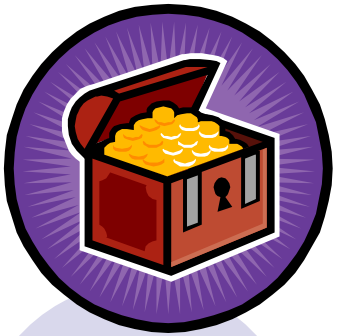


Integrating methods and practice across health, social and community services

Sally McClean

University of Ulster

Northern Ireland

Plan of the Talk

- Background & Motivation
- Model Selection
- Interacting with Healthcare Professionals
- Data Collection
- Evaluation
- Impact
- Conclusion

Peter Millard, Emeritus Professor of Geriatric Medicine, St. George's Hospital Medical School, former President of the British Geriatric Society

- "The nosokinetics challenge is to develop a model that describes the total system of care.
- Clinically and mathematically, the key to the control of resources in acute care lies at the interface between rehabilitation and long term care.
- Sally McClean developed the semi-Markov model of movement of older people through the total system of care.
- Her early research into movers and stayers in employment underpins the development of Markov models of flow."

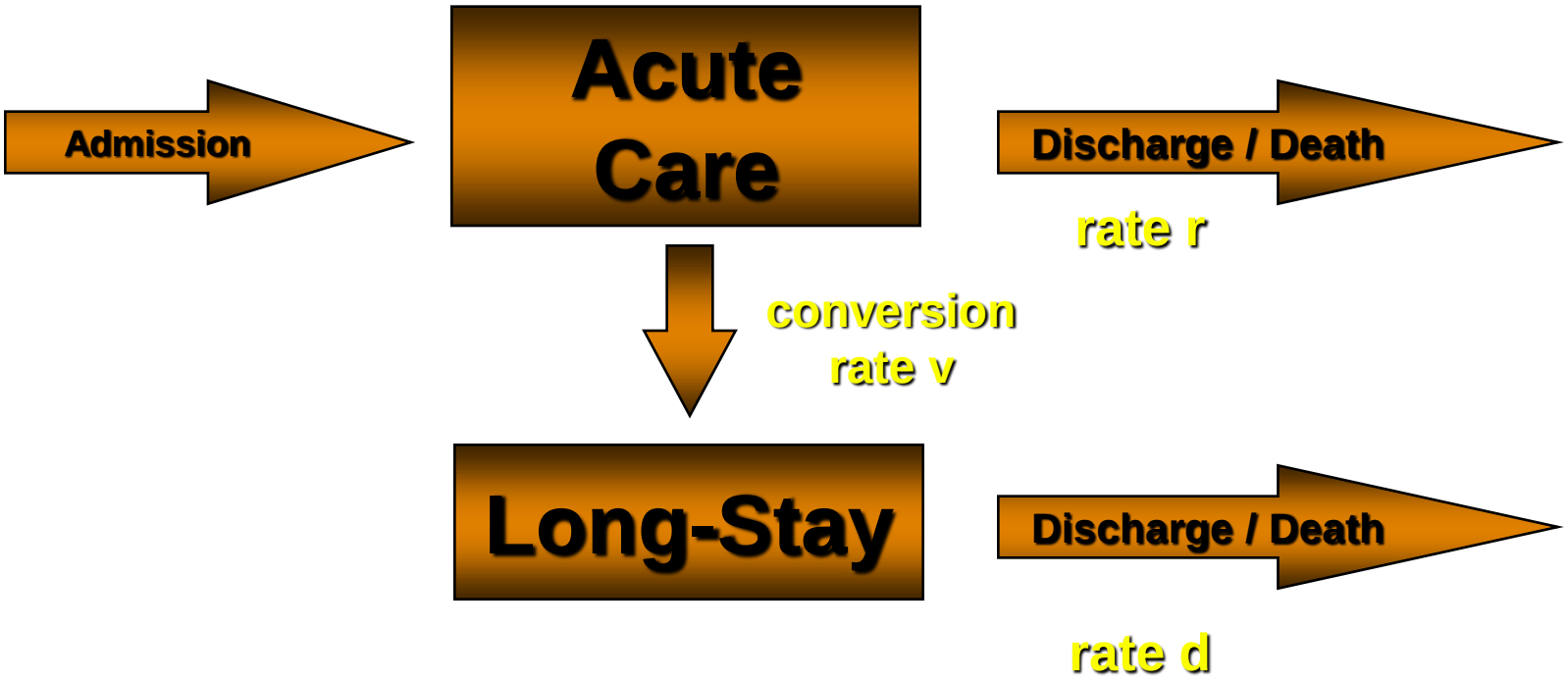
Movements of Geriatric Patients

- Models of the movements of geriatric patients have been developed by Professor Peter Millard (and others).

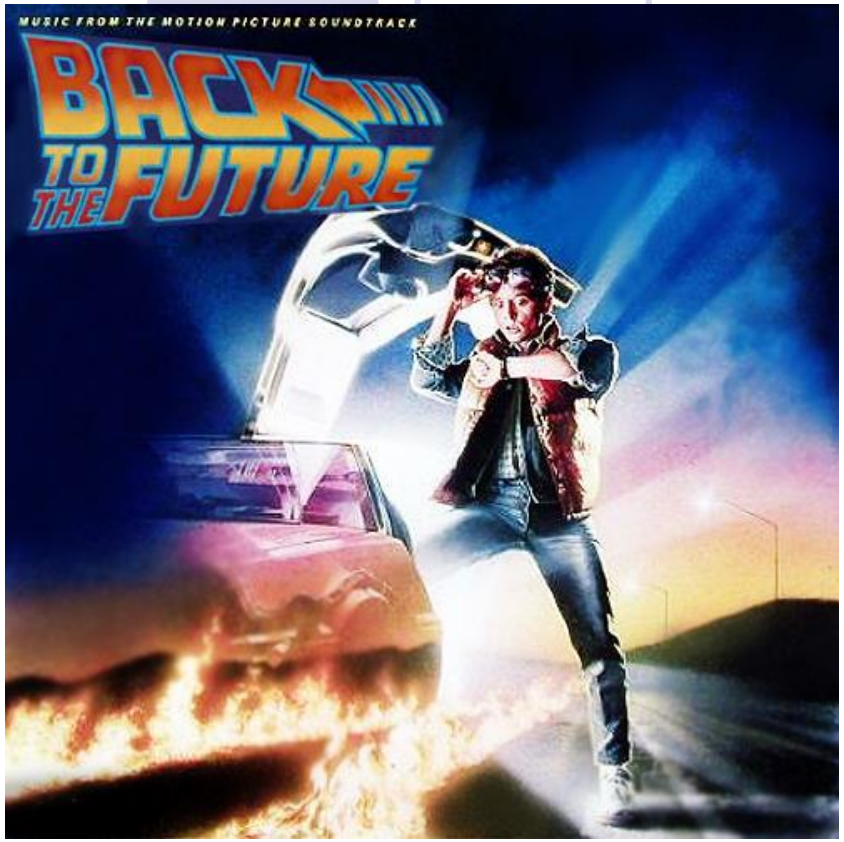
- Departments of Geriatric Medicine undertake two distinct types of activity: acute/rehabilitative and long-stay care.

Harrison GW and Millard PH (1991) Balancing acute and long term care: the mathematics of throughput in departments of geriatric medicine. Methods of Information in Medicine 30: 221-228

Patient Flows



Millard P, and McClean S, eds. (1994). Modelling hospital resource: a different approach to the planning and control of health care systems, Royal Society of Medicine Press, London.



