

# Adaptive planning of staffing levels in health care organisations

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## Main ideas

- Performance - Objectives and domains
- Modelling - Conceptualise details of the service delivery network
- Optimisation - Improve service delivery
- Results

## Performance framework (PF) for UK

- NHS performance in UK is the responsibility of the DH, SHAs, PCTs.
- The PF published by DH(June 2009) sets out among others,
  - 1 importance on dynamic performance assesment of NHS providers
  - 2 standards and targets
  - 3 intervention

## Performance framework for UK

- Case for centralised performance framework
  - ① expectations
  - ② accountability
  - ③ under performance
  - ④ time scales for recovery
  - ⑤ penalties
- Why?
  - ① Prevent organisational failure
  - ② Incentivise good performance

## Performance optimisation

- Domains
  - 1 operational standards and targets
  - 2 finance
- Performance benefits
  - 1 evaluation of policies
  - 2 measurement of strategies
  - 3 management and clinical priorities

## Scope of implementation

- Assessment tools - current methods
  - offline analysis of recorded data to produce statistics
  - not dynamic or high frequency updates
  - isolated use
- Predictive and verification tools - proposed research
  - process models
  - real-time measurement
  - continuous updating
  - bottlenecks
  - variations in patient flow
  - patient segmentation
  - real-time reporting of statistics

## Staffing in healthcare

- Currently performance is target based and require staff to work harder
- Proposed view
  - Real-time measurement of the system
  - Identification of problem areas - excess delays & queue lengths
  - Recommendation of staff levels to achieve performance targets

## Performance pressures on A&E centres in UK

- A&E department service target - 98% of patients must spend 4 hours or less from arrival to admission, transfer or discharge (Waiting time).
- Increase in the number of attendances to A&E departments and walk-in centres in England.
- In 2003 – 6, seven hospital trusts reported one or more A&E departments closed or downgraded, with one new A&E department opening.
- A&E departments need to predict patient variability  
Optimal staffing level that meet cost and service target.

## Context

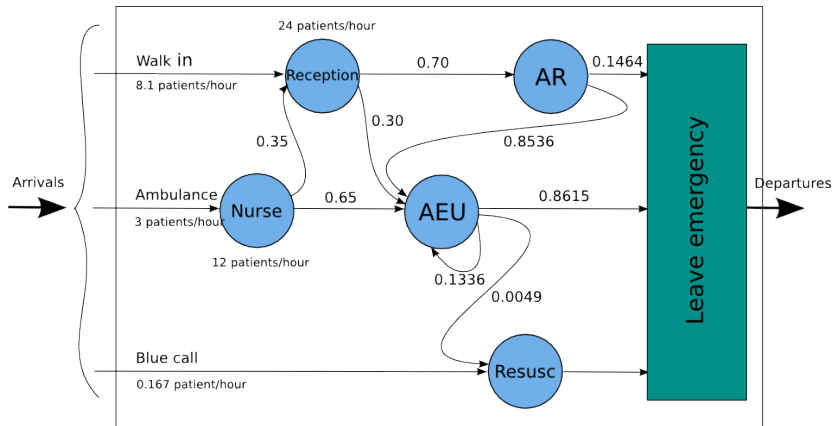
Previous application of queueing models to A&E in UK by Coats et. al. [1], Mayhew et. al. [2, 3] are limited by,

- 1 do not tie performance to resources and patient arrivals.
- 2 do not model natural phenomena that occur in real life systems - variability in patient arrivals.

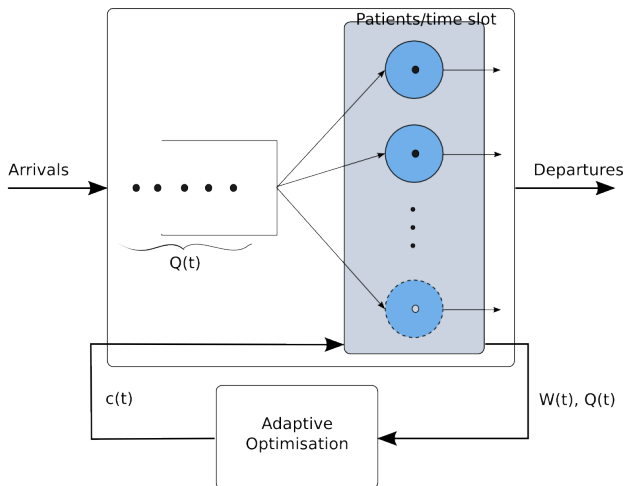
For the first time this work presents,

- 1 transient queueing model - adaptable
- 2 dynamic optimisation - real-time measurements
- 3 finds an optimal/sub-optimal policy - e.g. staff resources that achieve waiting time targets and minimise cost

## A&E Queuing model



## Simple staffing model



## Objective

Consider maximum waiting time target  $W_{\max} = 4$  hours,  
Assume resource cost  $C_r$ , penalty  $C_p$  & patient queueing cost  $C_s$

Objective function,

$$V_{\pi} = E_{\pi} \left[ \int_{t=0}^{\infty} (C_r c(t) + C_p \max(E[W(t)] - W_{\max}, 0) + C_s Q(t)) dt \right]$$

