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Bed occupancy in acute and mental health hospitals

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Introduction

In recent years the NHS has had a series of highly publicized winter bed crises. In the years leading up to the bed crisis there was a widely held supposition that 85% average occupancy was the optimum for an efficient hospital and that this occupancy allowed a suitable margin for peaks and troughs in demand. Beds were then closed to meet this target.

More recent NHS guidance now suggests that no Trust should exceed a target of 82% average occupancy and that an extra 2,100 general & acute beds will be made available (1). The provision of extra beds appears to have partly arisen out of the analysis in the consultation document on the findings of the National Beds Inquiry (2) while the figure of 82% may have arisen out of work sponsored by the NHS and DOH. For example, one study looked at the effect of average occupancy on the percentage of 'crisis days' for emergency admissions (3).

Given the dramatic shift in the target for occupancy, some questions beg to be asked - how was this figure derived, is it adequate, does it equally apply to all sizes of hospital and is there a simple method available to hospital and primary care managers to enable them to appraise current occupancy levels?

To answer these questions we need to explore the limitations of NHS bed statistics and assumptions relating to average bed occupancy and utilize some well known mathematical equations to explain how often a bed will not be available to the next arriving patient.

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Efficient bed management

There is considerable debate about the efficiency of bed management. It is often assumed that higher average occupancy is evidence of higher efficiency. This simplistic view ignores the fact that for any given level of demand and bed provision there will be a resulting occupancy and an associated turn-away (or queuing) rate.

Turn-away is the proportion of patients who are unable to gain immediate access to the correct bed and therefore have to wait hours or days at home, on a trolley, in another bed pool or waiting after a cancelled operation. These patients form a queue to gain entry to the correct bed but still require care. The higher the average occupancy the higher the turn-away rate and hence the greater the demands placed on the community-based healthcare system.

The mathematical description of arrival events and turn-away was developed in 1909 by A.K. Erlang. This has subsequently been widely applied to hospital beds (4). From Erlang's equation it is possible to accurately predict the turn-away associated with any level of average bed occupancy.

What is a bed pool?

A bed pool is any group of beds dedicated to a particular purpose. For instance, Maternity, Gynaecology, male/female beds in Orthopaedics, day case vs overnight, etc. Under normal circumstances the bed pool has a closed boundary since it is not resourced to handle other types of patient.

There are 22 NHS categories of overnight bed. For each Trust and category of bed both the number of available beds and the annual average occupancy are available (5). Unfortunately the simple definition of a bed pool is obscured within the NHS in a number of ways:

- Bed numbers are reported by Trust total, hence a trust operating from multiple sites will add all beds from a similar category and report this as the bed pool. For example, the 1851 general & acute beds for the Leeds Teaching Hospital will be the summation of many wards over multiple locations (see below regarding general & acute beds).

- The 22 categories of bed type are highly specific in some cases, i.e. 3 categories for intensive care (neonate, paediatric, adult), 7 categories for mental illness (children/adult/elderly for short-, long-stay or secure unit) and 5 for learning disabilities (children/adult for short-, long-stay or secure unit). Unfortunately there is only one category called 'general and acute' that is used to describe 50% of all NHS beds, namely, the surgical and medical specialties of a large acute hospital.

- There is no opportunity to differentiate mixed and single gender wards.

- The numbers are all decimals, indicating that beds are opened and closed as required and there is ambiguity over when to count a bed as 'available'. For example, how do we report five beds, in an otherwise fully staffed ward, kept empty every weekend to ensure all surgical patients are admitted on the following Monday.

What is % Occupancy?

The occupancy is simply the sum of the number of days stay for all patients (occupied bed days) divided by the time the beds were available (available bed days). The calculated % occupancy obviously depends on the way the available bed pool is reported.

Many Trusts have beds that are only reported as 'available' when they are fully staffed. Beds closed over the weekend are likewise not reported by some Trusts. This is partly because low % occupancy was regarded as a sign of inefficiency within the NHS and generally led to threats of bed closure. This will lead to the overstatement of the true occupancy against the available beds in some Trusts.