J. R. Statist. Soc. A
(1976), **139**, *Part* 2, p. 205

The Two-Stage Model of Personnel Behaviour

By Sally McClean

The New University of Ulster

Summary

A stochastic two-stage model describing the way in which personnel behave during employment, and leave from a company is presented. The model is fitted to observed leaving patterns for several companies and compares favourably with the well-established lognormal and transition models. Recruitment is described as either being Poisson or dependent on the size of the company. Deterministic and continuous time stochastic models of company behaviour are developed which combine these recruitment patterns with two-stage leaving. These models are tested against the observed growth patterns of several companies and the results show good agreement.

Keywords: TWO-STATE MODEL; LABOUR TURNOVER; WASTAGE, PERSONNEL BEHAVIOUR; COMPANY GROWTH; COMPANY BEHAVIOUR; MANPOWER PLANNING MODEL; CONTINUOUS TIME STOCHASTIC MODEL

1. Introduction

It is now a firmly established result that, for a company, propensity to leave is highly dependent on length of service. In general, as an employee's tenure in a company increases, he becomes more committed to that particular firm and is consequently less likely to leave. This relationship between leaving and tenure has been described by the lognormal law, and the lognormal distribution has been fitted to length of service on leaving for a wide range of firms with great success. The main shortcoming of this lognormal hypothesis, however, is that there is no satisfactory model of leaving which explains its use in terms of the internal behaviour of staff in a company.

Bartholomew (1959, 1971) suggested the mixed exponential distribution to describe the distribution of the completed length of service (CLS) on leaving. Therefore the p.d.f. of CLS is $f(t) = p\lambda_1 e^{-\lambda_1 t} + (1-p)\lambda_2 e^{-\lambda_2 t}$, where $\lambda_1, \lambda_2 \geq 0$ and $0 \leq p \leq 1$. He suggested (1971) that an explanation for this is that leaving is exponential with rates λ_1 and λ_2 from two groups which are present in the proportions p and $1-p$ (Fig. 1).

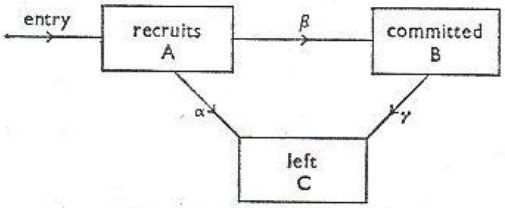
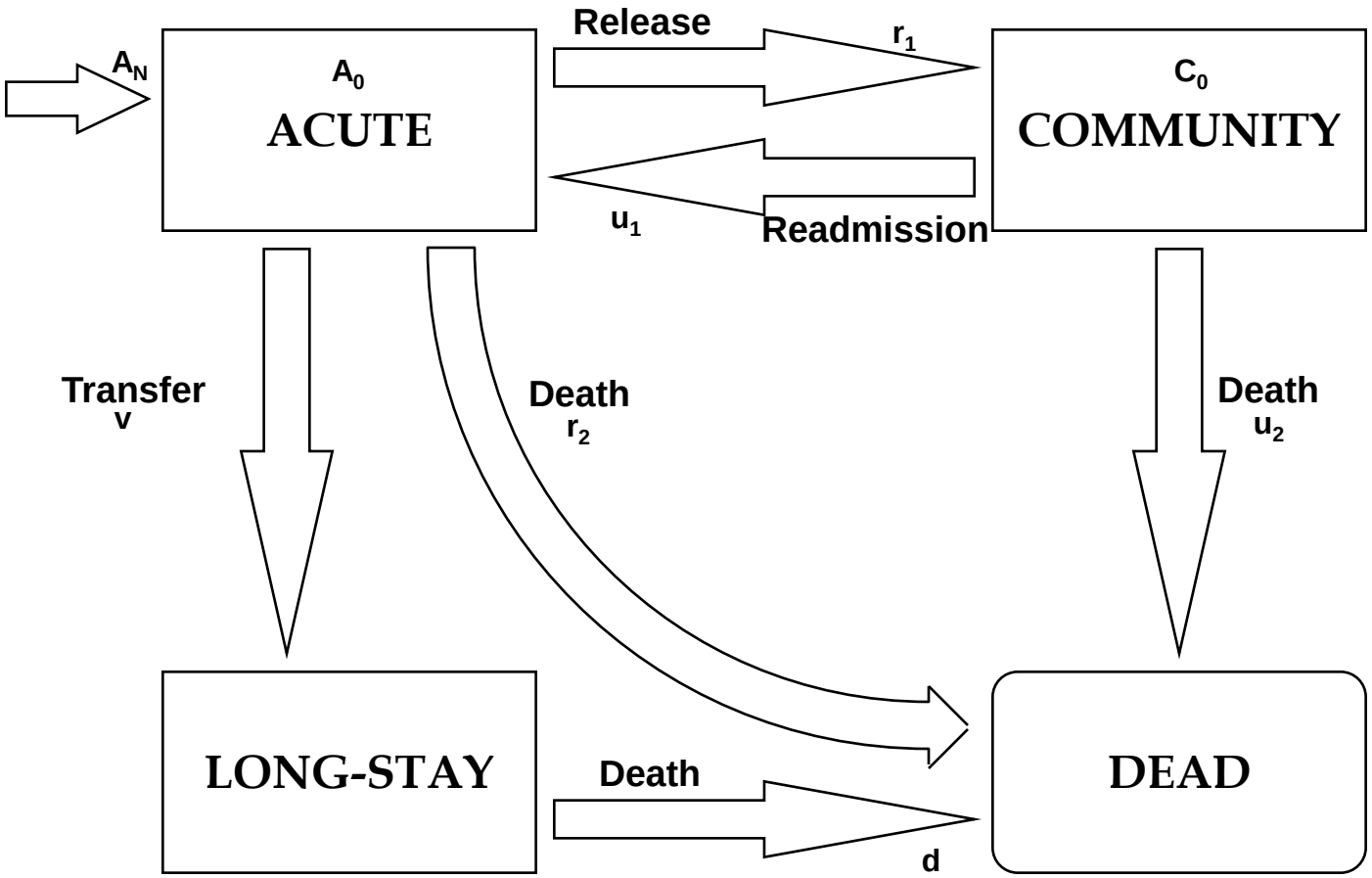


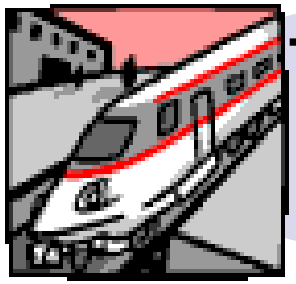
Fig. 1. The mixed exponential model.

Bartholomew (1959) fitted this distribution to data from three companies and in all cases it was found that λ_1 was considerably greater (of the order of ten times) than λ_2. This would suggest that some people (those in group 1) are more mobile than others (group 2) who have a much smaller turnaround. This hypothesis is consistent with the so-called "mover–stayer" model of labour mobility which postulates that a certain proportion of employees (the "stayers") do not change their job while others (the "movers") tend to move around from

The Four Compartment Model

G. J. Taylor, S. I. McClean, P. H. Millard ((2001). Stochastic models of geriatric patient bed occupancy behaviour, Journal of the Royal Statistical Society: Series A, Volume 163, Issue 1, pages 39–48, 2000, Wiley.

