia and the carers of persons with dementia, the cost of welfare payments, and home modifications and aids. The indirect cost of dementia care in 2002 was estimated at $2.2 billion [3].

Despite these very alarming predictions an overall strategic plan for dementia management doesn't exist yet and the message regarding the incoming health care crisis is not strong enough to trigger decisive actions from policy makers. Some of the possible reasons for such small impact from such a strong message could be very limited access to the computer models and big discrepancies in the actual figures that are being reported by different studies [16]. Such discrepancies may cast doubt on the whole process of making reliable predictions. Experts in the field agree that the prevalence of dementia is on the increase as illustrated by a Delphi study [10], but generally there is lack of consensus on how large that increase will be, and in particular how it should be managed [7].

Computer models are good tools for making predictions and are routinely used in finance and marketing. The use of computer models in health care is however still in its early stages [17][19]. Health models are additionally complicated by number of factors that influence the accuracy of such predictions [6][11]. In the case of models of dementia management the most crucial assumptions are the existing and future trends in population increase or decline over time with inclusion of such contributing factors as birth rate, in and out migration in specific age groups, background mortality rate and mortality specific to dementia [9]. Also there is uncertainty in estimating the burden of disease associated with dementia, and the coexistence of other critical illness episodes that may contribute to neurocognitive effects makes projections even more difficult [14]. The recently published report "The burden of disease and injury in Australia 2003" offers great insight into co-morbidity and shows how changes in life expectancy could be related to having more than one chronic illness including dementia [4].

Accurate prediction of the numbers of dementia cases also depends on precise estimates of ratios between diagnosed and undiagnosed cases of dementia. Current diagnostic practices and sensitivity of the diagnostic tools may have a substantial impact on the dementia incidence rate. The demand for health care services can be further complicated by the behavioural and psychological symptoms of dementia (BPSD)[8]. These may include depression, anxiety, aggression and disinhibition. Management of BPSD is costly and puts additional burdens on family and carers. Therefore it will be very helpful to not only know the real costs associated with dementia but also to have projections of costs associated with BPSD as this may lead to the development of better management strategies [15].

The model. Figure 1 below shows the user interface of the agent-based model that has been developed at the Dementia Collaborative Research Centre. This model focusses on the management of behavioural and psychological symptoms of dementia. The blue and red icons represent virtual patients that move in X (age) and Y (severity of BPSD) space [21]. The accuracy of forecasts strongly depends on the accuracy of the parameters used to calibrate the model such as (A) general population increase and decrease over time in each of the age groups, (B) prevalence and incidence of dementia over time and (C) prevalence and incidence of BPSD over time. The age-specific and dementia-specific mortality rates were converted into a table of probabilities and then used by each virtual patient to make a decision regarding an exit from the model.