The occupancy is also an annual average. This is a very important point since the actual occupancy varies hourly, daily, weekly and monthly. It is for this reason that beds are used in a flexible way in most hospitals, however, it then becomes difficult to report bed numbers in a single standard way.

A further complication arises with borrowed beds. In time of need a bed from another bed pool is used to house a patient. This bed is then added temporarily to the bed count and subtracted temporarily from the other bed count. The bed reverts back as soon as the patient is able to move to the correct bed pool. This has the effect of increasing the apparent % occupancy of both bed pools. This is another source of the fractional beds reported against almost all bed categories.

Despite the limitations of NHS bed data it is still useful as a starting point to compare apparent efficiency between Trusts.

A Model for % Occupancy and Turn-away

It is possible to describe all NHS bed demand in terms of randomness in the arrival of patients. Randomness is described by Poisson statistics and can be used to describe typical arrival events such as emergency admissions, GP outpatient referrals, customers arriving at a supermarket checkout, etc. Poisson statistics is therefore used to describe the formation of queues and hence the turn-away or queuing rate. This happens when a new arrival cannot find an immediately available bed, outpatient appointment slot, check-out, etc.

In a NHS context elective surgery may be seen to be a non-random event. However it must be recalled that its fundamental origin lies in GP referral which is subject to Poisson randomness. Hence even elective demand can be approximated by a Poisson-based approach (6). This avoids enormous over-complication and allows us to calculate an approximate turn-away rate that will include cancelled operations and will not be too far distant from real life for even an acute hospital with a mixture of emergency and elective admissions.

The model basically works as follows. If the average rate of arrival is 1 per day then Poisson statistics tells us that we can receive anywhere between 0 and 7 patients per day (where an arrival rate of 7 occurs on 0.01% of occasions). If we are resourced to receive the average of 1 then on 26% of occasions we will be faced with more patients than we are able to immediately handle, i.e. 26% is the frequency of receiving 2 or more patients. To maintain an average of 1 the high occurrences are counterbalanced by a 37% likelihood of not receiving any patients on a particular day.

A Poisson distribution is essentially a skewed distribution with a higher proportion of events less than the average but counterbalanced by a long tail of lower probability higher than average events. It is this tail that creates the problems in a health care context.

A modified Erlang equation can be used to describe bed occupancy where there is an associated average length of stay (4). It is a fortunate feature of the Erlang equation that a line of constant turn-away, which is independent of average length of stay, can be drawn on a graph where % occupancy is the Y-axis and bed pool size is the X-axis.

It is important to remember that the turn-away lines represent the instantaneous measure of turn-away resulting in a queue for admission. For example, a trolley wait, a cancelled elective operation, diversion to another hospital (or other bed pool) or a period of waiting at home under the care of a GP or community health care team. Such patients are not denied care but must receive intermediate care during their wait for a bed in the correct bed pool.

Tables One and Two provide information on acute and mental health hospitals throughout England. Poisson randomness via the Erlang equation is used to predict the turn away-rate (or queuing rate) associated with particular average bed occupancy. Four levels are given – less than 0.1% turn-away, 1% turn-away, 5% turn-away, 20% turn-away and 50% turn-away. The reported performance of NHS Trusts is compared against these levels of turn-away.

Table 1: Average occupancy (%) giving rise to different levels of turn-away in different sized bed pools

Available Beds	**Percentage turn-away (%)**				
	0.1%	**1%**	**5%**	**20%**	**50%**
10	30%	44%	59%	78%	92%
50	65%	76%	85%	94%	98%
100	74%	83%	91%	97%	99%
500	88%	92%	96%	98%	99%

Poisson randomness also explains why bed occupancy decreases in an approximately exponential manner as the bed pool size decreases. It is therefore far easier for a large bed pool to achieve high occupancy and it is a meaningless measure to take average bed occupancies from different sized bed pools.