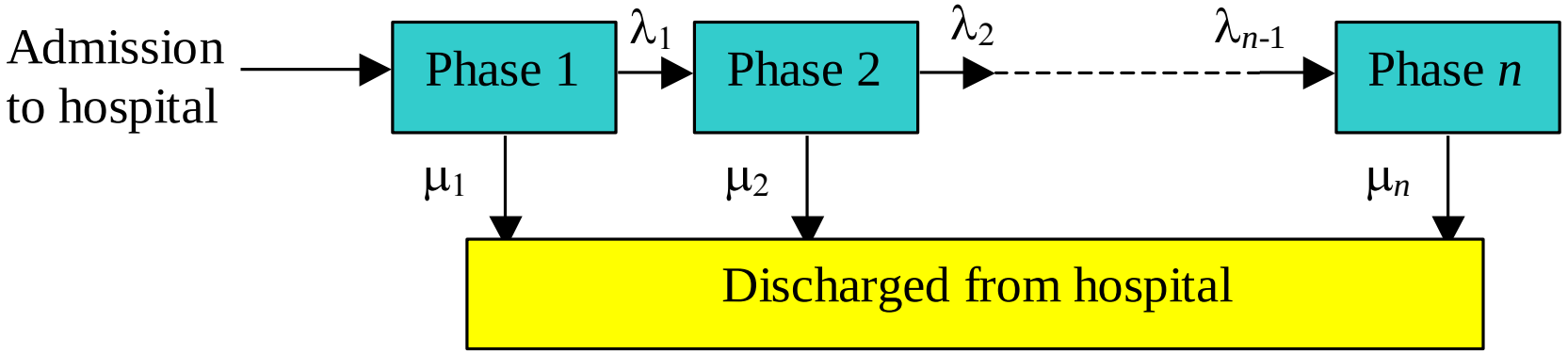




The Coxian Phase Type Distribution

(with Gordon Taylor, Malcolm Faddy, Adele Marshall, Mary Shapcott, Lalit Garg, Jennifer Gillespie and……Peter Millard)

Patient flow can be modelled as an *k* state Markov process with Coxian phase type distributions



The λ's and μ's are probabilities of moving between states.

McClean, S.I. and Millard, P.H. (2006), Where to Treat the Older Patient? Can Markov Models Help us Better Understand the Relationship Between Hospital and Community Care?, Journal of the Operational Research Society, 58 (2), pp. 255-261.

Model Selection

	STATIC	DYNAMIC
DETERMINISTIC	Algebraic	Differential/ Difference equations
NON-DETERMINISTIC	Statistical and Probabilistic relationships	Stochastic Models

Faddy, MJ, McClean SI (2005), Markov chain modelling for geriatric patient care. Methods of Information in Medicine; 44:369-373.

RIGHT

EPSRC

Brunel UNIVERSITY WEST LONDON

UNIVERSITY OF CAMBRIDGE

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

UNIVERSITY OF Southampton

University of ULSTER

RIGHT (Research Into Global Healthcare Tools) was a cross-sector collaborative research project to establish the feasibility of applying to Healthcare some best-of-breed simulation and modelling techniques used in other sectors, such as manufacturing and aerospace.

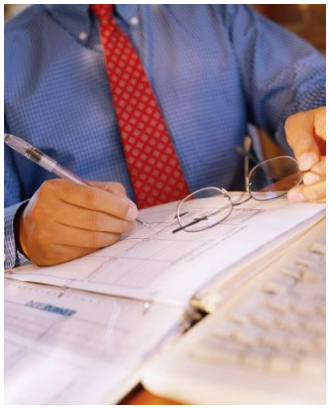
Which models?

Modelling in…

Healthcare

Stakeholder analysis

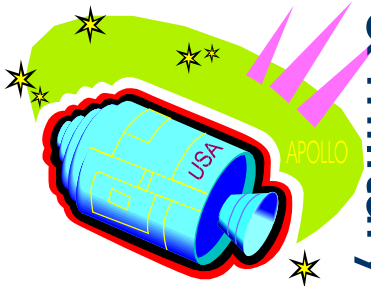
Management & Planning in…



Healthcare

Industry

Industry

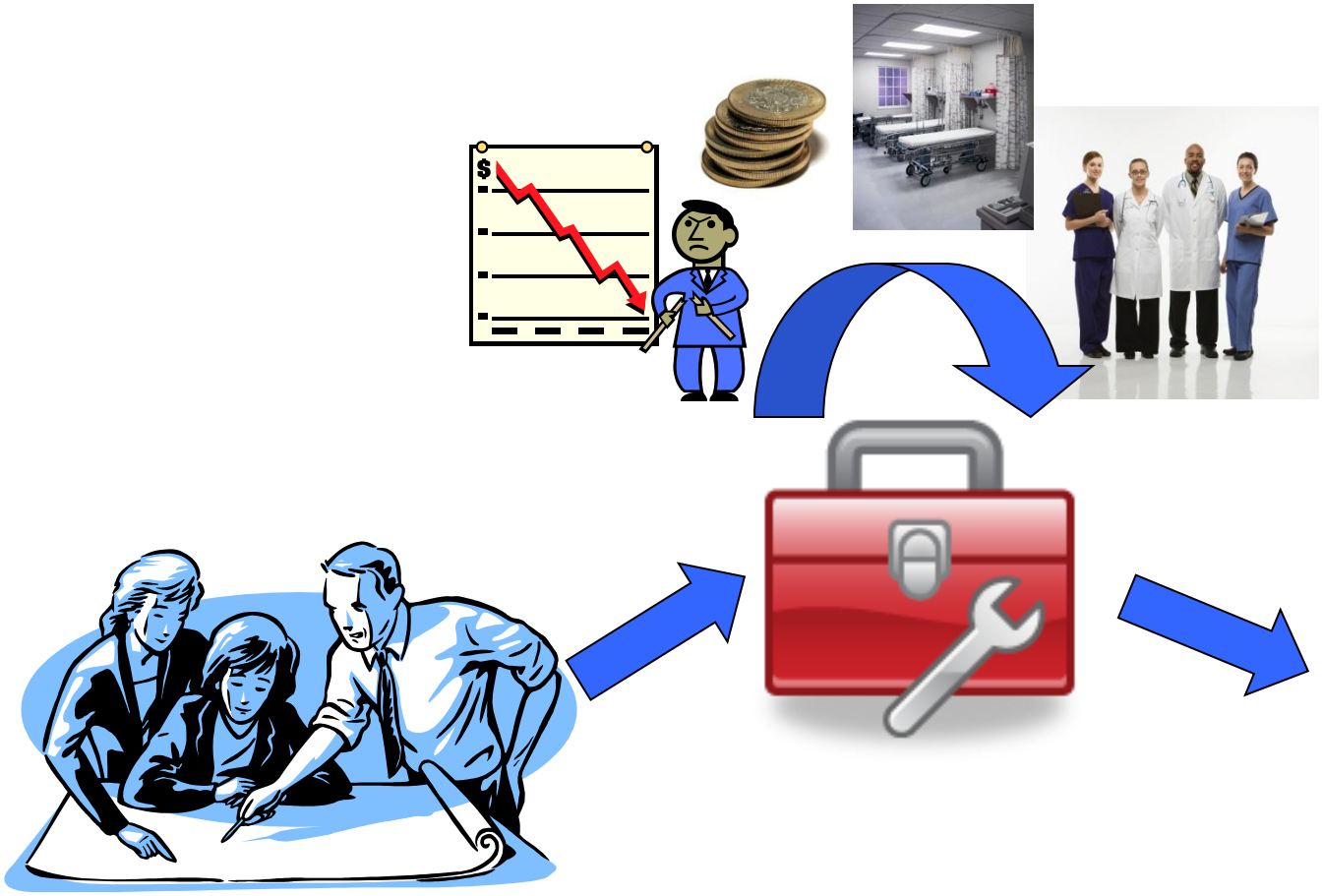


Aerospace & military

Who has made a framework of such methods?