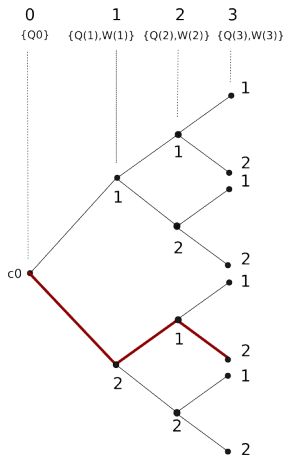
$V_{\pi}$  - Cost of operating the system under staffing policy  $\pi$

$W(t)$  - Patient waiting time in the system

$Q(t)$  - Patients queueing for service

$c(t)$  - Number of staff ranging from 1 to  $K$

# Optimal staffing policy $\pi$



Assume  $K = 2, T = 3, t \in (0, 3]$

$$\pi^* = (c0, 2, 1, 2) \Rightarrow V_{\pi^*}$$

$$V_{\pi^*} < V_{\pi}$$

Method

1. Uniformisation to obtain a discrete-time representation of the object function  $n = 0, 1, \dots, N$

**Cost at n:**

$$C(Q(\bar{n}), c(n)) = [C_r c(n) + C_p (\bar{W}(n) - W_{\max})^+ + C_s \bar{Q}(n)] / \Delta \quad (1)$$

$\Delta$  - uniformisation constant

## Optimal staffing policy $\pi$

2. **One-step look ahead cost at n:** Approximate dynamic programming to get a sub-optimal solution ( $c = 1, 2$ )

$$V(Q(n+1), c) = \sum_{\forall j} p_{ij}^{c(n)} [C_r c + C_p (W(n+1|n) - W_{\max}) + C_s Q(n+1)] / \Delta \quad (2)$$

3. **Staff level at (n+1):** from (1), (2)

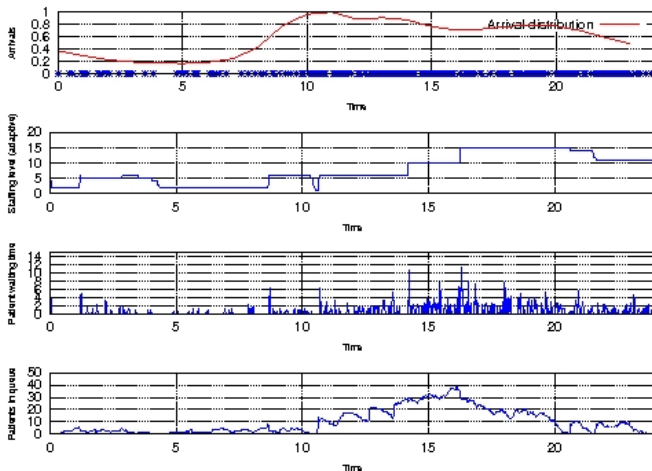
$$c(n+1) = \min_{c \in \{1,2\}} [C(\bar{Q}(n), c(n)) + V(Q(n+1), c)] \quad (3)$$

## Discrete-Event Dynamic Simulation

- Actual arrivals data from an NHS A&E unit in London (one year period)
- Arrival rate distribution for a 24 hour period is computed by averaging over all the days in the year
- Service rate of each staff member is assumed to be 1.379 (patients/hour)
- Cost parameters in cost units per hour are assumed to be,
  - (1)  $C_s = 3$  cost of patients waiting in a queue per patient
  - (2)  $C_p = 2$  penalty of missing the 4 hour waiting time target per patient
  - (3)  $C_r = 5$  resource cost per staff member

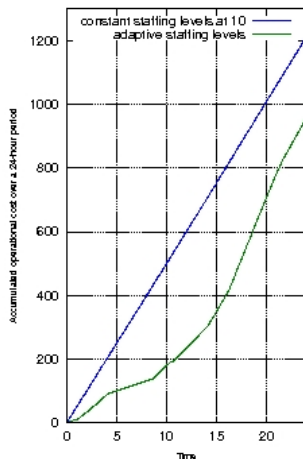
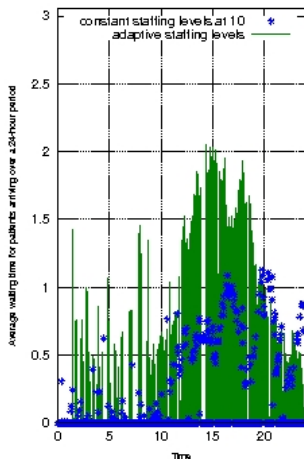
## Discrete-Event Dynamic Simulation

The adaptive staffing policy decides values from the set  $\{1, 2, 3, 4, 5, 6, 10, 15, 20\}$  at 2 minute time slots



## Discrete-Event Dynamic Simulation

### Performance targets



There is a cost saving of approximately 20% in this instance.

## Conclusions

- Summary
- Future research
  - Detailed model - bottlenecks
  - Patient classes - priorities, flu patients
  - New technologies - Asset tracking and management

Thank you  
?



Coats, T.J., Michalis, S., Mathematical modelling of patient flow through an Accident and Emergency department. *Emergency Medicine Journal*, 18 (2001) 190192.



Mayhew, L., Carney-Jones, E., Evaluating a new approach for improving care in an Accident and Emergency department: The NU-care project. Technical report, Cass Business School, City University, (2003).



Mayhew, L., Smith, D., Using queueing theory to analyse completion times in Accident and Emergency times in the light of the government 4-hour target. Technical report, Cass Business School, City University, Actuarial Research Paper No. 177 (2006).