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# More bang for your buck: using modelling & simulation to add value to healthcare evaluation studies

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# 1-minute intro to Operational Research

- "All models are wrong, but some are useful"
- A toolkit of modelling techniques and methods
- Some methods are mathematical and involve computer software … others don't (e.g. cognitive mapping)
- Some methods assume all the parameters are known and fixed (deterministic models) … others take account of individual variability and uncertainty (stochastic models)
- Some methods try to find the best solution (optimization) … others just try to find a good solution (simulation)

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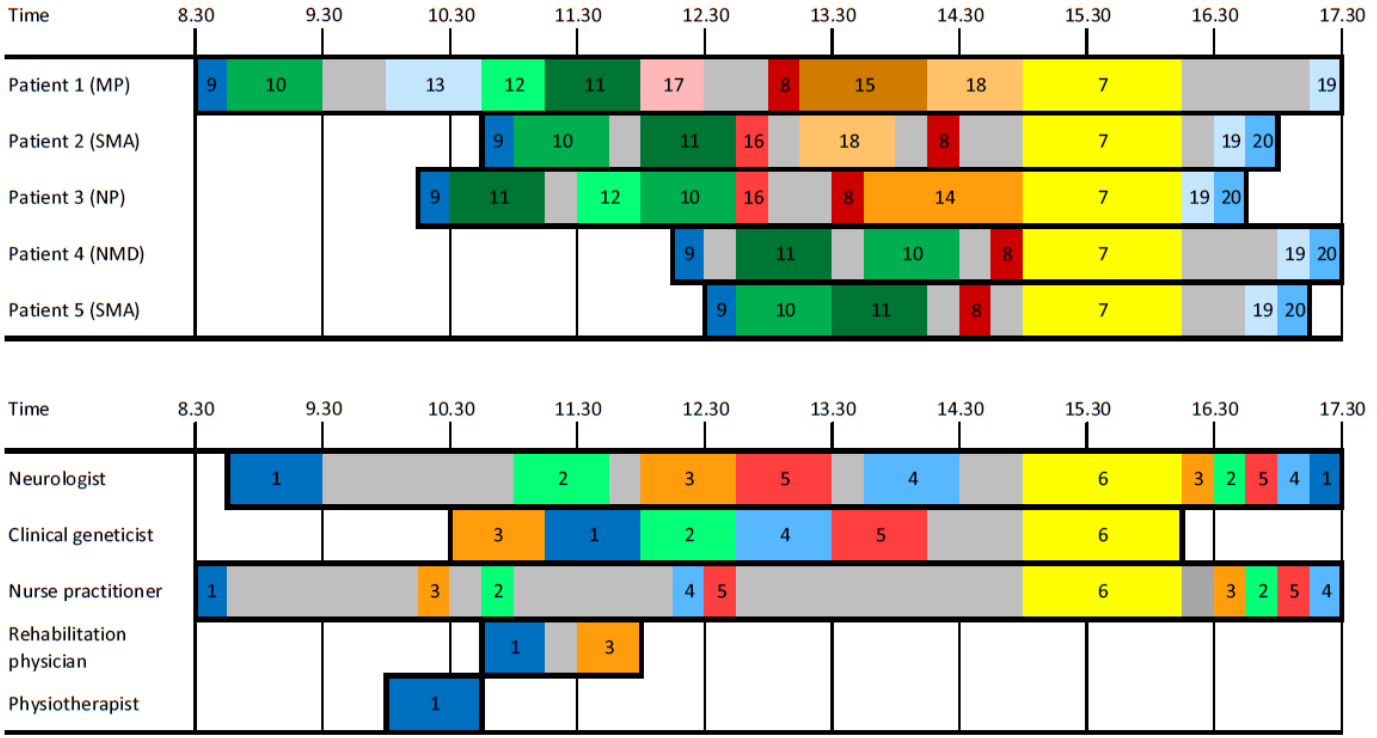
# An optimization model