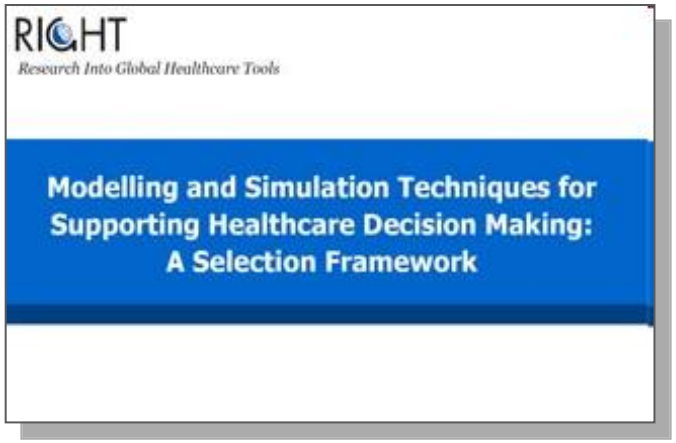
So what did we aim to produce?

A toolkit that enables users in healthcare to analyse their problems and resources, and to select appropriate methods in designing services.

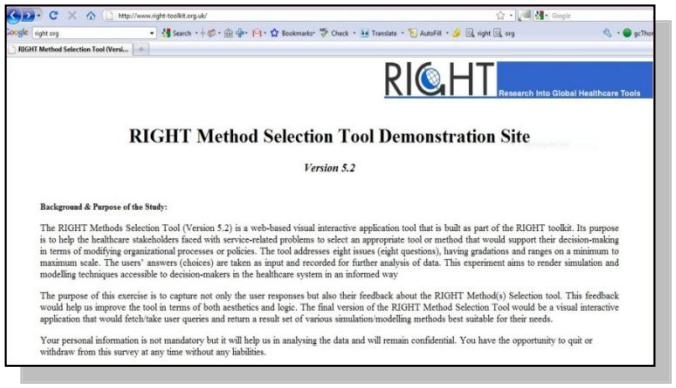


Outputs

- Gaps in knowledge particularly on input resource requirements for modelling and simulation methods
- The framework was developed to assist with the selection of modelling and simulation methods appropriate to supporting particular decision making processes



Workbook (ISBN 978-0-9545243-3-3)

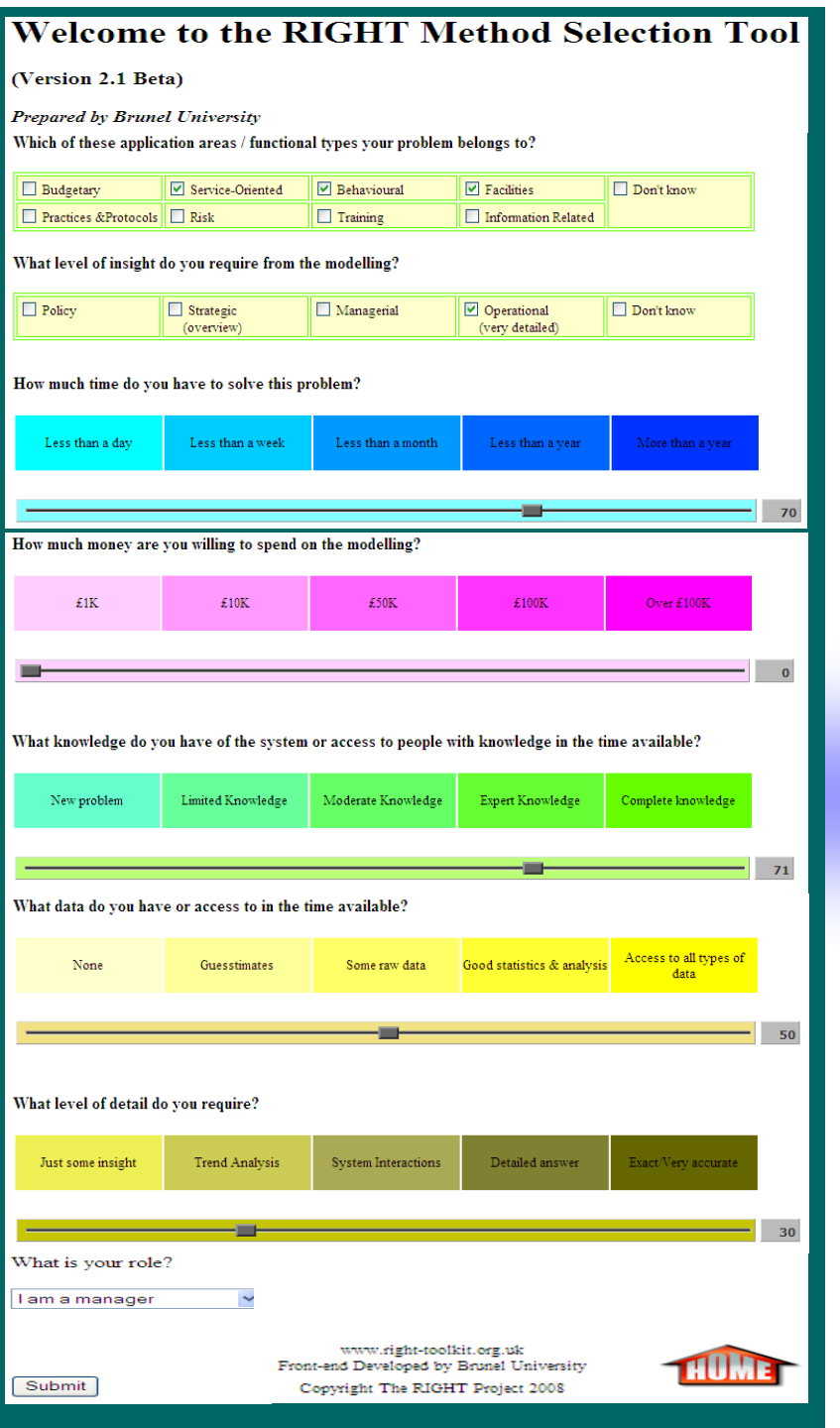


Online-toolkit (http://www.right-toolkit.org.uk/)

