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New Approaches to Bed Utilisation – making queuing theory practical

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Executive Summary

The various forms of the Erlang equation accurately predict performance of bed pools. The turn-away rate, length of queue and occupancy rate are simultaneously predicted for any given arrival rate and LOS.

Randomness in both emergency admissions & elective demand and bed pool size are the primary factors determining bed requirements and occupancy. Hospital efficiency via average length of stay has a secondary (but important) role.

Bed occupancy can only be increased at the expense of increasing turn-away, e.g. cancelled operations, increasing waiting lists, longer A&E trolley waits, diversion to another hospital, admission to a bed in the wrong specialty (i.e. medical patients in surgical beds), hidden waiting lists (i.e. intermediate care by community services), etc.

Smaller bed pools are more susceptible to these forces, i.e. it is easier to manage the pressures as the bed pool gets larger.

Current methods for bed planning used within the NHS are subject to considerable bias and lead to the under-provision of beds. The reasons for this are discussed in detail.

In a resource constrained system the Erlang equation coupled with Monte Carlo simulation can be used to optimise the allocation of beds between specialties and to do what-if calculations looking at the impact of changes in arrival rate and LOS. The number of cancelled operations associated with various levels of throughput can also be calculated.

The Erlang equation can also be used to size Intensive Care (Neonatal & Adult), Maternity & Specialist Care units. Unique applications also lie in the correct sizing of Mortuaries and A&E facilities.

Introduction

Before looking at the application of queuing theory to the calculation of bed requirements it is necessary to investigate why other methods have failed and what pitfalls need to be avoided in order to derive meaningful answers. By this we mean the right number of beds available at the right time.

Flaws in the past method

For the past 30 years the NHS has used the following formula to forecast bed requirements:

$$\text{Beds} = \frac{\text{Activity x (LOS + TOI)}}{365}$$

Looking at each of these component parts in turn.

Activity

Activity has been typically forecast using access rates (age-sex weighted admissions per 1,000 head of population). Since the catchment area of any hospital is impossible to define the population of the host health authority is usually used as a proxy. This avoids the high statistical uncertainty that would arise, even in the largest hospital, due to the very small numbers resulting from subdivision of activity across all of the age-sex bands for all of the specialties. An approximate catchment is then calculated and the admissions in future years then forecast using population forecasts. Population forecasts at a detailed age-sex level can have up to a 5% error. Access rates change (increase) over time for the simple reason that it is medical technology that drives the trends rather than population demographics per se. Hence the forecast future admissions tend to be too low. This method appears to give better results for the surgical specialties, however, the resulting forecast should be double checked against another method and the access rates chosen for the future should be adjusted for the underlying trend in the access rate.

Access rates are usually an annual total and therefore take no account of seasonal peaks and troughs in activity due to general winter illnesses, influenza epidemics and summer holidays. These peaks and troughs, particularly in the medical specialties, are usually far greater in magnitude than the shorter-term trends[1]. Lastly, raw access rates take no account of increasing outpatient and inpatient waiting lists. Suitable adjustment should always be made to account for this factor. The true waiting list should always be used to make these calculations. For inpatients this means the total of active + suspended + booked waiting lists.

A simple linear trend based on total admissions to a specialty (with adjustment for known local developments) appears to give a workable alternative[2]. This method relies upon the fact that trends in admissions tend to follow a linear trend irrespective of population up to the point that there is a development in medical technology. At this point they then follow another linear trend of slightly different slope. The reason for this linear behaviour of apparent insensitivity to population demography is that available GP appointment slots act as a rate-limiting step and thus have a self-regulating effect and it is new technology that alters the referral threshold. The only problem here is that no one knows when the next relevant development in technology will occur and what effect it will have.

A recent method based on bed-days rather than FCE and using the direct hospital age distribution for each specialty which is then coupled to population trends appears to give a suitable basis for 'relevant' forecasts.[3]

The simple message is this; do not rely on a single method. It is important to openly display the results of alternative calculations and discuss the likelihood of the various forecasts.

