A simulation of dementia epidemiology and resource use in Australia

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With the ageing of the Australian population, the number of people living with dementia is predicted to rise markedly in the next four decades. As the number increases so will the burden these debilitating and degenerative diseases place on private and public resources. These increases are likely to challenge the efficiency and sustainability of many health systems in the developed world. It will be important to develop predictive models to assist decision makers to plan and rationally allocate limited health care resources to areas that are likely to maximise benefit most efficiently.

Given the increasing number of people expected to be living with dementia and the capacity constraints that are likely to emerge as health care systems evolve to meet these constraints; it would seem important that any modelling methods used to plan future health care resource allocation have the ability to capture the implications of these effects. The choice of modelling method in this situation has the potential to result in different resource allocation decisions that may alter the overall efficiency of the health care system being studied. The model developed here allows the effect of capacity constraints to be explored through discrete event simulation methods with dynamic queueing (DES). This modelling process allows the researcher to investigate the implications of altering demand for resources (e.g. people with dementia requiring residential aged care beds) and the level of resources available (e.g. the number of aged care beds). This is important in situations where demand for resources exceeds supply. In these settings, queues into important resources may lengthen to such a point that people are redirected to less efficient and less appropriate health care pathways thereby reducing the efficiency of the health care system as a whole.

Methods

A hybrid individual level patient simulation (IPS) model using state-transition (microsimulation) with DES techniques and dynamic queueing (i.e. hybrid-DES model) was developed to estimate the potential future prevalence and health care resource use associated with dementia in Australia. The simulation comprised a natural history model (Supplementary Figure 1a) that predicts an individual patient's disease progression over time and a health system level model (Supplementary Figure 1b) to predict health care system resource use. The model was developed in AnyLogic© 7.2.0 multi-method simulation software. The simulation was populated with published regression analyses derived from large linked individual patient data sets where possible. The incidence of dementia applied in the model was taken from the publication by Fratiglioni. It was assumed that the age-standardised incidence of dementia was constant over time. As shown in Supplementary Figure 1a, the natural history model has four health states that reflect the progression of dementia from mild to moderate to severe disease and then death over time. All simulated persons with incident dementia are assumed to start in the mild dementia health state. Simulated people are redirected to less efficient and less appropriate health care pathways thereby reducing the efficiency of the health care system as a whole.
patients then progress to any of the other health states according to the multinomial regression analysis (MNR) described by Spackman and colleagues. In line with the results from this analysis the model also allows the simulated patient to regress (dashed lines Supplementary Figure 1a), although this is exceedingly rare. The rate of transition through these health states is governed by individual patient characteristics that are tracked in the simulation and their effects on disease progression captured through the MNR analysis (e.g. age, gender, marital status, ethnicity, years of education, etc).

Supplementary Figure 1b shows the structure of the health system component of the hybrid DES model of dementia. The majority of simulated persons with dementia enter the model in the community setting, however, a proportion of incident dementia cases occur in persons already residing in permanent residential aged care (P-RAC).

Simulated persons with dementia in the community may be assessed by an Aged Care Assessment Team (ACAT) to determine if they are recommended to live in the community or P-RAC and whether or not they qualify for services such as respite residential aged care (R-RAC) and support in the community through home care packages (HCP). For patients assessed by ACAT transitions into R-RAC are governed in the simulation by two logistic regression (LR) models, one for persons recommended by an ACAT to live in the community (LR1), and the other for patients recommended to live in P-RAC (LR2). These LR models are based on linked data from 32,000 people collected through the Pathways in Aged Care (PIAC) project conducted by the Australian Institute of Health and Welfare (AIHW). Transitions from R-RAC to P-RAC in persons with dementia were also based on analyses of the PIAC data-set (LR5). The number of all-cause hospitalisations per year (excluding Emergency Department presentations) in persons with dementia, regardless of origin (e.g. community or P-RAC), was informed by data from the Hospital Dementia Services (HDS) Project, which recorded any hospital stay of patients with a principal or additional diagnosis of dementia in the most populous state of Australia. This linked data set included 20,748 patients with dementia aged 50 years and over who had a completed hospital stay including at least one night in a public hospital in 2006–07.

Transitions of persons with dementia from hospital to RAC (permanent or respite), or to the community, were determined through a LR model based on linked data on over 900,000 discharge records of patients across Australia over the 2008–2009 period (LR3). A separate LR model based on a sub-analysis of these data using around 34,000 records of patients directed to RAC was then used to determine the probability of patients entering permanent versus respite RAC (LR4). Full details of all the input parameters applied in the model are presented in online Supplementary Table 1.

The model had a ‘run-in’ period of 24 years (1987 to 2010 inclusive) to allow dementia prevalence levels to develop from incident cases and mortality over time. This run-in period also allowed queues into constrained resources to develop over time.