Table 2: Percentage of English Trusts having various levels of turn-away

Turn-away	Maternity	Paediatric	Acute	Mental Health	Intensive Care
>50%	0	0.4	0.3	2	18
20% - 50%	0	3	1	5	21
5% - 20%	5	6	10	18	36
1% - 5%	14	9	15	27	18
0.1% - 1%	16	13	15	24	4
<0.1%	65	67	50	24	2

Range in % Occupancy

As can be seen in Tables One & Two the occupancy ranges from 40% to 100%. The previously assumed optimum occupancy for NHS beds of 85% can be seen to be inappropriate and has probably been a significant contributory factor to the winter bed crisis.

For example, if 1% turn-away is a desirable objective then average occupancy around 70% is appropriate to a 50-bed hospital while 83% is appropriate for 100 beds. A figure of 85% is only appropriate above 150 beds (assuming all beds are equally accessible by all patients).

In both figures a line representing the running average of 11 hospitals centered around the 6th hospital has been included for comparison. The average is best interpreted as representing the point at which 50% are 'less than' and 50% are 'higher than'. Note the proximity of the average line to the lines of constant turn-away at different bed pool sizes.

In general, larger bed pools have higher average occupancy at the same turn-away rate. These are the benefits of scale. The comments regarding the lumping of many bed pools into a single figure for general & acute must be seen in this context. The effect of this would be to reduce the % occupancy for some Trusts at any given reported bed pool size.

General & Acute

Beds designated 'General & Acute' form the bulk of what the public regard as 'hospital' beds. These are the beds that are the source of the winter bed crisis. First perceptions can be misleading and a more detailed analysis shows that the winter bed crisis will be restricted to particular hospitals. For example, some 35% of Trusts with fewer than 100 general & acute beds are operating at an average turn-away of higher than 5%. Across all

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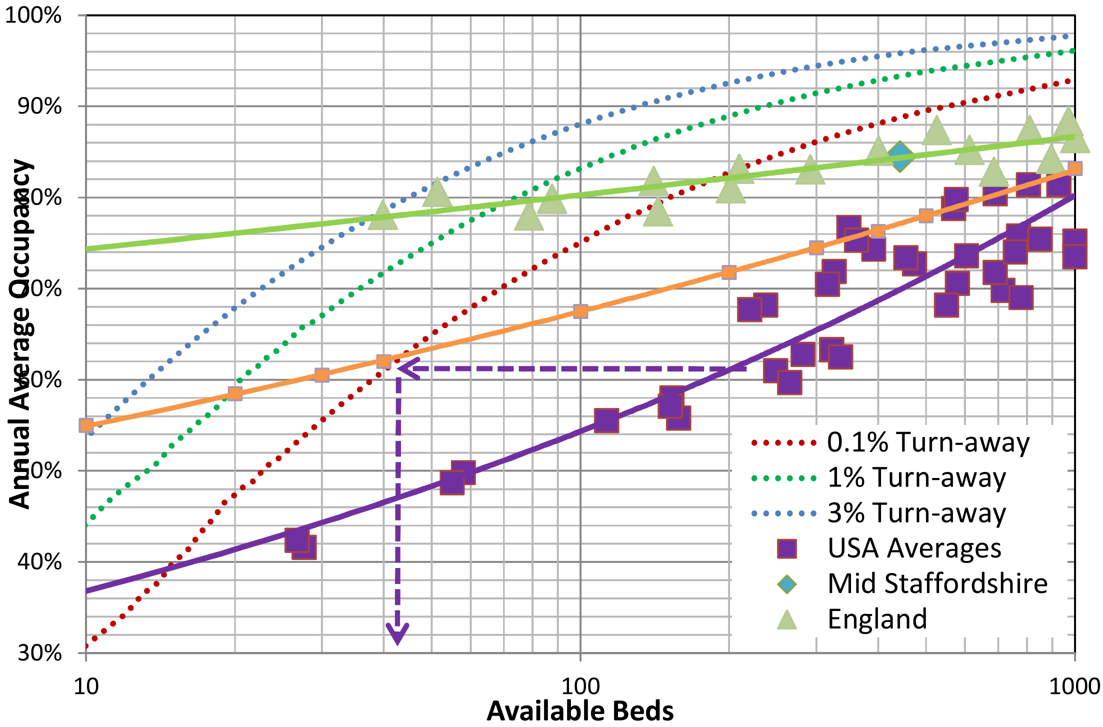
sizes, some 92 Trusts are operating with higher than a 1% turn-away rate – obvious first candidates for the extra 2,100 beds promised to the NHS.

