

# **CAPACITY IN CRITICAL CARE**

## **History, update and future**

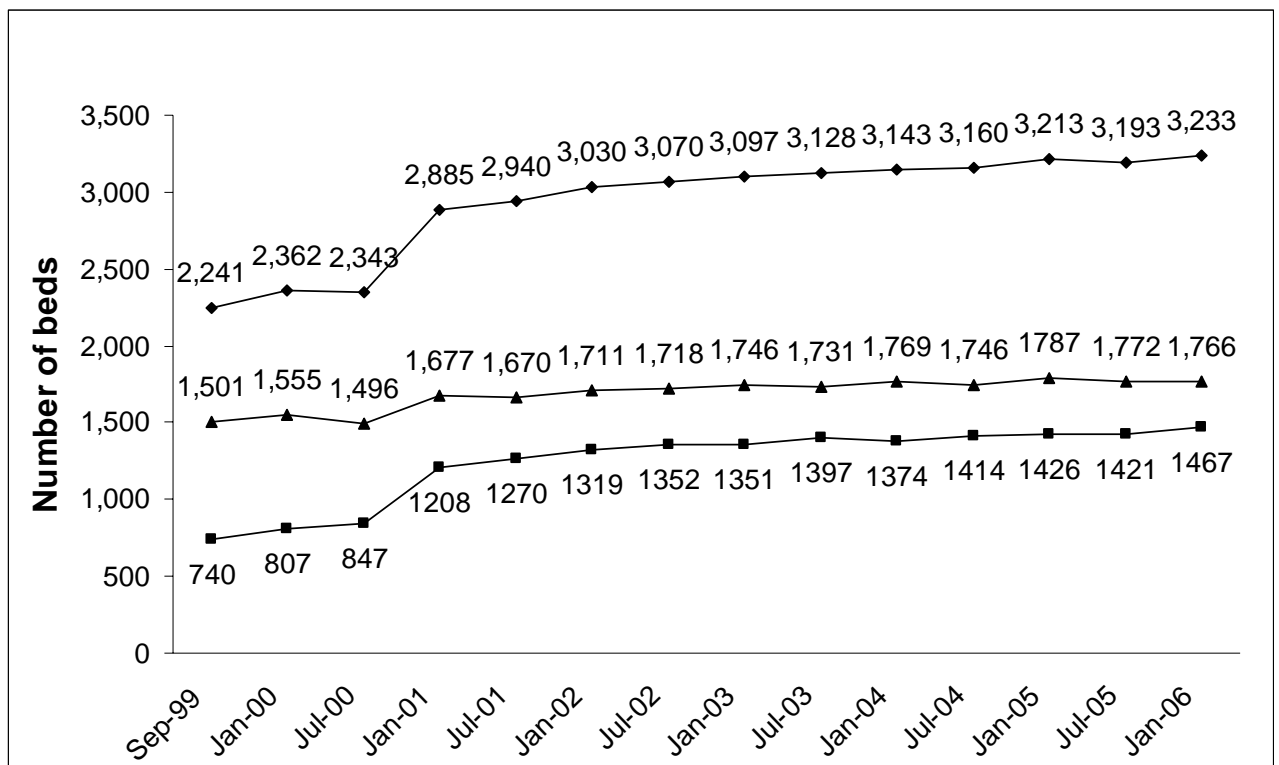
The Intensive Care Society's and Department of Health's Working Group on

Patient Flows in Critical Care

## History

Critical care is recognised to be one of the key acute hospital services [1]. Unfortunately, due to the competing demands of emergency and elective admissions, patient flow through the entire hospital can be constrained by inadequate critical care capacity. Such constraints are usually manifest as postponed operations for elective admissions and non-clinical transfers for emergency patients. Although the number of critical care beds has increased since 2000 [2] (Figure 1) it is unclear, in the face of greater hospital activity, whether the extra critical care capacity is sufficient to prevent critical care from being a 'bottleneck' within the hospital system.

Figure 1. The number of ICU beds (triangles), HDU beds (squares) and total critical care beds (diamonds) in England reported in the bi annual critical care bed KH03a census.