Length of stay (LOS)

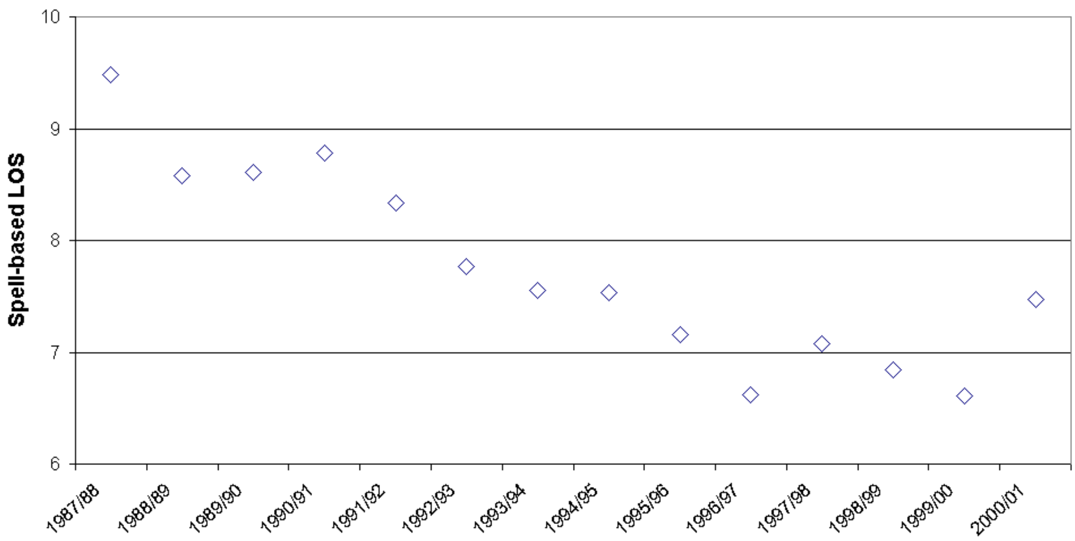
[1] Jones, R.P. (1997) Admissions of difficulty. Health Service Journal, 27th March, pp 28-31.
[2] Jones, R.P. (1995) How many patients next year? Healthcare Analysis & Forecasting, Reading
[3] Jones,R.P (2002). This method has been developed by Healthcare Analysis and Forecasting.

An outside 'consultant' will typically be called in to 'forecast' a length of stay – usually much lower than present. More accurate statistical forecasting methods are available for LOS[4] and should be coupled with an inter-hospital comparative efficiency tools. Wide variation in day case rates between consultants & hospitals has been reported and should also be investigated[5] - although to avoid embarrasment this analysis should be done at the level of 4 figure OPCS codes rather than some vague total day case rate.

Of even greater interest is the fact that the Spell-based LOS in most specialties at one of the highest throughput per bed hospitals in the UK has not significantly changed in the past 6 years – chart for T&O attached as an example.

The trend to lower inpatient LOS has apparently been offset by the consequences of a trend to higher day case rates, i.e. the remaining non-day case patients have more complex operations and hence stay longer. This hospital also has one of the lowest ratios of FCE per Spell in the UK[6] and has HRG-adjusted LOS which is well below national average. One can only presume that part of the national trend to lower LOS is due to FCE inflation rather than any real improvement in 'efficiency'. As an aside, note the considerable random variation in average LOS between years arising from variation in the ratio of emergency:elective, casemix and the age profile of admissions – a reality usually ignored in most bed planning. Note also that the Australian healthcare system also experienced a cessation in the reduction in LOS in 1994/95.

Figure One: Trauma & Orthopaedics
(data excludes all 0 LOS stays)



The final adjustment to LOS arises from the use of whole numbers to measure the LOS of individual patients. All patients admitted and discharged on the same day have a zero LOS and cause the calculation of average LOS to be an underestimate. The degree of underestimation increases with increasing proportion of zero LOS patients. This causes significant distortion since 0 LOS patients can account for up to 45% and 21% of Gynaecology and General Surgery emergency admissions respectively and are generally around 8% to 12% of elective admissions (day case admissions excluded). The correct way to treat average LOS is to exclude all 0 LOS admissions but to treat the number as contributing to daytime bed occupancy, hence, LOS excluding 0 LOS gives midnight bed requirement to which is added a daytime bed requirement. Up to 5% more beds can be required when this is taken into account.

[4] Farmer,R.D.T & Emami,J. (1990) Journal of Epidemiology & Community Health. 44, 307-312.
[5] Audit Commission (2001) Review of national findings for day surgery. Acute Hospital Portfolio, December 2001 no. 4, pp 1-16
[6] The hospital referred to is the Royal Berkshire & Battle Hospitals NHS Trust. At the RBBH number of Spells with 1 FCE is 97% while NHS average has declined from 95% to 91% over 6 years (Source: CHKS)

Turn over interval (TOI)

Turn over Interval (TOI) is the supposed time the bed stays empty between patients. To reduce the bed requirement you simply reduce the TOI thereby increasing the percentage occupancy. It contains the implicit assumption that TOI is the by-product of 'inefficiency' and hence its reduction leads to greater 'efficiency'. This is a flawed assumption since the TOI (and occupancy) is set by the randomness associated with emergency admissions. An external 'expert' was usually invited to make prognostications regarding future values for TOI (always lower than present) – since 'efficiency' must be increased. This approach is guaranteed to underestimate the true bed requirement.