To account for stochastic variation in the modelled results resource use and prevalence data were calculated as the mean of five model runs each using unique random number streams with about 10,000 simulated patients per run. The stochastic variation between these runs is described using 95% credible intervals (CI). To cross-validate the natural history component of the analysis the model’s predictions of future dementia prevalence were compared to other published estimates of future dementia prevalence in Australia (see Figure 1). The age distribution of dementia prevalence, by gender, was also compared to other published estimates of the age distribution of dementia prevalence in Australia (see Supplementary Figure 2). Each queue used a simple single server structure to reflect the total throughput of the service being modelled (e.g. P-RAC beds). The queues used in the DES-DQ model employed a first-in, first-out scheduling discipline, however, priority access to P-RAC beds was given to P-RAC residents returning home over those persons seeking a P-RAC bed for the first time. The queues allowed reneging due to patient or carer refusal to wait for the service of interest (dashed lines Supplementary Figure 1b).

To explore future prevalence and resource use the modelled analysis was then extended to run from 1987 to 2050. The level of future resource use was explored in three scenario analyses in which different levels of dementia incidence were assumed (i.e. low, mid and high incidence scenario). The low-incidence scenario explored the impact on resource use should the incidence of dementia be assumed to be 20% lower than that presented in Supplementary Table 1. This low estimate is based on the recently published study by Matthews and colleagues that suggest that dementia incidence may have decreased by 20% over the past two decades. The mid-incidence scenario applied the incidence estimates described in Supplementary Table 1. The high-incidence scenario assumes that the incidence of dementia applied in the model is around 18% higher than the mid-incidence scenario; this ensures that the model generates similar prevalence estimates to those projected from the Anstey study (see Figure 1). Each of these scenarios is presented in two ways; the first assuming that there are capacity constraints on the number of RAC beds available for persons with dementia, and the second analysis demonstrates the impact of removing all RAC bed capacity constraints from the analyses.

Results

Model validation

Figure 1 shows a comparison of the simulation model’s estimation of dementia prevalence from 2011–2050. These results are cross-validated with other published projections of dementia prevalence. It should be noted that the Anstey study explored the prevalence of dementia through Australian-based surveys; it did not make predictions about dementia prevalence into the future. Instead, these estimates were made by applying the dementia prevalence by age strata reported by Anstey and colleagues to the level B population projections for Australia produced by the Australia Bureau of Statistics (ABS). This makes the implicit assumption that the age-stratified prevalence of dementia is constant over time.

The model predicts that around 298,000 persons will have dementia in 2011, increasing to around 387,000 in 2020 and 928,000 by 2050. These estimates most closely accord with the projections produced by the AIHW and Deloitte Access Economics (DAE). Supplementary Figure 2 shows the age distribution of dementia predicted by the model cross-validated to data from other published research for males and females. Figure 2 presents validation of the health services resource use generated by the model when compared against known historical levels of health care resource use in Australia in 2011. The model appears to predict similar levels of services use for all-cause
hospitalisation, P-RAC, R-RAC, transitional care, HCP and ACAT assessments.

**Projections of future resource use**

Figure 3 presents the hybrid DES dementia model’s prediction of resource use by category over time for three scenarios (i.e. (1) low; (2) mid; and (3) high-incidence). Each scenario is presented in two ways; the first assumes that there are capacity constraints on the number of RAC beds available for persons with dementia (Scenario 1a, 2a and 3a – constrained RAC bed numbers) and the second analysis demonstrates the impact of removing all RAC bed capacity constraints from the analyses (Scenario 1b, 2b and 3b – unconstrained RAC bed numbers).

In the low-incidence projections, the constrained and unconstrained analyses produce similar results. Both analyses predict around 204,000 P-RAC beds will be used and there will be around 467,000 all-cause hospitalisations in 2050 for persons with dementia. The similarity between these analyses demonstrate that at the lower level of dementia incidence adopted in Scenario 1 the demand for RAC beds does not exceed supply in the constrained analysis (i.e. Scenario 1a).

In contrast, in both the mid- and high-incidence scenarios, the constrained and unconstrained analyses diverge appreciably. In Scenario 2a the use of P-RAC and R-RAC beds plateau in the last decade of the analysis as demand for these services exceeds supply. This leads to an accelerated use of hospitals as persons with dementia seeking RAC placement are re-directed to hospital while they wait for placement in appropriate RAC accommodation. In Scenario 2a and 2b it is estimated that around 226,000 and 254,000 P-RAC beds will be used by persons with dementia by 2050, respectively. In the same year, it is estimated that around 642,000 and 576,000 hospitalisations will occur in persons with dementia in Scenario 2a and 2b, respectively. The time to reneging (i.e. prematurely leaving the queue) from RAC queues into hospital is decreased from 1-month to two weeks in Scenario 2a (constrained) the number of hospitalisations increases to around 690,000 in 2050. Conversely, if the time before reneging is increased to 2 months, the number of hospitalisations predicted in 2050 decreases to 619,000.