There is wide variation in all aspects of critical care. Most importantly, there are enormous differences in the lengths of stay of patients. Such differences are present even between patients within the same diagnostic group because of variations in the severity of their illness. The case-mix of patients will vary between critical care units depending upon the specific hospital population they serve. For example, there are specialist critical care units looking after patients following cardiac or neurosurgery and units providing specialist care to paediatric, liver and burns patients, as well as more standard general adult critical care units. Such heterogeneity frequently makes it difficult for managers or purchasers of healthcare to gain an overall picture of how a critical care unit is operating. It also makes it almost impossible to compare critical care units, which might be considered similar. Clinicians delivering critical care often have to concentrate on operational aspects of service delivery, such as when the next ICU bed will become available and, if necessary, which patient will be transferred to another unit. As a result, clinicians can lose, or fail to appreciate, the overall dynamics of patient flow through their units and what might be done to improve, or at least ameliorate, the situation.

The understandable response to seemingly inadequate capacity is that critical care needs more beds. This may indeed be true, but two important questions need to be answered before simply increasing critical care bed numbers. First, is there any evidence to show that the present capacity is being used as effectively as possible? Clinicians running busy critical care units may, with some reason, argue that consistently high occupancy rates demonstrate that

there is little they can do to improve efficiency. However, this may not necessarily be true. Second, what improvement in patient flows could be expected following any investment in expensive critical care beds? Rather than qualitative answers, purchasers could reasonably expect accurate forecasts about the expected increase in numbers of patients treated and the numbers of postponed operations and non-clinical transfers following the investment of £310,000 per annum, the price of a Level 3 (intensive care) bed [3].

## **Methods**

In early 2004, the Modernisation Agency, and subsequently the Emergency Care Team at the Department of Health and the Intensive Care Society agreed to review the possible ways in which these two questions could be addressed. A small working group of interested volunteers was formed and the group is now in a position to describe some of their results. After reviewing the literature for prior examples of flow and capacity modelling applied to critical care, the group felt that the two questions would be best answered by the following approaches.

### ***a) Mapping patient flow through critical care***

A simple patient flows model had been produced under the auspices of the Modernisation Agency [4] and was tested in a number of individual critical care units and also across whole critical care networks. The Working Group recognised that various enhancements could be made to the model to make it both easier to use and more useful to clinicians, managers and purchasers.

Based upon experience within the Working Group and after a call for suggestions from the critical fraternity, various adjustments to the model were made.

### ***b) Effects of changes in flows***

As critical care bed spaces are expensive to equip and staff, it is not unreasonable to try and quantify the likely consequences of any capacity changes. This would quantify the enhancement in service delivery in terms of extra patients treated, decreases in postponed elective operations and decreases in non-clinical transfers. Computer simulation has been used in other spheres of medicine and is recognised as a robust technique [5-7]. The combination of an appropriate grouping of the patients using classification and regression tree analysis (CART) [8,9] and the computer simulation of patients passing through a critical care unit can evaluate the effects of changes in critical care capacities and selected changes in the case load or case mix. This combination has been described previously for critical care [10,11] and since then the model has been refined further.