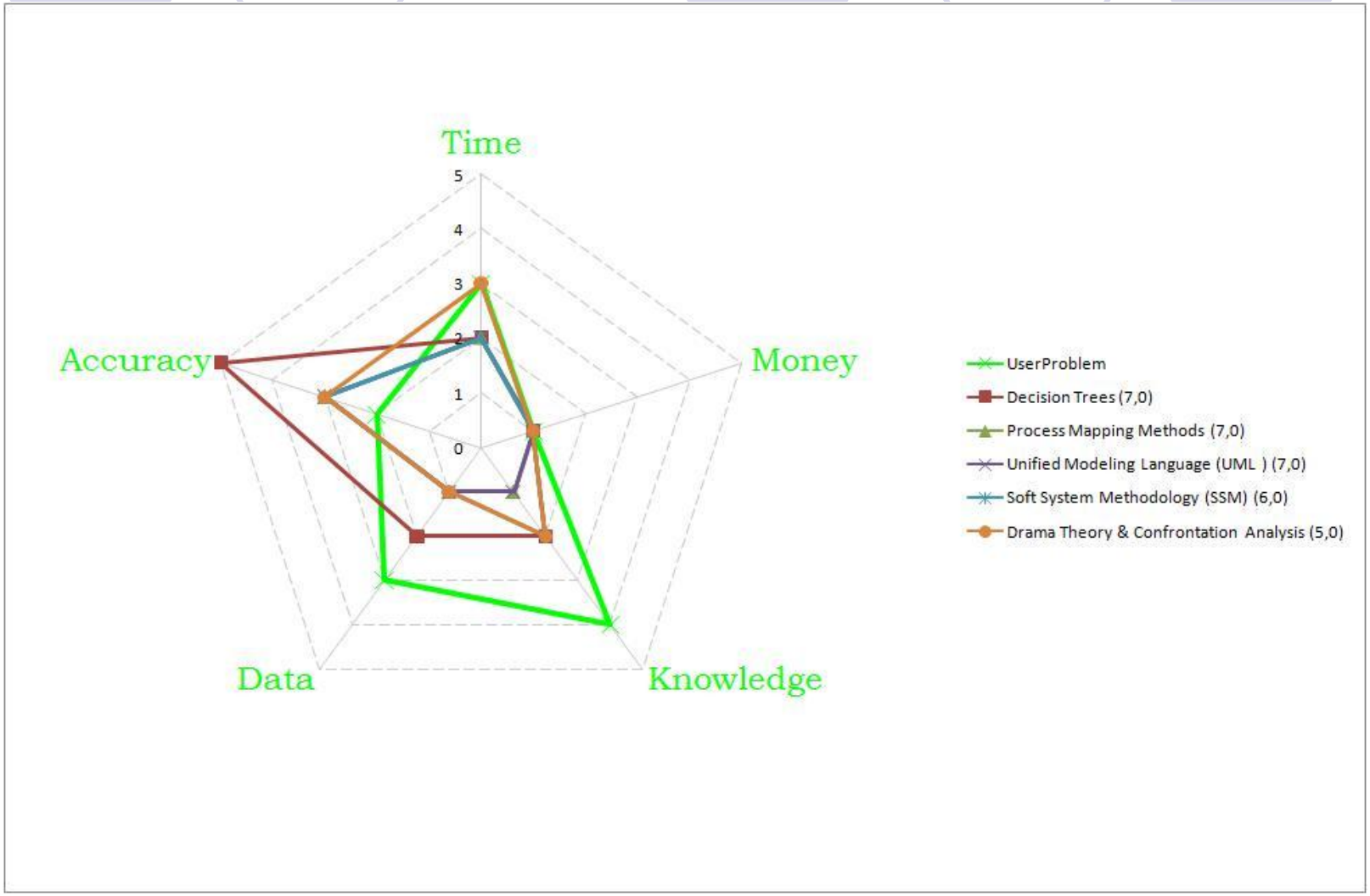
Tools developed as part of RIGHT

improvement

Selection tool for service



A typical output



Analytic versus Simulation Models

- The analytical approach is limited in terms of restricted accessibility to users who have consequently less “ownership” and commitment to the model
- A simulation model with a graphical interface is also more user friendly than the analytical approach and the user can more easily leverage this approach to participate fully in model development
- Also, typically, a simulation model can be more flexible in terms of assumptions.
- Simulation modeling has been used previously to describe complex pathways of treatment in terms of cost-effectiveness and the patients’ quality of life.

On the other hand…

- Analytic models, can be superior in terms of accuracy, computational cost and software portability.
- An analytic model can be readily used for rapid development of a computationally efficient executable, that is easily ported into different hospital and computing environments.
- Thus the analytic model can quickly evaluate changes while the simulation model lets the modeler work with stakeholders to incorporate and assess additional features and more complexity.

Interacting with Healthcare Professionals

- Models and simulation need to span diverse services, with potentially different management structures and funding streams.
- Also many diseases are highly complex with heterogeneous outcomes and multiple strategies for treatment, therapy and care.
- It is therefore essential that modelers work closely with clinicians and other health and social services professionals to ensure that the ensuing models are realistic and there is a clear dissemination and deployment strategy from theory to practice.

- BUT THIS CAN BE VERY TIME-CONSUMING.

How can we engage?

- Work with an enthusiastic healthcare professional who believes we can help.
  - Ideally find a champion
- Identify the real problem
  - Optimisation/Improvement of clinical outcome, cost, patient experience, or process e.g. A&E might want to optimise clinical outcome rather than patient experience or process.
- Plan ahead for ethical approval
  - We need to protect the patients (anonymisation/raising their hopes/hurting them)
  - Protect the healthcare professionals (wasting their time)
  - Protect the Health Services (wasting their resources)
  - Protect the researchers (wasting their time).

Models of Engagement

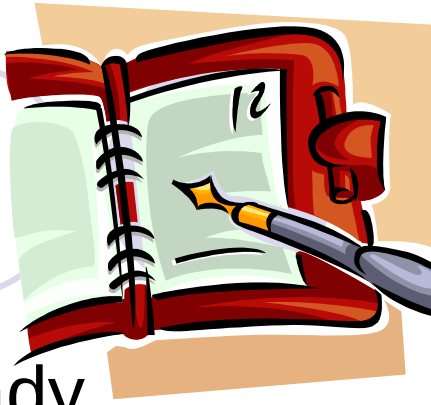
- Work through your champion
  - They will make sure that you are solving the right problem, using the right data and that you work is eventually used in practice.
- Work with the healthcare professionals via a “facilitator” who can help improve the dialogue and make your work more effective.
- Use public domain data and well understood problems
  - Less time-consuming for the modeller but less likely to be innovative and less likely to have impact

Data for Phase-type Modelling

- We have used data for geriatric patients at St George's Hospital, London, over the period 1969-85.
- Durations of hospital treatment were available from a number of patients, along with two covariates: age at admission and year of admission.
- This analysis was concerned with finding a suitable distribution to describe the variation in the duration times and assessing the effects of the covariates on this distribution.

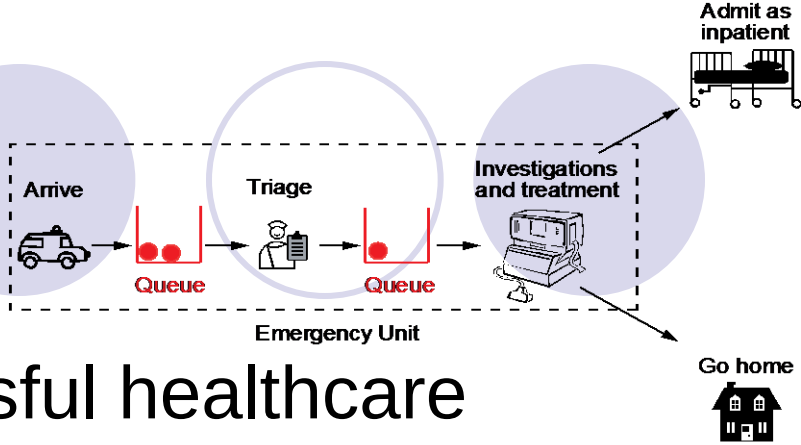
Faddy, MJ and McClean SI (2007), Using a Multi-State Model to Enhance Understanding of Geriatric Patient Care, *Australian Health Review*, Feb;31(1):91-97.

Data Availability



- We were lucky that Peter Millard had already collected a valuable dataset and was very committed to trying to understand it.
- Some data are available in standard hospital databases e.g. the Patient Administrative System, PARIS for our RIGHT Stroke exemplar.
- Often there is a paucity of detailed data but you can extract some from the literature or by a discussion with the “experts”.
- (Inter)nationally available datasets are also available e.g. HES.