The high-incidence analyses mirror the mid-incidence analyses except that the number of RAC beds used in the unconstrained and constrained analyses diverges earlier leading to a more rapid acceleration in the use of hospitals over time in the constrained analysis (Scenario 3a). In Scenario 3a and 3b it is estimated that around 226,000 and 298,000 P-RAC beds will be used by persons with dementia by 2050, respectively. In the same year it estimated that around 958,000 and 691,000 hospitalisations will occur in persons with dementia in Scenario 3a and 3b, respectively.

The use of HCP in persons with dementia is predicted to accelerate over time in all analyses as the Australian Government increases the ratio of community-based HCP available to persons aged 70 or over in the future.13

**Discussion**

This study uses a novel DES that combines models of dementia epidemiology and natural history with models of the health and

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**Figure 1:** Model validation: comparison of dementia prevalence projections generated by the hybrid DES model and other published estimates in Australia, 2011–2050.

**Figure 2:** Model validation: comparison health care services use predicted by the hybrid DES model of dementia and literature-based estimates in Australia (2011).
aged care sectors to generate quantitative estimates of the future dementia-related demand on hospitals, permanent and respite residential aged care, transitional care and aged care assessment and community care programs in Australia. This is also the first study to use discrete event simulation techniques to dynamically demonstrate the effect capacity constraints in aged care may have on the health care sector.

The validated model presented herein was based on a series of large linked individual patient data-sets that may be used to generated predictions of future dementia epidemiology and resource use across Australia. The model generates realistic estimates of dementia prevalence over time when cross-validated to other published projections of dementia prevalence developed for Australia.\textsuperscript{1,10,11} The model also generates realistic estimates of health service use when validated against known historical values.

By incorporating DES dynamic queueing methods the model also allows the exploration of the possible implications

Figure 3: Predictions of future resource use generated by the hybrid DES dementia model by resource use type (2011–2050).
capacity constraints on RAC bed numbers may have on other health services in Australia. For instance, under-resourcing of the number of RAC beds would lead to increased waiting times for these resources and the potential for persons with dementia to be redirected away from appropriate care in RAC accommodation and into more expensive and less appropriate care in hospital. The model predicts that to avoid these effects the number of P-RAC beds for persons with dementia will need to increase more than threefold from 2011 to 2050.

Further, unlike cohort-level modelling methods (e.g. Markov cohort models), individual patient simulation (IPS) methods such as DES are not limited by the Markov assumption of memorylessness whereby the probability of a given transition in the system is independent of the nature or timing of earlier transitions. Instead, IPS methods allow more realistic depictions of the process being modelled by allowing individual entities to accrue complex histories that can affect the individual patient’s future prognosis and pathways through the modelled health care system. In this way, DES methods lend themselves to modelling complex systems where individual-patient level heterogeneity is important and analysis of resource utilisation and capacity constraints is of particular interest.

The scenario analyses presented here allow the researcher to explore the potential implications that increased or decreased dementia incidence (and resultant dementia prevalence) may have on the demands made on health services in Australia into the future. This is particularly important as there is currently conflicting research that has found that dementia incidence has decreased over time, while other research suggests that dementia incidence may increase beyond what is predicted by demographic ageing alone due to increasing mid-life obesity in Australia.5,14

This research is not without its limitations. The time between a person joining a queue to enter RAC and reneging from that queue is assumed to be 1-month. Reducing this time period leads to an increase in patient movement to hospitals and vice versa. The model presented here is designed at a reasonably high level of abstraction focussing on Australia as a whole. Implicit within this level of abstraction is the simplifying assumption that RAC beds are equally accessible across the country. This is not necessarily the case and, therefore, it should be noted that inconsistencies in the supply and demand for RAC beds by region are not captured in the model. Clearly, to accommodate these regional variations would require a substantial increase in the complexity of the model and attendant data requirements. However, this is the focus of future research. Further, it is important to note that, due to the difficulties in obtaining accurate data characterising Emergency Department admissions for persons with dementia, the use of these services has not been quantified in the current analysis. As with any model we rely on historical data and analyses to predict the future. Some of the data used to populate the model, while comprehensive, are ageing and we cannot rule out that this may have an effect on future projections. Clearly, over time, the health care system, epidemiology, new methods of diagnosis, differential diagnosis rates, new treatments and interventions or preventative measures for dementia may change and this may significantly alter these predictions over time. However, the strength of models such as the one presented here is that they can be modified in line with these changes to test the implications of resourcing decisions and the evolution in our understanding of the complex epidemiology of dementia. While it would be comforting to delay decision making until all unknown factors are resolved, this is unlikely to ever occur. Further, decision makers are in the invidious position of having to plan and act today with imperfect information to meet future health service demands. In this way, analyses such as the one presented herein, can act as a useful and flexible guide for rational decision making about future health service resourcing for persons with dementia in Australia.

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References


Supporting information

Additional supporting information may be found in the online version of this article:

Supplementary Table 1: Summary of the input parameters used in the hybrid DES model of dementia.

Supplementary Figure 1: Simplified depiction of the structure of the hybrid DES model of dementia.

Supplementary Figure 2: Model validation: comparison of dementia prevalence generated by the hybrid DES model and published estimates, by age strata and gender in Australia 2011.