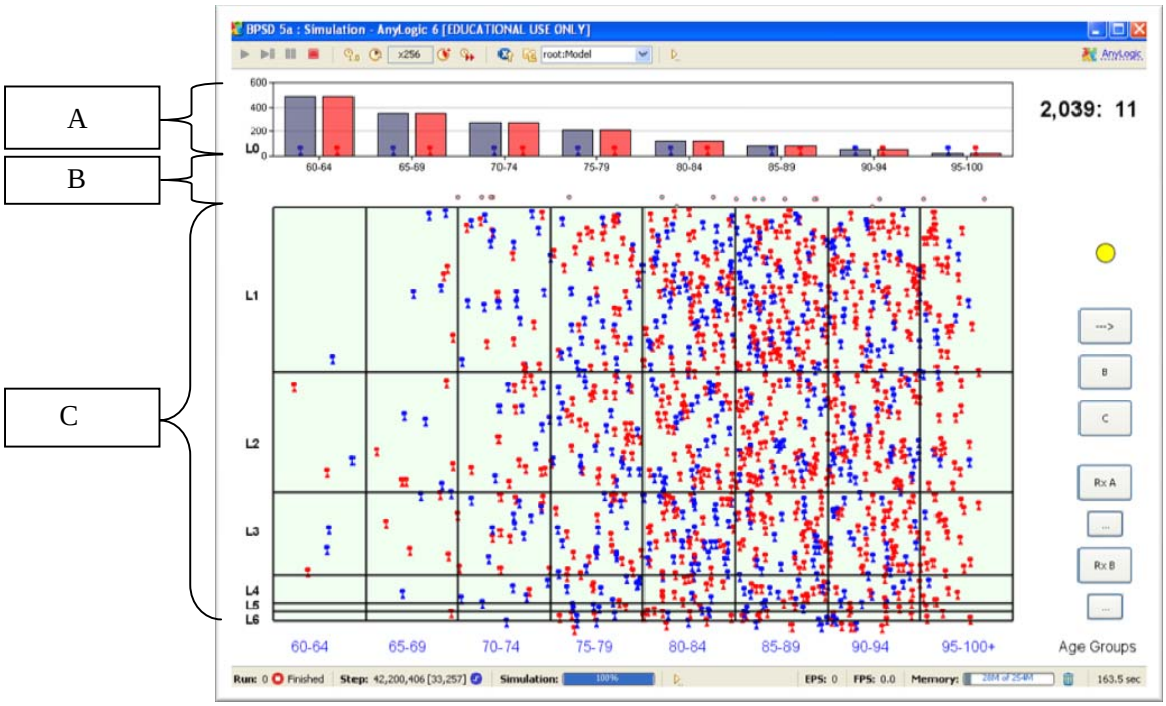

Figure 1. User interface of BPSD management model.

At the beginning of the virtual experiment the model initialised a population of virtual patients that reflected the prevalence of disease. Putting all other factors aside the model continued to run through 1500 time steps which reflect 30 years of virtual time. Two things happened during that time: each week new patients diagnosed as having BPSD were added to the population and some of the patients expected to die and leave the model. The probabilities of these two events in each patient's life cycle were determined by the incidence of BPSD and mortality rate. The main issue during the calibration of the model was how to determine these probabilities for groups of patients and for an individual patient.

At present the model uses probabilities that are the average estimates of prevalence, incidence and mortality rate derived from the literature. . These parameters are inserted into the lookup tables at model initialisation and remain unchanged during the run of the virtual experiment. This may not be an ideal situation for two reasons: one, population numbers may not reflect the predicted numbers due to the probabilistic nature of the agent-based model, and two, individual characteristics of the virtual patient may not be taken into account when calculating probabilities. In our experimental work we decided to consider three approaches to the model's calibration and then show the test results for at least one of these approaches in the laboratory setting.

Fixed parameters approach: 'I am as everybody else'. The probability of how long the virtual patient lives and how it behaves are fixed in stone. The parameters represent average values for the Australian population and include all biological, social and environmental factors that contribute to population change, prevalence and incidence of dementia, prevalence and incidence of BPSD and mortality rates. Values that are average for the age group also apply to each of the individual patient in that group. Figure 2 shows how three lookup tables can be use to calibrate the model. The overall number of patients in the model is not centrally controlled except for the general population distribution table.

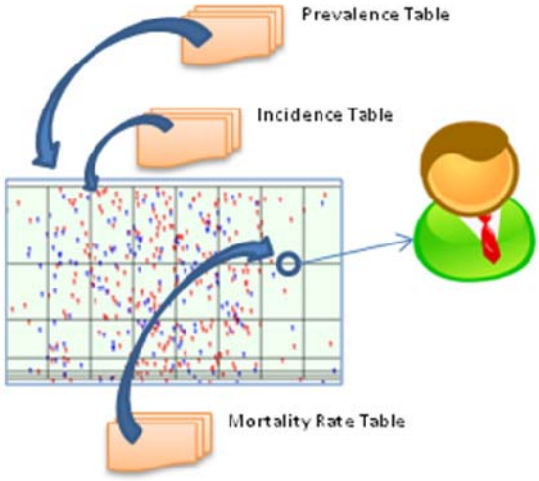

Figure 2. Calibration parameters are identical for each virtual patient.