These probably form the bulk of hospitals identified as Cluster A (and to a lesser extent Cluster D) within the National Beds Inquiry (2).

Figure 1: Relationship between available beds, average occupancy and turn-away



Footnote: The original Figure 1 is no longer available. The Figure here is from Jones R (2011) Hospital bed occupancy demystified and why hospitals of different size and complexity must operate at different average occupancy. ***British Journal of Healthcare Management*** 17(6): 242-248. A draft version of this article can be accessed at http://www.hcaf.biz/hospitalbeds.htm. The published version is available at www.bjhcm.co.uk or via an Athens login

The final statement needs to be qualified by reference to overall efficiency. For example, neither high average length of stay (relative to best practice for that particular condition) nor low day case rates are valid reasons for requiring additional overnight beds (2). However sub-division of the total bed pool into individual specialties will mean additional beds are required. This is because the effective bed pool size is thus reduced, i.e. a 100 bed hospital (at 73% overall occupancy) with two mutually exclusive bed pools of 50 beds will be experiencing 1% turn-away rather than 0.1% turn-away.

From Figure One we can also see that between 100 and 400 beds the 'average' occupancy corresponds to around 0.1% turn-away. Both common sense and 'average' practice therefore suggest that this is probably the 'optimum' turn-away rate for an acute hospital. It is turn-away rather than occupancy that should be used as the basis for comparison within the context of the other whole system factors identified in the national Beds Inquiry (2).

In many ways occupancy has very little to do with efficiency. Occupancy is the outcome of demand and bed pool size. The randomness in demand then sets the turn-away. Higher occupancy than that set by the Erlang equation then expresses itself in even higher turn-away.

As an overall comment, the bed needs of each acute trust would need to be evaluated in more depth before categorically declaring that there were insufficient beds. Particular emphasis would need to be placed on the degree of exclusivity between specialties and the need to provide separate bed pools for women and men. Other whole system factors will also be important (2).

Mental Health

The data shows considerable spread with 13% of trusts having less than 0.1% turn-away and another 13% having higher than 20% turn-away. Compared to acute trusts, mental health occupancy and turn-away is higher. For example, in smaller hospitals (less than 100 beds) some 45% and 35% of mental health and acute trusts respectively operate above 5% turn-away. In addition some 34% and 20% respectively of mental health and acute trusts operate at a turn-away of higher than 1% but less than 5%.

These differences are consistent with a greater emphasis on care in the community within mental health. The average position in mental health is therefore one of higher turn-away (50% of trusts over 1% turn-away) and thus higher levels of community based support required to operate at this level of turn-away.

In total (across all sizes) some 38 mental health trusts are operating at higher than 5% turn-away. No acute trust (>100 beds) operates above 20% turn-away while this is the case for several mental health trusts. In the 38 locations where turn-away is greater than 5% there is the possibility that the community-based services are inadequate to meet the demands being placed upon them. In these 38 locations additional hospital beds may prove the most effective option to minimize the total healthcare cost within the constraint of a limiting availability of supporting healthcare staff. A whole systems approach would however be required to answer this question.