Does it matter?



- A key component of successful healthcare modeling and simulation is a strong underpinning with up-to-date and relevant patient data.
- Often the acquisition of such data depends critically on strong commitment from the health and social services professionals and relies on their willingness to work alongside the modelers
- We need to ensure that important aspects of the healthcare problem are incorporated into a model which is underpinned by high quality data.

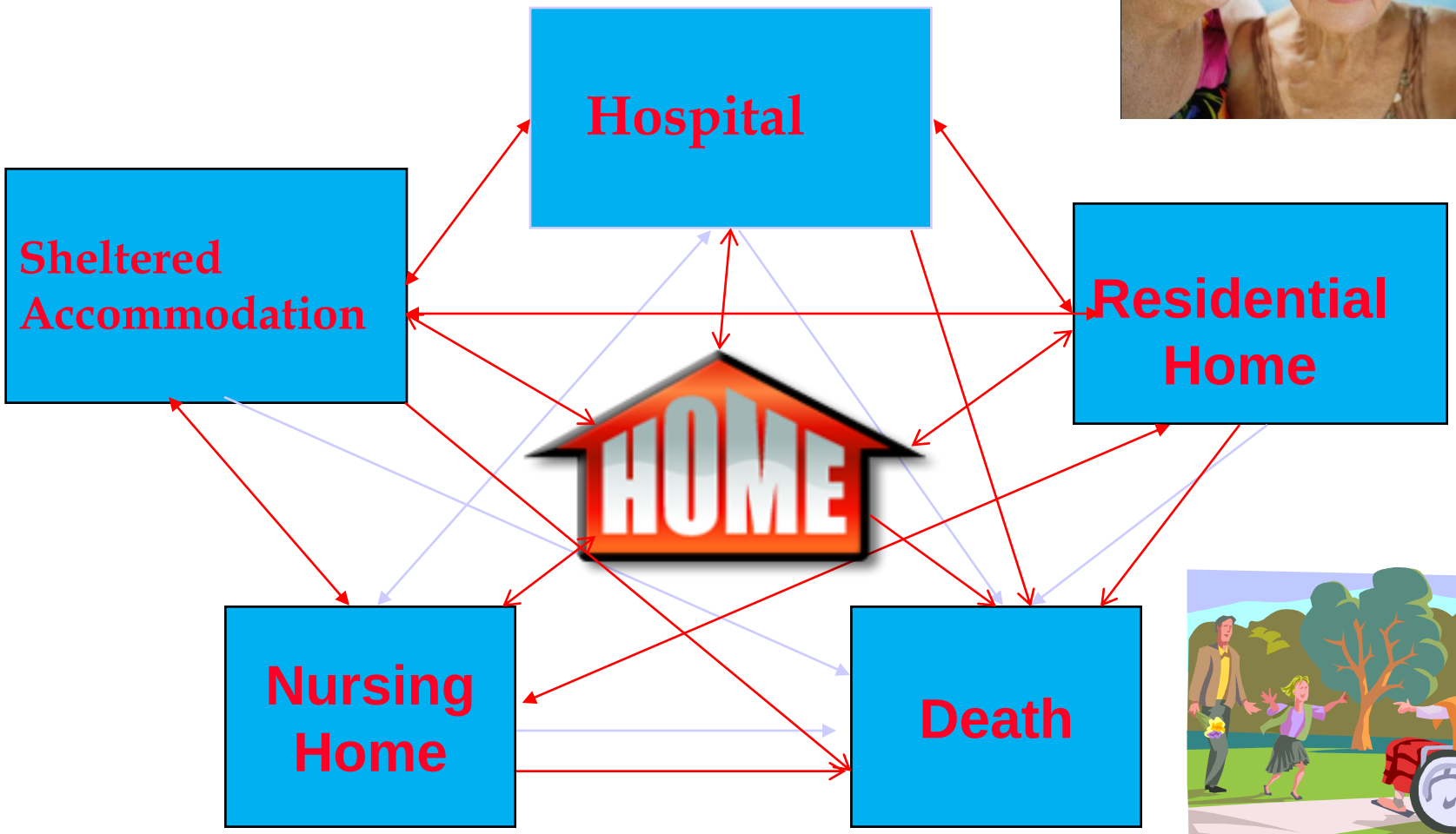
The Ulster Stroke Exemplar

- Champions
  - Dr Ken Fullerton, Belfast City Hospital
  - Dr Ivan Wiggam, Belfast City Hospital
  - Dr David Wilson, Queen's University Belfast
  - Maria Kinnaird, Belfast City Hospital
  - Professor Peter Millard, St. George's, University of London

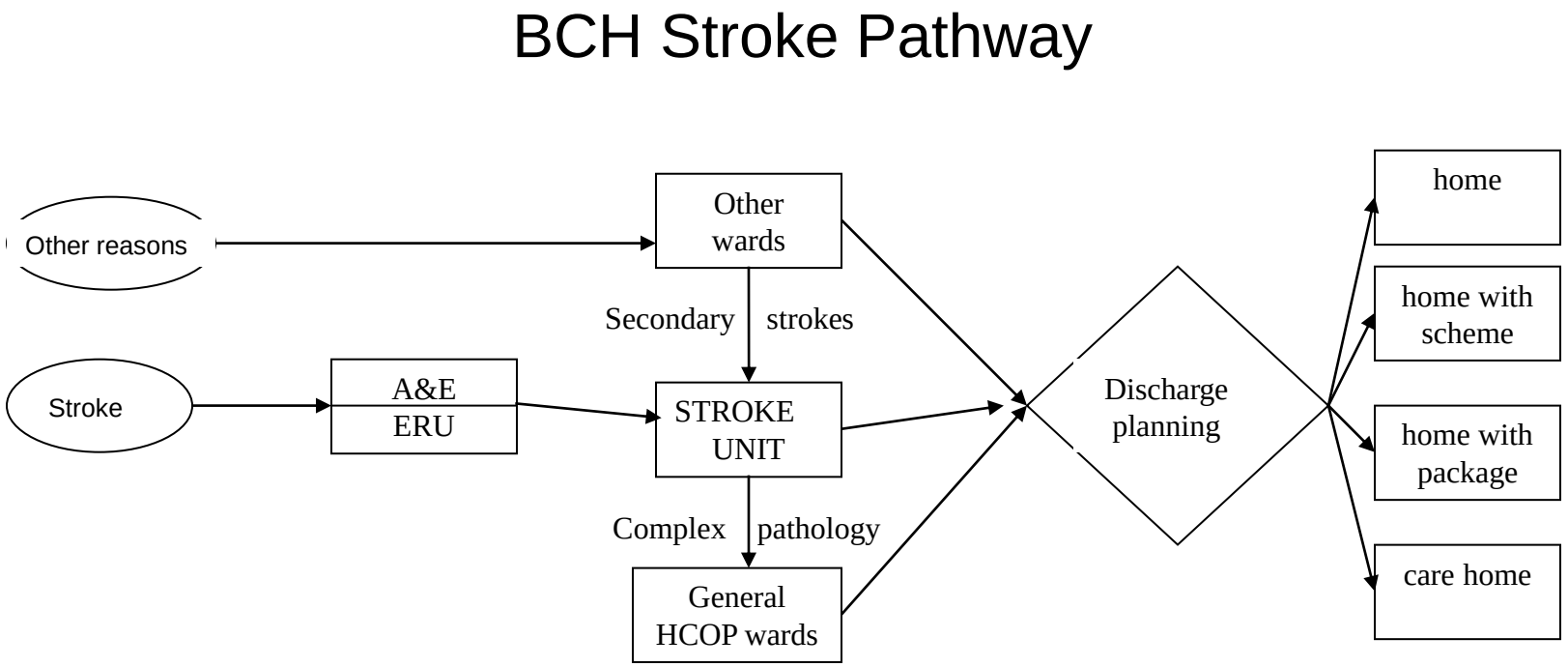
- Research Questions?
  - What are the major pathways for Belfast City Hospital stroke patients in terms of survival distributions, outcome probabilities, and pathways, taking account of the phases of care from referral to admission and discharge, movements between hospital, different social care options and readmissions?