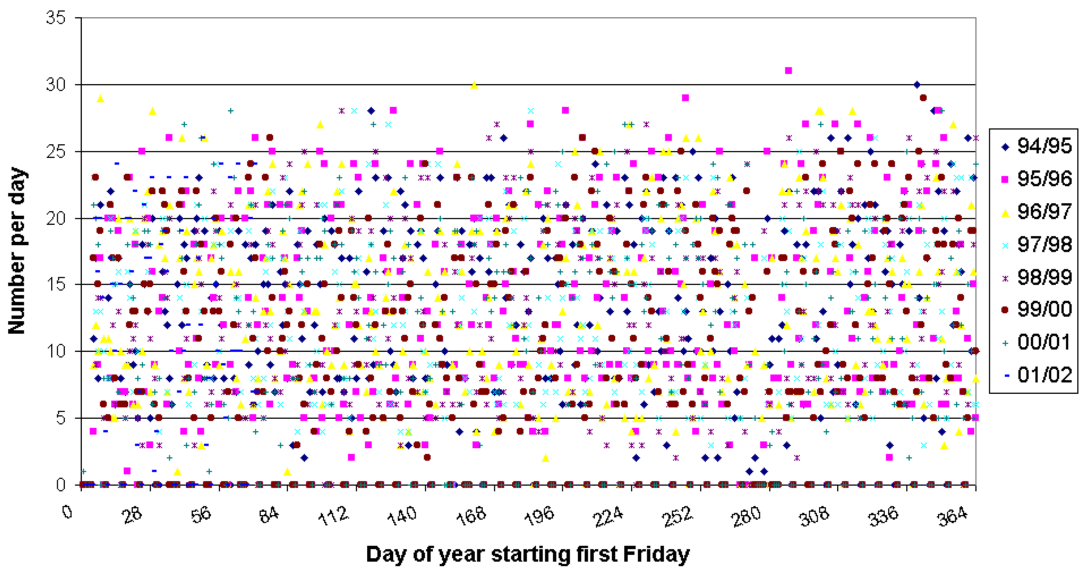
365 days per year

The 365 is simply the number of days in a year and contains the implicit assumption that an acute hospital and the surrounding healthcare & social systems operate on a 24 hour 7 day per week basis. As can be seen in Table One the rates of emergency admission via the primary care system show a distinct weekday bias for most specialties.

The assumption of 365 days per annum further acts to underestimate the true bed requirement for any hospital. For instance a daybed unit will typically operate on a Monday to Friday basis and hence should be sized using 251 workdays per year. Elective surgery is likewise usually conducted on a Monday to Friday basis and hence the use of 365 instead of 251 is potentially equivalent to 31% fewer beds than could be needed[7]. This difference of 114 days also accounts for a significant part of the supposed TOI associated with elective admissions.

This dearth of beds between Monday and Friday is further compounded by the fact that the bulk of emergency admissions occur between 9 a.m. to 5 p.m. – exactly the same time that the elective admissions are planned to occur. Daytime occupancy is therefore much higher than the annual average **midnight** occupancy reported within the NHS. It is the weekday and daytime occupancy that therefore needs to be known.

Figure Two: Gynaecology - all 0 LOS elective incl DC



Common use of theatres for both elective overnight and day case operations can lead to highly misleading averages. Figure Two gives a useful illustration for a Gynaecology unit where the annual average throughput is 15.5 patients per day. This is around half the required maximum throughput

[7] In practice only around 8% extra beds are required due to the use of beds over the weekend, i.e. Friday admission for Monday discharge, etc.

required on those days when theatre capacity is directed exclusively to day case work. Clearly a common pool of beds, used in a flexible way, is required to cope with the natural peaks and troughs in demand imposed by structural constraints (in this case theatre capacity as a rate-limiting step).

Lastly the use of annual averages in either admissions or LOS is completely at variance with the seasonal nature (either in onset or severity) of most diseases or conditions[8]. Hence monthly average LOS and admission rates both vary considerably with season. Bed demand is therefore highly seasonal.

Why did this method appear to work?