Effect of Seasonal Peaks in Demand

The fact that most bed pools experience seasonal peaks in demand is one reason why it is not wise to calculate the bed requirement of a new hospital based on annual averages. For example, for a large acute hospital up to 15% of the total beds may need to be switched to cover emergency medical admissions over the winter months (7).

In addition to seasonal peaks in demand there are also weekly and daily peaks, hence, the fact that many acute hospitals have to resort to trolleys to even out the natural fluctuations in demand.

Benefits from Process Redesign

Genuine benefits can be achieved by redesign of processes leading to a reduction in length of stay (LOS). For instance, a 10% reduction in LOS leads to a 10% increase in throughput at the same level of occupancy and turn-away. At the same throughput a 10% reduction in LOS leads to a slightly less absolute reduction in turn-away, i.e. from 20% down to 12%, etc.

Within the acute sector an increased proportion of patients seen as a day case will also act to reduce the level of demand placed upon the overnight bed pools although this may be partly offset by an increased average length of stay in the remaining overnight patients.

Beds are Expensive

One may suspect that the 85% occupancy 'rule' arose from the assumption that beds are expensive, hence, minimize the number of beds to minimize the expense. Beds in themselves are not expensive. The initial low cost of purchase is depreciated over a number of years. Likewise floor space does not attract an enormous overhead cost. Beds become expensive when a fixed level of staff is employed to support them. Hence the argument goes that to limit beds is to limit the opportunity for occupancy and hence associated expense. There is a partial truth in this statement (2), however, its implementation does place considerable demands on the community-based healthcare services.

There is another argument that an open bed is an occupied bed. The data from NHS trusts does not support this theory and neither does the observation that the average US hospital operates at 65% occupancy (6). The availability of 'excess beds' is therefore a key factor to the efficient operation of a large hospital. For example, many maternity units open and close wards in response to random fluctuation in demand. This represents a suitable route to minimize total cost and yet avoid turn-away.

It must be emphasized that the number of beds and hence the resulting occupancy and turn-away are the choice of a healthcare system. Hence while 85% average occupancy may be technically too high, it may well be appropriate to certain (but not all) types of bed pool within the overall context of the surrounding healthcare system. This would also include the number of beds in nursing homes – a lack of which leads to bed blocking and high apparent length of stay in some acute trusts.

The Impact of One More/Less Bed

The ability to correctly size small bed pools is governed by the effect of randomness. For instance, a hospital with 20 beds and 42% occupancy (no turn-away) may have been advised to close beds to 'save money'. Our imaginary hospital dutifully closes 5 beds thus planning to increase average occupancy to 56%. This takes them from 0% to nearly 5% turn-away! The local GP's go on strike refusing to visit the extra patients now waiting at home for admission. The 5 closed beds do not save any money since the number of patients per year does not change and hence the nursing workload is not affected. The hospital may however have to employ a full-time bed manager to 'manage' the problems thus created and the GP's will be consuming hours and petrol 'managing' those patients who have to queue for admission.

This is precisely the reason that some bed pools appear to have more beds than are required to achieve no turn-away. Maternity bed pools (data not given) are an example of this. Allowance for seasonal variation (winter emergency pressures, etc) and the avoidance of widespread disruption elsewhere in the healthcare system explains what at first appears to be 'inefficient' (low) occupancy.

Turn-away does imply additional expense and hence it can be useful to consider the impact of one additional bed. One additional bed reduces occupancy by the proportion of the incremental change. Hence to go from 9 to 10 beds reduces occupancy by 10% and from 10 to 11 beds reduces occupancy by 9.1%, etc. The lines of constant turn-away in Figures One & Two can be used to estimate the effect of occupancy on turn-away and the associated costs then estimated for the entire healthcare system.

Economies of Scale

Since large acute hospitals are made up of many smaller bed pools, how then do many hospitals achieve higher than 85% average occupancy? By blurring the boundaries of all the bed pools they actually perform as a single large bed pool. This suggests smaller community hospitals need to have almost no boundaries between bed pools in order to maximize throughput for a set number of beds.