Population-specific approach: 'I follow global trends'. The calibration parameters can be dynamically generated during the virtual experiment. The fixed values in the lookup tables can be recalculated with each time step of the model. A system dynamics models can be used to provide smooth population distribution and trends over time. The SD model may run in parallel with the agent-based model. In a similar way to the 'fixed' parameter approach, each virtual patient's parameters are calibrated with the same values but these values are dynamically generated and may reflect changes over time in prevalence, incidence and mortality. The age specific and gender specific parameters can be easily acquired here and that may further improve the model's accuracy. However in this approach virtual patients can't individually respond to events that could otherwise change an incidence or mortality. They can only follow trends that apply to groups and sub-groups in the general population. Figure 3 shows how three lookup tables that were used in the 'fixed' parameters approach are replaced by a SD model, calibrated with the scenario specific parameters e.g. future increase in the use of more sensitive tests to diagnose dementia. The overall number of patients in the model is not centrally controlled but it reflects more accurately population changes and factors influencing prevalence, incidence and mortality e.g. increased mortality due to co-morbidity with other diseases.

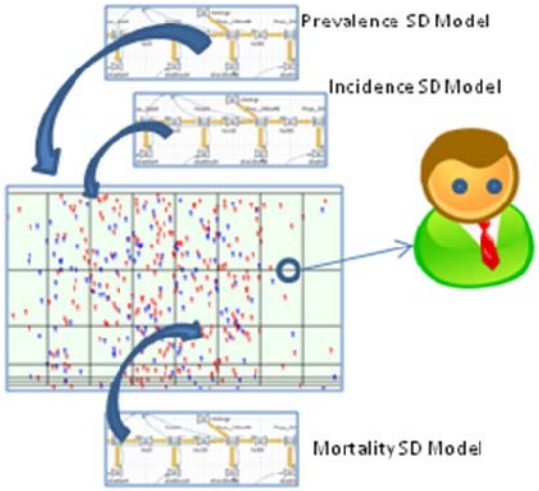

Figure 3. Calibration parameters are dynamically generated by a SD model.

Event-specific approach: 'I am an individual'.

In real clinical situations an individual patient may have different characteristics and may respond differently to specific events. For example poor general health with a low score in Chronic Health Status (CHS) may alter the probability of death in a way that is only specific to cancer. Figure 4 shows how the SD model is now imbedded inside the virtual patient and provides a basis for calculating individualised calibration parameters.

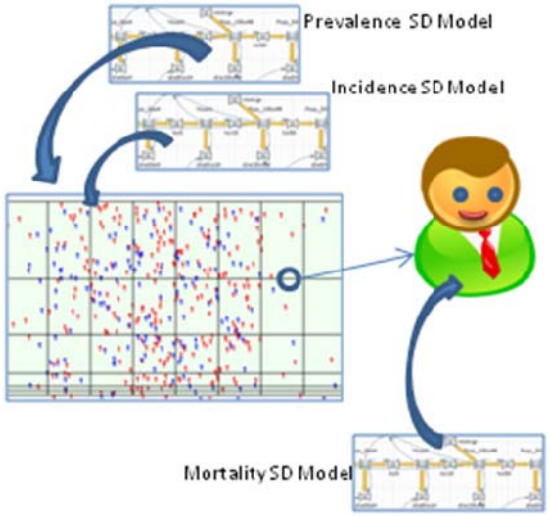

Figure 4. Each of the virtual patients has its own mortality rate adjustment related to the SD model.

AIMS OF THE MODEL EXPERIMENTS

The aim of this project was to develop a computer model of the management of behavioural and psychological symptoms of dementia (BPSD) for the Australian population and calibrate it with available data on prevalence, incidence and mortality rates. We outlined three possible approaches to model's calibration and tested one of them in the laboratory setting.

METHODOLOGY

The multi-method AnyLogic software, within the Eclipse software framework, was used to develop the model [5][24]. An agent-based approach was chosen as a programming method to allow for relative autonomy of the virtual patients. The clinical framework of the model was based on the paper-based static model of BPSD management which was published elsewhere [8]. The behaviour of each virtual patient was governed by statecharts which were developed in cooperation with a senior psychiatrist. These statecharts were used to drive the behaviour of individual patients [13]. Each of the 10 000 virtual patients used in the model was assigned with characteristics during initialisation of the model. Characteristics included clinical variables such as level of dementia and level of BPSD, and non-clinical variables such as accommodation level.