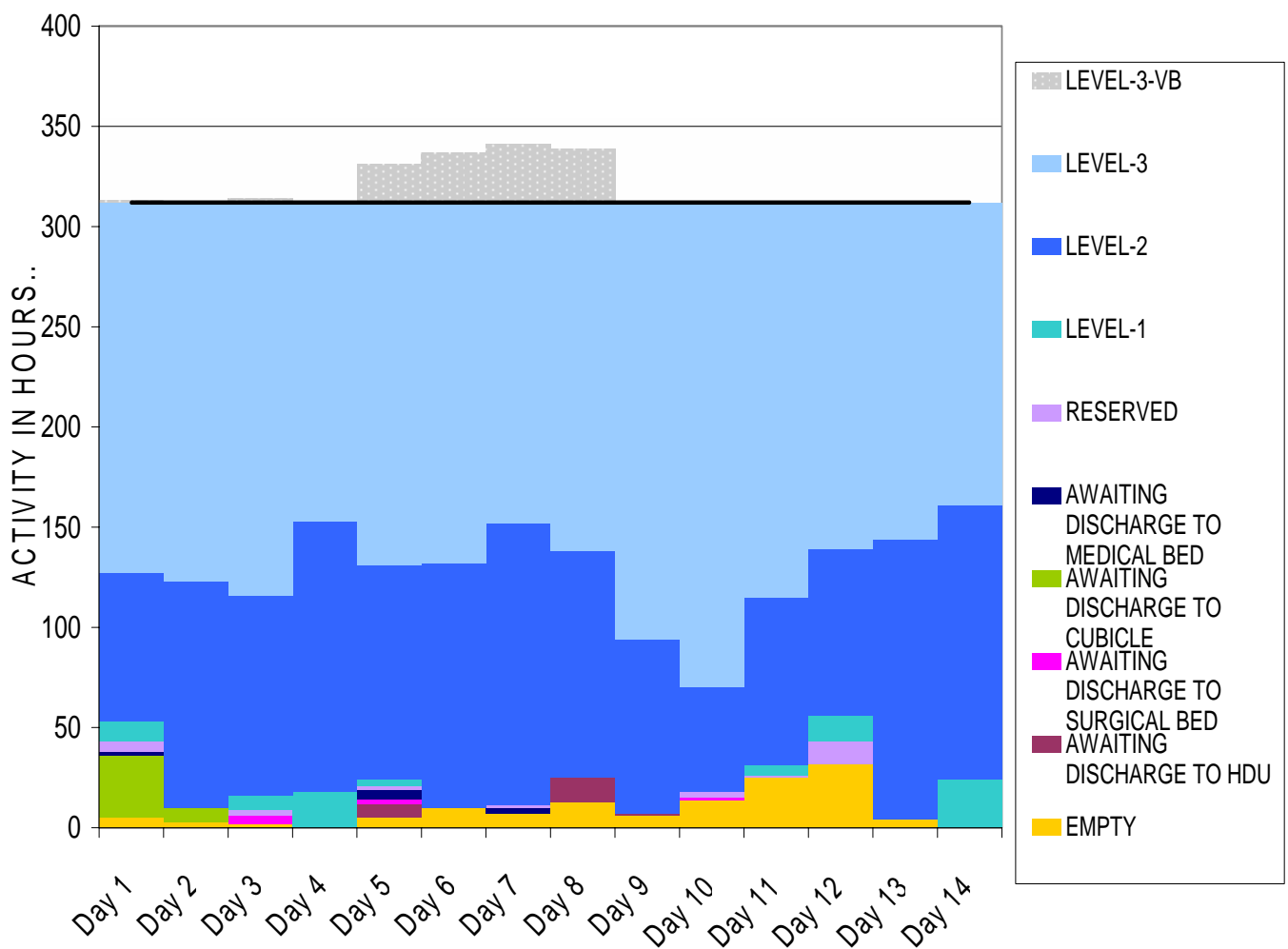
## **Results**

### ***a) Mapping patient flow through critical care***

The patient flow model is available for download from the Patient Flows webpage of the Intensive Care Society's website ([www.ics.ac.uk](http://www.ics.ac.uk)). The flow model graphically describes the current use of critical care beds on an hour-by-hour basis. The model requires relatively simple inputs (i.e. the level of care required by the patients in any occupied beds or the status of any unoccupied

beds e.g. empty, being cleaned, closed) and also records the actual demand for critical care (as opposed to simply measuring activity). Any unmet demand is captured by creating 'virtual' critical care beds that indicate a patient being cared for elsewhere (e.g. theatre recovery, Accident & Emergency Department or another hospital). A high number of virtual patients is a clear marker of demand exceeding capacity. The graphical output of the model can be customised, but principally shows the hourly occupancy of all the beds over time (Figure 2 shows an example). The output is useful because it shows the relative demand for level 2 (high dependency) care versus level 3 (intensive) care. It clearly demonstrates what impact closure of beds (e.g. due to staff shortages) and delayed discharges will have on occupancy and patient flows.

Figure 2. An example of a summary graph from the flows model. The format and the data displayed can be tailored to suit the end user. The levels describe the level of care required by the patients; VB are virtual beds representing patients elsewhere awaiting admission. The solid black line represent unit capacity (at 310 hrs activity).



**b) Effects of changes in flows**

In essence, using historical data from a particular critical care unit, CART produces an appropriate grouping of patients which reduces the heterogeneity in their lengths of stay. A computer programme then uses these groups of

patients to simulate the flow of all patients through the critical care unit for a fixed length of time (usually one year). The simulation is run several times to get sufficiently precise results and the final output summarises all these simulation runs. Table 1 compares the model predictions based on running the model for 50 x 1 year simulations for a critical care unit with 13 beds using CART analysis of the available data and the information about the unit. This table includes the 95% confidence limits for the mean values calculated from the 50-year run. There is a good match between the available data and the tuned model giving reasonable estimates of the various mean values.