# But … behind the scenes…

$$\min \sum_{i=1}^{n} U_i$$

Subject To

$$\sum_{t=1}^{T-p_i+1} v_{it} = 1 \quad \forall i \qquad (5)$$

$$\sum_{i=1}^{n} \sum_{\varepsilon=t-p_i+1}^{t} v_{i\varepsilon} \leq 1 \quad \forall t \qquad (6)$$

$$\sum_{t=1}^{r_i} v_{it} = 0 \quad \forall i \qquad (7)$$

$$\sum_{t=1}^{T-p_i+1} v_{it} + p_i - d_i - 1 - MU_i \leq 0 \quad \forall i \qquad (8)$$

$$v_{it} \in \{0,1\} \quad \forall i, \forall t < T - p_i$$

$$U_i \in \{0,1\} \quad \forall i$$

$$c_2^* = \min \sum_{i=1}^{n} U_i$$

Subject To

$$t_{k+1} - t_k - \sum_{i=1}^{n} p_i u_k^i \geq 0 \quad \forall k \qquad (14)$$

$$t_k - \sum_{i=1}^{n} r_i u_k^i \geq 0 \quad \forall k \qquad (15)$$

$$t_k + \sum_{i=1}^{n} (p_i - d_i) u_k^i \leq 0 \quad \forall k \qquad (16)$$

$$\sum_{i=1}^{n} u_k^i \leq 1 \quad \forall k \qquad (17)$$

$$\sum_{k=1}^{n} u_k^i + U_i = 1 \quad \forall i \qquad (18)$$

$$u_k^i \in \{0,1\} \quad \forall k, i$$

$$U_i \in \{0,1\} \quad \forall i$$

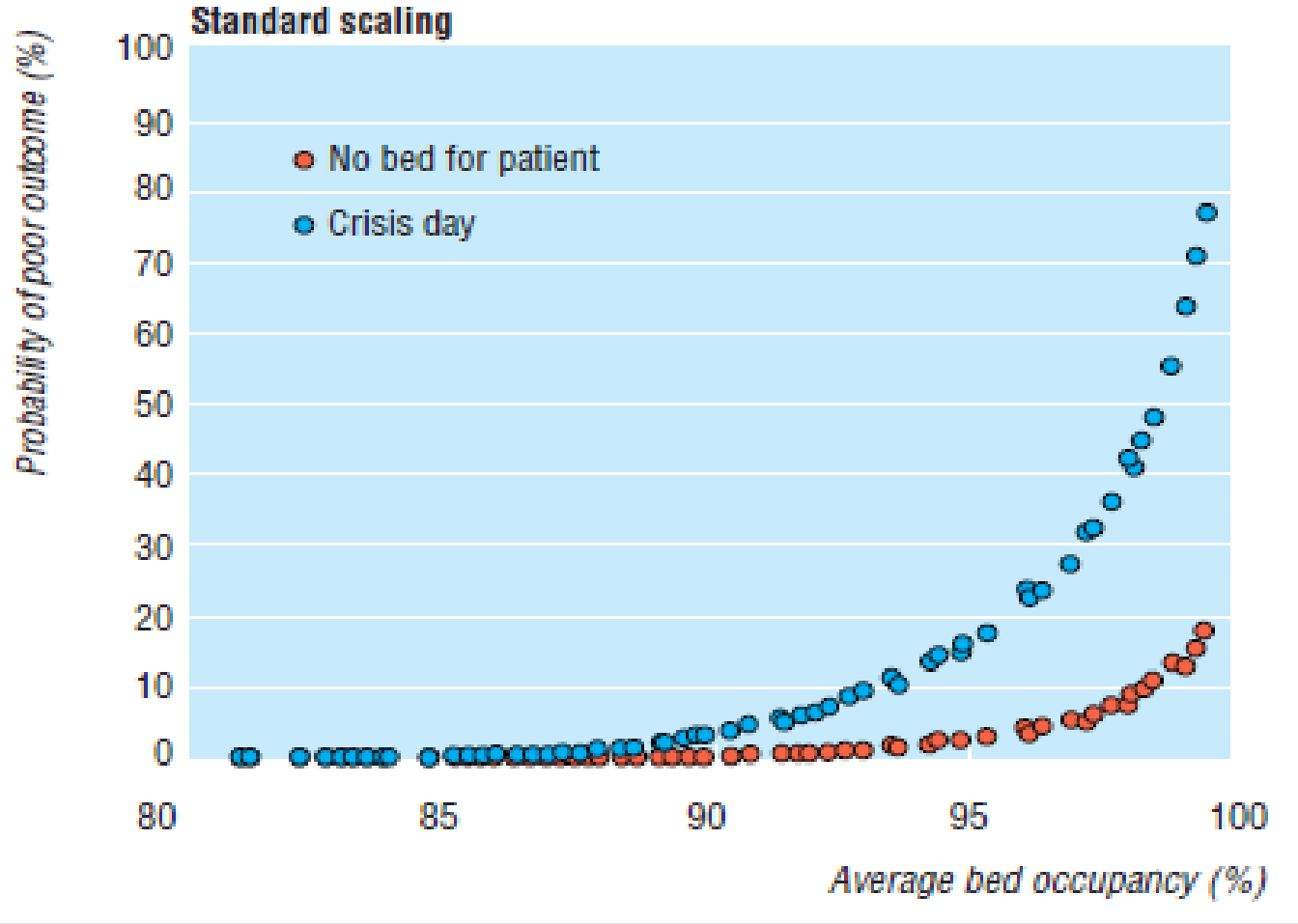
# A discrete-event simulation (DES) model