Incremental changes to bed pool size do have an enormous impact on the overall efficiency of the healthcare system surrounding smaller community hospitals. Given that the total bed pool of such hospitals is often less than 100 beds then the only way to gain the benefits of size is to designate one ward as a general 'overflow' ward which acts as the buffer between supply and demand. Admittedly the patient has to be moved to their final bed (which is not patient friendly) but it is perhaps the only option open to small sized hospitals.

It is probably even likely that many Primary Care Trusts will be debating whether to increase the size of their newly inherited community hospitals. The methods given here will allow them to make rational decisions and to forecast the likely total cost of turn-away.

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Dis-economies of Scale

For the larger acute hospitals (>100 beds) there are significant numbers of trusts in the region 90% to 100% average occupancy. Above 300 beds this appears to rapidly drop off and at 1,000 beds the range is between 70% to 90% occupancy, i.e. roughly the occupancy expected of bed pools with only 100 beds.

Hospitals in the range 100 to 300 beds seem able to make greatest use of the flexible boundary between bed pools. Above 300 beds organizational complexity and sheer size prevents economy of scale and leads to blockages to overall throughput. Super-trusts behave as if they were made up of a series of 100 bed pools each with a closed boundary.

Another reason that large hospitals may show lower occupancy is that they tend to see far more elective patients. Many of the hospitals with around 100 beds and operating in the range 90% to 100% occupancy are community hospitals. Some of the community hospitals are probably acting as an extended overflow bed pool for any nearby large acute hospitals.

High percentage turn-away is crippling to the operation of a waiting list and will result in very high levels of cancelled operations. An occupancy level of around 80% would therefore tend to be a suitable balance between throughputs and turn-away for a large acute hospital.

Limitations of the National Beds Inquiry

One outcome of the National Beds Inquiry was a capitation-based approach to forecasting bed needs. This national approach is then scaled down to local level to forecast the bed requirements of individual hospitals. The Erlang equation shows that this approach is fundamentally flawed because it makes no allowance for the effect of size. Smaller populations require higher numbers of beds due to the higher turn-away associated with smaller size bed pools.

For example, two hospitals service need-weighted populations of 1,000,000 and 100,000 respectively. Assuming the bed requirement is 0.5 beds per 1,000 head of population then the two hospitals would have 500 and 50 beds respectively, i.e. equal allocation in terms of population size. Both hospitals would have 82% average occupancy but the smaller hospital would have 5% turn-away while the larger would have less than 0.1% turn-away, i.e. highly inequitable bed provision.

To achieve a similar level of turn-away to the larger hospital (e.g. close to 0.1% turn-away) the smaller hospital would need to operate at only 65% average occupancy and would require 63 beds – a 25% increase in its bed allocation. The 'one size fits all' approach simply does not work and generates yet another set of healthcare inequalities. In this instance the community-based services surrounding the smaller hospital would be working far harder than those surrounding the larger hospital. Yet everyone would be telling them that they have got the 'correct' number of beds based on their population!

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Conclusions

Any combination of beds and occupancy has an associated turn-away rate. An adequate bed requirement therefore depends on the size of the bed pool, the category of beds and the supporting structures in the community-based part of the healthcare system. The previously assumed figure of 85% occupancy will lead to unacceptable turn-away in all but the largest bed pools (assuming that there are no boundaries between adjacent sub-pools). The more recent figure of 82% is likewise only appropriate to greater than 100 beds (1% turn-away) and assumes that there are no boundaries between bed pools.

Large acute hospitals handling a high volume of elective surgery via a number of specialty specific bed pools should probably have an average annual occupancy around 80%. Other types of bed need to be evaluated with reference to the entire healthcare system. High turn-away will imply a high level of supporting community-based services. The extent of the required community services can be calculated with some precision using the Erlang equation. Capitation formulas fail to take the important effect of relative size into account. Smaller community hospitals will therefore need up to 25% more beds in order to achieve equity in terms of equal turn-away.

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