Table1. Critical care data (actual data first column) and model predictions for a unit with 13 beds

	Actual data and information	Model mean value	Model lower 95% limit	Model upper 95% limit
Emergency Admissions	822	821	814	828
Elective Admissions	190	191	187	195
Total Admissions	1012	1012	1004	1020
Bed Occupancy	About 80%	80.3%	79.3%	81.3%
Deferral Rate	About 20%	21.5%	20.5%	22.5%
Transfer Rate	About 1%	1.2%	1.0%	1.4%

A successfully tuned model can be used to evaluate a variety of scenarios about capacities and patient flows. Table 2 illustrates the effects of changes

in both the number of beds and patients in terms of bed occupancy and the service delivery. With increased capacities and the original number of patients (1012), service levels will improve and the pressure on the critical care unit, as measured by the bed occupancy rate, will decrease. With the base case service levels, increased capacities will mean that a greater number of patients can be admitted to the critical care unit.

Table 2. Predictions for the effects of increased capacities and increased number of patients. The original situation is 13 beds.

Beds	13	14	14	15	15	16	16
Emergency Admissions	821	819	912	822	934	944	1047
Elective Admissions	191	190	208	192	212	210	234
Total Admissions	1012	1009	1120	1014	1146	1154	1281
Bed Occupancy	80.3%	74.2%	82.3%	70.2%	79.8%	74.5%	81.8%
Deferral Rate	21.5%	12.6%	24.0%	7.8%	17.9%	11.0%	19.7%
Transfer Rate	1.2%	0.6%	1.8%	0.4%	1.1%	0.5%	1.2%

Table 3 shows the effects of a particular change in the case-mix of the patients and Table 4 shows the effects of reductions in the delayed discharges.

Table 3. Predictions with an extra 20 planned general surgical patients.

	Data	13 Beds	14 Beds
Emergency Admissions	822	822	819
Elective Admissions	210	209	212
Total Admissions	1032	1031	1031
Bed Occupancy		81.8%	76.2%
Deferral Rate		23.0%	15.1%
Transfer Rate		1.3%	0.6%

Table 4. Predictions for improved service delivery with reductions in delayed discharges

	Data	Tuned Model	0.5 Day reduced 13Beds	12Beds	1.0 Day reduced 13Beds	12Beds
Emergency Admissions	822	822	818	820	825	816
Elective Admissions	190	192	192	194	190	194
Total Admissions	1012	1014	1010	1014	1015	1010
Bed Occupancy	About 80%	79.2%	70.4%	76.6%	62.1%	68.4%
Deferral Rate	About 20%	19.8%	11.5%	19.1%	4.2%	9.3%
Transfer Rate	About 1%	1.2%	0.5%	1.1%	0.1%	0.4%

## **Discussion**

### ***a) Mapping patient flow through critical care***

The information provided by the patient flows model enables process anomalies to be identified that can then be the focus of improvement efforts.

Persistently high critical care usage is graphically shown over time, rather than as a single summary occupancy percentage, thus better communicating the operational realities that critical care clinicians face on a daily basis.

Clinical experience with the model suggests that once in place, this level of data collection and entry is not considered onerous by most staff.

If a critical care unit can demonstrate that despite making every effort to prevent bed closures due to staff shortages, minimise delays in discharge and provide best practice care, occupancy and virtual patient numbers are persistently high, then its request for additional capacity would seem well founded.

### ***b) Effects of changes in flows***

The combination of grouping patients and simulating their flow is a very helpful planning tool for making robust decisions about changing capacity and/or case load. This sort of modelling approach can also be used for managing existing capacities and existing patient flows through a “diary planner” which considers the current state of the critical care unit and looks ahead, for example, to four weeks. Such short-term prediction could allow the matching of staffing levels to peaks and troughs in demand, booking of

elective patients and, as a result, better matching service delivery to demand. This work is being undertaken by the Working Group at present.

## **Conclusion**

The patient flows model and supporting documentation is freely available on the Intensive Care Society website. This approach to better understanding capacity and demand issues is being actively promoted via Critical Care Networks and the Intensive Care Society. Use of the simulation model requires training and it is hoped that this will be available in the summer of 2006. Validation of the predicted effects of changes in capacity for a small, medium and large critical care unit are being performed at the moment and will be published in the summer of 2006. The short-term prediction model for managing existing capacities and existing patient flows is likely to be ready by 2007. The patient flows model and capacity simulation may help Trusts to develop robust cases for alterations in critical care provision. The graphical representation of the effects of these changes may be more easily appreciated by all concerned with the delivery of critical care.

## **Competing interests**

Dr Shahani developed the capacity-planning model at Health Data Analysis and Modelling Group, GeoData Institute, University of Southampton, SO17 1BJ. This is an academic not-for-profit facility within the University of Southampton.