# Example 1: Bagust et al (BMJ, 1999)

- A (fairly) simple discrete-event simulation model which showed the impact of variability in arrivals and LoS
- Performance measures:
  - the annual % of emergency arrivals who cannot be accommodated owing to a lack of available beds
  - the % of days in a year when there is at least one such patient (termed a crisis day)
- Influential on government policy about bed occupancy targets

**Bagust, Place & Posnett** (1999) Dynamics of bed use in accommodating emergency admissions: stochastic simulation model. BMJ 1999; 319:155-159

# Results


Standard scaling
Probability of poor outcome (%)
100
90
80
70
60
50
40
30
20
10
0
No bed for patient
Crisis day
80
85
90
95
100
Average bed occupancy (%)

# Example 2: Diabetic retinopathy screening

- Joint research with Ruth Davies and Chris Canning in the 1990‘s
- Population-level discrete-event simulation model of the natural history progression of retinopathy in individual patients with diabetes
- Data on incidence, prevalence and progression from the literature (mainly the UK Prospective Diabetes Study and the Wisconsin Epidemiologic Study of Diabetic Retinopathy) and on screening modalities from clinical trials
- Model run for 30 years (1990-2020) in many different UK populations: wide variety of screening methods and policies were tested
- Outcome measure: cost per sight year saved

# Results

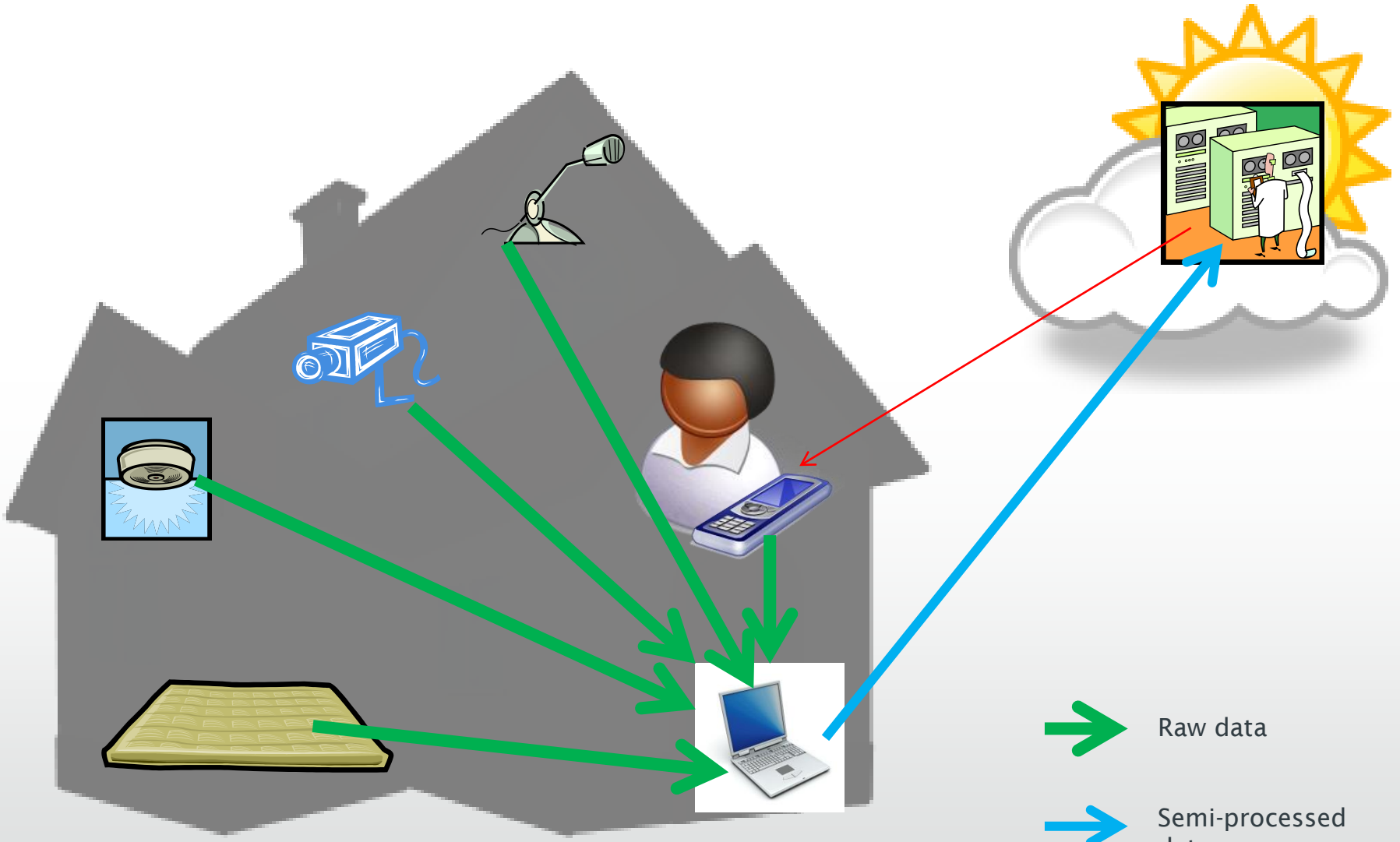
- Mobile van was the most cost-effective method (at the time)
- Differences between methods were small in comparison with compliance issues: getting people to attend is key
- Led to further research into ways of including human behaviour in simulation models: e.g. modelling mammography attendance