  - Can we develop and use models to predict and compare outcomes and costs of rehabilitation and care options for Stroke patients?

The Integrated Patient Care System



Modelling stroke patient pathways



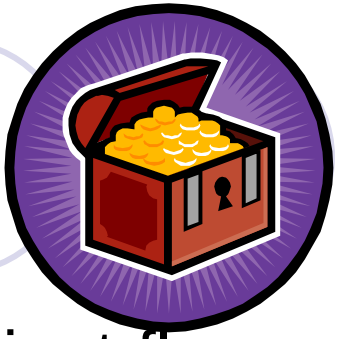
- LOS and costs for different stages of the pathway depends on various factors, such as age, gender, and diagnosis.
- We need to take account of such heterogeneity in the models

Heterogeneity of Patient Pathways

- Heterogeneity of patient pathways and Length of Stay (LOS) characteristics arises from a number of sources e.g. method of admission, diagnosis, severity of illness, age, gender, and treatment.
- A number of approaches have been employed to utilise such factors to cluster LOS data and generate patient groups (classes), based on phase-type distributions:
  - Bayesian Belief Networks and conditional phase-type distributions (Marshall, McClean et al.)
  - Phase-type survival trees and their extensions (Garg, McClean et al.)
  - Via the phase-type parameters (Faddy, McClean et al.).
- We also incorporate multiple patient outcomes such as discharge to home, discharge to private nursing home, or death.

Lalit Garg, Sally McClean, Brian Meenan, Peter Millard (2009), "Non-Homogeneous Markov Models for Sequential Pattern Mining of Healthcare Data", *IMA Journal of Management Mathematics*,

Costing the Models



- We have extended the Markov model of patient flows to a Markov system where admissions of new patients are modelled by Poisson arrivals and the state space is expanded to include spells in the community.
- By assigning costs to the various states of the model, we may determine the overall costs involved in treating cohorts of patients.
- Using locally obtained transition rates and costings, hospital planners may thus identify cost-effective strategies that balance differential costs in the various components of the system.

Lalit Garg, Sally McClean, Brian Meenan, Peter Millard (2010). A non-homogeneous discrete time Markov model for admission scheduling and resource planning in a cost or capacity constrained healthcare system. *Health Care Management Science,* 13(2) 155-169

The multiple class, multiple absorbing state, phase-type model

- As well as multiple states and phases within hospital care (for different diagnoses, male and female, and different discharge destinations), we also have different outcomes (usual residence, private nursing home, death etc.).

- These can be incorporated into the phase-type models as additional phases.

McClean S. I., Barton M., Garg L., Fullerton K. (2011) Combining Analytical and Simulation Approaches to Model Patient Flows. *ACM Transactions on Modeling and Computer Simulation*, to appear.

The multiple class, multiple absorbing state, phase-type model

In the multiple absorbing state phase-type model, we define C classes, where there are k_c phases (states) in class c. Tranistions occur from state S_i (i = 1,2,…, k-1) to state S_{i+1} of class c with transition rate λ_{ic}. Also transition is possible from any state S_i *of class c* to the absorbing state j *with transition rate* μ_{ijc}, for i=1,..., k, j=1,..,m, c=1,...,C .

The transition matrix ***Q*** *is now given by:*

$$\mathbf{Q} = \begin{pmatrix} \mathbf{Q}_1 & \mathbf{0} & . & . & \mathbf{0} \\ \mathbf{0} & \mathbf{Q}_2 & . & . & \mathbf{0} \\ . & . & . & . & . \\ . & . & . & . & . \\ \mathbf{0} & \mathbf{0} & . & . & \mathbf{Q}_C \end{pmatrix}$$

where

$$\mathbf{Q}_C = \begin{pmatrix} -(\lambda_{12}^c + \sum \mu_{1j}^c) & \lambda_{12}^c & . & . & \mathbf{0} \\ \mathbf{0} & -(\lambda_{23}^c + \sum \mu_{2j}^c) & . & . & \mathbf{0} \\ . & . & . & . & . \\ . & . & . & . & . \\ \mathbf{0} & \mathbf{0} & . & . & -\sum \mu_{k_c j}^c \end{pmatrix}$$

$$\mathbf{p} = (\mathbf{p}_1 \cdots \mathbf{p}_C)$$ and $$\mathbf{q}^c = \begin{pmatrix} \mu_{11}^c & . & . & \mu_{1m}^c \\ . & . & . & . \\ . & . & . & . \\ \mu_{k_c 1}^c & . & . & \mu_{k_c m}^c \end{pmatrix}$$

Finding the absorption probabilities

The vector of p.d.f.'s of length-of-stay in hospital prior to departure to the various absorbing states is then given by:

$$\mathbf{f}(t) = \mathbf{p}\exp(\mathbf{Q}t)\mathbf{q} = \sum_{c=1}^{C} \mathbf{p}_c \exp(\mathbf{Q}_c t)\mathbf{q}^c$$