The statecharts had their initial transitions assigned according to the probabilities and rules derived from the published literature. They include demographic data such as incidence and prevalence of dementia and incidence and prevalence of BPSD in the Australian population [16][20]. The age-specific and gender-specific mortality rates [12][18] were also included in the model using 'fixed' parameter approach described above. All virtual patients were monitored by acquisition of statistics

from groups of agents selected by criteria such as age group, gender and level of BPSD. The time step of the model was set to 1 week and the model was run over 1500 steps which is equivalent of 30 years.

RESULTS

The computer model consisted of graphical user interface with multiple screens. The start-up screen was used to customize the initial parameters e.g. number of virtual patients. All the essential calibration parameters were taken from the lookup tables as described above in the 'fixed' parameters approach. We ran a number of calibration tests before the model could be used in virtual experiments and we discovered two main issues that could affect the accuracy of the model: (1) larger than expected group of virtual patients 'lived' for over 100 years, and (2) bigger than expected variations over time in overall population of virtual patients.

One of the general rules for the behaviour of virtual patients was such that each patient gradually moved along X (age) axis as the age counter increased. With each time step of the model patient's statechart was checked to see if it should remain in the model. When a randomly acquired number exceeded the probability assigned in the lookup table for the corresponding age group then the patient continued to live, otherwise the patient was removed from the model and population statistics were decreased by one. The initial tests revealed the average values for mortality rates acquired from the published literature were not very accurate. In fact they were too low for the older groups. Visually this lack of accuracy was presented as patients moving far beyond the right border of the model.

The second issue with the 'fixed' parameter approach was manifested as very high fluctuation in the number of patients. The overall population of patients in the model was continuously counted and charted. That also applied to sub-groups associated with BPSD levels. When the charts were examined they showed jittery lines and steps associated with transitions between age groups for which different parameters were used.

DISCUSSION

The main reason for developing this BPSD model was to help clinicians and health managers to make better decisions [23] for patient with dementia. These two target group however have rather different views on what is essential in the management of disease. Clinicians typically concentrate on the individual patient and are interested in details. On the other hand health managers and policy makers are focusing primarily on groups and populations. These viewpoints are reflected in published literature where case studies are contrasted with large demographic studies.

In order to build the model that is useful to both clinicians and health managers we have chosen an agent-based framework. It allows zoom-in to the level of an individual virtual patient or zoom-out to examine behaviour of groups and populations. The trade off however, in comparison with system dynamics models is a loss of central control over the variables in the model. Smooth trends and transitions typical for SD models are replaced by jittery charts that reflect the probabilistic nature of the patient's behaviour.

As we have seen during laboratory evaluation of the agent-based model the accuracy of the model with 'fixed' parameters was not sufficient for reliable virtual experiments. Random changes could as well be mistakenly taken as outcomes of therapeutic intervention if impact of such interventions was tested using the model. In terms of employed methodologies the agent-based models are frequently contrasted with system dynamics models. Most certainly each of them has its place and purpose but we believe that combining both frameworks together will have essential benefits particularly in the medical domain.

In theory at least, the population-specific approach to calibration of the agent based model seems to be superior to the 'fixed' parameter approach. It offers smooth transitions between age groups and inclusion of important clinical and non-clinical variables that can shape the trends. One major limitation remains however, and that is inability to individualise the characteristics of virtual patients from just one centrally placed SD model.

The AnyLogic object-oriented computer modelling platform offers the ability to replicate and encapsulate multiple SD models [24]. This opens the prospect of running simultaneously large amount of SD models by imbedding them in virtual patients. Such an approach which we called here the event-specific approach could give opportunities to increase accuracy and individualisation of the patient's behaviour. Firstly, the SD model offers stock and flow feedback loops that represent how general population would behave over time in typical circumstances [22]. Secondly, an embedded SD model [5] can be calibrated with parameters coming from just one single patient. It is as if the projected trends were created for a population that is identical to that particular patient. The trends are smooth and at the same time they reflect individual characteristics.

We plan to implement this third approach and to test it against the current implementation which is based on the fixed lookup tables. If that proves to be an adequate control mechanism for prevalence, incidence and mortality in the model we will than use a real database of dementia patients to further validate the model.

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