## **References**

- 1) Critical Care Stakeholder Forum (2005). Quality Critical Care: Beyond Comprehensive Critical Care. London: Emergency Care Team.
- 2) Department of Health. Critical Care Bed Census Form KH03a.  
[http://www.performance.doh.gov.uk/hospitalactivity/data\\_requests/download/critical\\_care\\_beds/ccbed\\_jan06.xls](http://www.performance.doh.gov.uk/hospitalactivity/data_requests/download/critical_care_beds/ccbed_jan06.xls).
- 3) National Cost Block Programme (2005). 2003-04 Report. Sheffield: National Cost Block Programme.
- 4) Modernisation Agency. Critical Care: Patient Flows 1.  
<http://www.wise.nhs.uk/sites/clinicalimprovcollab/cc/PatientFlows/Forms/Description.aspx>.
- 5) Lattimer V, Brailsford S, Turnbull J, Tarnaras P, Smith H, George S, et al (2004). Reviewing emergency care systems I: insights from system dynamics modelling. *Emergency Medicine Journal*, 21: 685-91.
- 6) Shahani A K, Korve N, Jones K P & Paynton D J (1994). Towards an operational model for prevention and treatment of asthma attacks. *Journal of Operational Research Society*, 45: 916-26.
- 7) Bowie C, Duff C, Harper P, Shahani A K, Wilderspin H & Yates J (2004). Long-term planning to meet UK government coronary heart

disease revascularization targets. *Health Service Management Research*, 17: 132-40

- 8) Breimann L, Friedman J, Olshen R & Stone C (1993). Classification and Regression Trees. New York: Chapman and Hall. ISBN:0412 048418.
- 9) Ridley S, Jones S, Shahani A K, Brampton W, Nielsen M & Rowan K (1998). Classification trees; A possible method for iso-resource grouping in intensive care. *Anaesthesia*, 53: 833-40.
- 10) Ridge J C, Jones S K, Nielsen M S & Shahani A K (1998). Capacity planning for intensive care units. *European Journal of Operational Research*, 105: 346-55.
- 11) Costa A X, Ridley S A, Shahani A K, Harper P R, De Senna V, Nielsen M S (2003). Mathematical modelling and simulation for planning critical care capacity. *Anaesthesia*, 58: 320-7.

Members of the Working Group:

Dr Steve Dumont Clinical Director Critical Care, Royal Gwent Hospital,  
Newport, South Wales, NP20 2UB

Dr Jane Eddleston Clinical Director Critical Care & Clinical Head of Division,  
Clinical & Scientific Services, Manchester Royal Infirmary.  
Clinical Advisor, Adult Critical Care Services, Department  
of Health, M13 9WL

Ms Di Elson Network Audit Coordinator, Mid Trent Critical Care Network,  
Nottingham City PCT, Nottingham NG1 6GN

Prof Fang Gao Consultant in Intensive Care, Birmingham Heartlands  
Hospital, Bordesley Green East, Birmingham B9 5SS

Dr Jane Harper Consultant in Intensive Care and Anaesthesia, Royal  
Liverpool University Hospital, L7 8XP

Mr Martin Johnson Audit Manager, Critical Care Services, James Cook  
University Hospital, South Tees Hospitals NHS Trust,  
Middlesbrough, TS4 3BU

Dr John Morris Chair, Critical Care Information Advisory Group,  
Department of Health. Consultant Anaesthetist, East Kent  
Hospitals NHS Trust, Ashford, Kent, TN24 0LZ

Mr Mark Mugglestone Associate – Service Transformation, NHS Institute for  
Innovation and Improvement, University of Warwick  
campus, CV4 7AL

Dr Chris Newson Consultant Anaesthetist, Manor Hospital, Walsall Hospitals  
NHS Trust, WS2 9PS

Dr Mick Nielsen Intensive Care Consultant, Southampton University  
Hospitals NHS Trust, Tremona Road, SO16 6YD

Dr Martyn S Read University Hospital of Wales, Cardiff, CF14 4XW

Dr Saxon Ridley Consultant in Anaesthesia and Intensive Care, Norfolk and  
Norwich University NHS Trust, NR4 7UY

Dr Arjan K Shahani Director, Health Data Analysis and Modelling Group,  
GeoData Institute, University of Southampton, SO17 1BJ

Dr Jayaraman Thiagarajan Consultant in Anaesthesia and Critical Care, Lister  
Hospital, Stevenage, SG1 4AB

Mr Barry Williams Chairman, Critical Care Patients' Liaison Committee,  
Intensive Care Society, 29 B Montague Street, London,  
WC1B 5BW

Mr Keith Young Department of Health Emergency Care Team, 11/3 New  
King's Beam House, 22 Upper Ground, London, SE1 9BW.