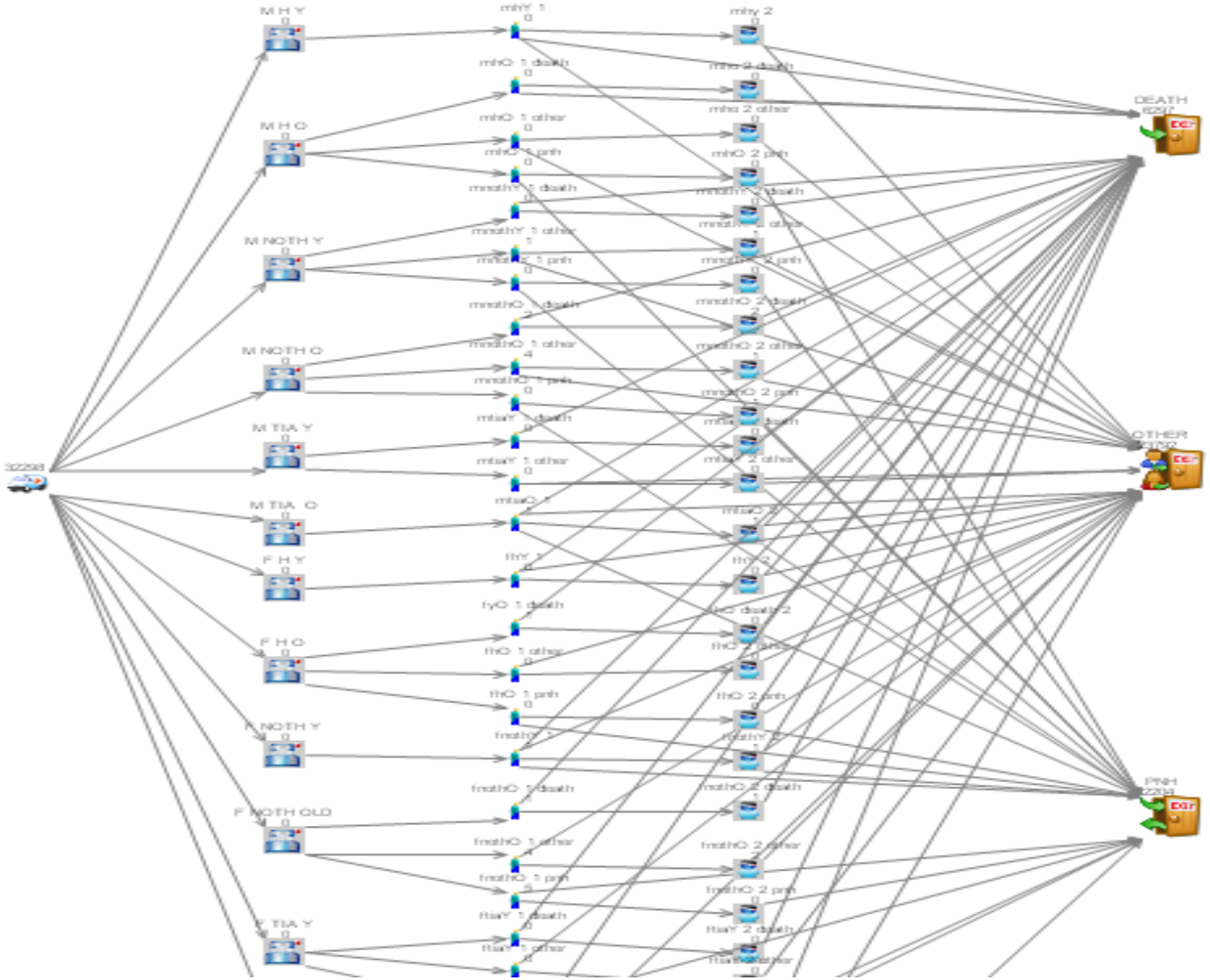
i.e. a mixture distribution where the mixing probabilities are the π_c's

Integrating this expression gives us the vector of absorption probabilities by time t, as:

$$\mathbf{F}(t) = \mathbf{p}(\mathbf{I} - \exp(\mathbf{Q}t))\mathbf{Q}^{-1}\mathbf{q}$$

Adele H. Marshall, Barry Shaw, Sally I. McClean (2007), Estimating the costs for a group of geriatric patients using the Coxian phase-type distribution, *Statistics in Medicine*, Volume 26, Issue 13, Pages 2716 – 2729.

The Simulation Model



Modelling Thrombolysis

- In collaboration with Dr Ken Fullerton and colleagues at the Belfast City Hospital, we have developed a detailed model of thrombolysis.
- Patient data were collected from the hospital, matched to social and community services data and combined with cost data from the literature.
- Costs are assigned to thrombolysis, hospital and to rehabilitative care within the community.
- The model also includes differential lengths of stay and probabilities of outcomes for thromolysed and non-thrombolysed patients
- Both analytic and Simulation models were developed
- Results indicate that thrombolysis is cheaper, and affords substantial improvements in quality of life.

Jennifer Gillespie, Sally McClean, Bryan Scotney, Lalit Garg, Maria Barton and Ken Fullerton (2011). Costing Hospital Resources for Stroke Patients using Phase-type Models, accepted for *Health Care Management Science.*

MATCH-Multidisciplinary Assessment of Technology Centre for Healthcare

EPSRC
Engineering and Physical Sciences Research Council

MATCH is an Innovative Manufacturing Research Centre

IMRC's cover a broad spectrum of areas and seek to create and/or improve value added processes.

Hence, the MATCH IMRC aims to create and/or improve value added processes in the life and healthcare industries.

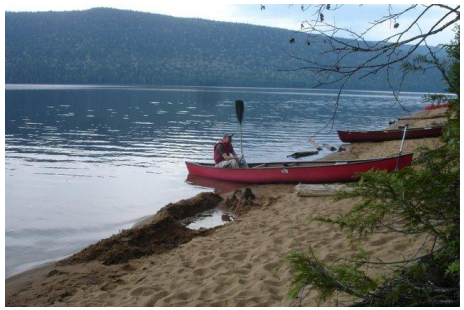
The MATCH partners are: University of Birmingham, Brunel University, University of Nottingham, University of Ulster

MATCH
Multidisciplinary Assessment of Technology Centre for Healthcare

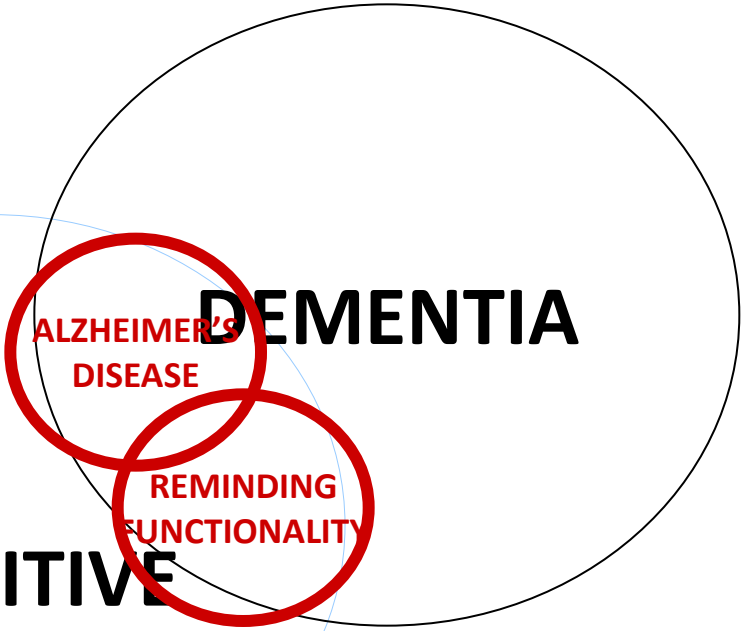
MATCH Plus

MATCH
Multidisciplinary Assessment of Technology Centre for Healthcare

- Within MATCH+ further funding has been obtained to focus on user requirements and evaluation
- At Ulster, MATCH+ is collecting and analysing data from users.
- This is in association with a previous project on developing a cell phone video streaming system for Alzheimer's patients.



Cell-phone Video Streaming (CPVS) in Alzheimer's Disease



"We view **cognitive prosthetics** as assistive technologies that help people with

Donnelly, M., Nugent, C.D., McClean, S.I., Scotney, B.W., Mason, S., Passmore, P. & Craig, D. (2010). IEEE MultiMedia, 17 (2), pp. 42-51.

Sonja A. O'Neill, Sarah Mason, Guido Parente, Mark P. Donnelly, Christopher D. Nugent, Sally McClean, Bryan Scotney and David Craig, (2011). Video Reminders as Cognitive Prosthetics for People with Dementia. Ageing International Volume 36, Number 2, 267-282.

The Cumberland Initiative

- The Cumberland Initiative aims to transform the quality and cost of NHS care delivery through simulation, modelling and systems thinking.
- The Initiative is led by a group of academics, who are developing an integrated programme of research, development and implementation, working with clinicians and industry to introduce significant change and benefit to the delivery of care in the UK and, eventually, around the world
- We hosted the last meeting in Belfast 2 weeks ago.
- Such intensive engagement is essential for Impact.

To summarise, for Healthcare Modelling & Simulation we need:

- A good healthcare collaborator (champion)
- The right approach to engagement
- Ethical Approval
- The right model(s)
- Suitable data
- Impact