**R.M. Davies, P.J. Roderick, C. Canning and S.C. Brailsford (2002).** The evaluation of screening policies for diabetic retinopathy using simulation, *Diabetic Medicine*, **19:** 762-770.

**Brailsford S C, Harper P R and Sykes J (2012).** Incorporating human behaviour in simulation models of Screening for Breast Cancer. *European Journal of Operational Research*, 219: 491-507.

# Example 3: the PAM project

- Joint EPSRC-funded research with engineers Christopher James, John Crowe and Evan Magill (2007 – 10)
- Enabling health, independence and wellbeing for psychiatric patients through Personalised Ambient Monitoring (PAM): evaluating the potential use of a system of wearable and ambient sensors to monitor activity patterns in people with bipolar disorder


Raw data
Semi-processed data
Alert (via SMS)

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Engineering and Physical Sciences Research Council

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# OR modelling in PAM

- A natural history model for bipolar disorder was developed and used to test the sensitivity and specificity of the PAM algorithms
- An Excel-based microsimulation model was used to conduct a "virtual clinical trial" on thousands of synthetic patients, using a combination of data from the clinical literature and artificial data
  - Could PAM possibly work? What would a PAM system look like?
  - How accurate (and/or reliable) would it have to be, to be useful?
  - Can we describe the types of patient who might benefit?
  - Where should the engineers focus their attention? Where are the critical weaknesses in the system?

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# Results

- The effectiveness of PAM was highly dependent on the individual's personal choice of sensors and prodromes (symptoms & behaviours)
- PAM was found to be inadequate for almost all the personalised choices of two prodromes only, but efficient for most choices of three prodromes
- The model informed future design decisions, even though the PAM system itself did not even exist when the model was being developed!

**Brailsford, S.C., Mohiuddin, S. and James, C.J. et al. (2013).** A multi-state model to improve the design of an automated system to monitor the activity patterns of patients with bipolar disorder. *Journal of the Operational Research Society* 64, 372-383

# Summing up .. and reflecting on data

- The Bagust et al model used very little real data, but it had a major impact on national target-setting policy
- The retinopathy model used data from a wide variety of sources, not all from the same setting (or even country)
- The PAM model was exceedingly hypothetical, even though it did use a limited amount of data from the clinical literature

- These models may all have been “wrong” .. but they were undoubtedly useful

# The benefits of OR modelling

- Provides a risk-free playground for experimentation and is vastly quicker and cheaper than trying things for real
- Provides a neutral framework for discussion: engages stakeholders and forces clarity through making assumptions explicit
- Can inform future work, data collection or the design of systems/things which do not yet exist
- Powerful when used in conjunction with other research methods for triangulation, experimentation etc
- You can always learn something from a model, even if you have no data
- A smart way to squeeze the last drop of value from your data!