If the method was so flawed why then did it work? The answer is that it was applied during a period of rapid change in medical science. Developments in technology and therapeutics led to a period when LOS reduced so rapidly that any method designed to underestimate bed requirements had a good chance of giving roughly the 'right' answers. However since the mid-1990's this trend has dramatically ceased. In addition, the ongoing reduction in bed numbers has led to an escalation in average occupancy to the point where hospitals experience an all year bed crisis. We are now in a period where the inherent flaws are starting to surface and the basic assumptions need to be revised.

What is needed to give adequate answers?

The greatest limitation of the previous method was its inability to give an indication of the consequences of an undersized hospital and it is at this point where a method such as queuing theory can be of enormous benefit.

The calculation of turn-away gives a basis for evaluating the cost of not having enough beds. Cancelled operations cost large amounts of money and result in the inability to generate revenue. The cost is incurred with no matching income. The delay to admission for emergency admissions also costs money to administer within a hospital and support within a PCT. Likewise the cost of medical patients in surgical beds (disjointed care, increased LOS, increased risk of cross infection) is an inevitable consequence of too few beds.

Tools for better bed planning

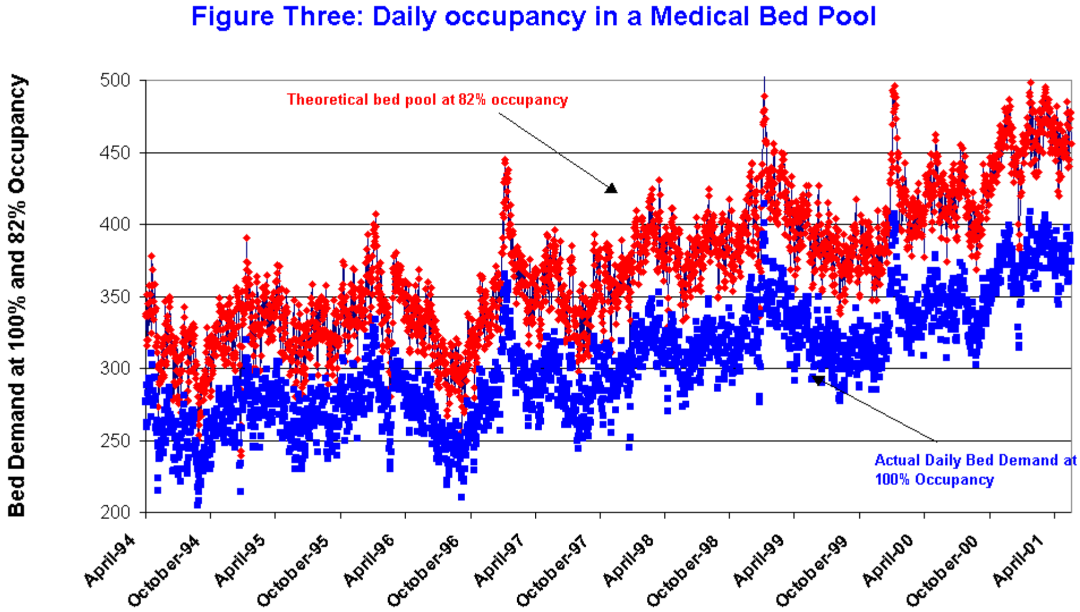
As discussed above the traditional method fails to reveal the complex and interacting forces behind bed requirements. The simplest way to visualise their impact is to look at occupancy on a daily basis over a number of years[9]. Figure Three gives one example covering a seven-year period. Note the very high short-term variation in bed demand due to randomness. From one day to the next there is an average difference of 8.4 beds (3% variation) with a maximum difference of 48 beds (15% variation). How is a hospital expected to cope with a 15% change in the demand for medical beds within the space of 24 hours?

Indeed we need to ask the question - how many beds do this group of medical specialties need? If you choose to avoid disruption of surgical activity the answer is somewhere less than 420 (peak winter demand in 1999). How many do they currently have? The answer is 320 - being the number forecast by the 'tried & tested' NHS method used over the past 30 years. Clearly there is a gap in expectations and the need for a more scientific or rational approach .

For this large bed pool the annual average for the most recent twelve months is 361 occupied beds – a figure larger than the entire bed pool of half of NHS acute hospitals (Table Two). At the new 'gold standard' for the NHS of 82% occupancy we have a supposed requirement for 440 beds – which is probably more than are genuinely required. How do we find the balance? The answer lies in the

[8] This assertion comes from a complete textbook devoted to listing every medical study on the seasonal nature of disease. It contained around 300 pages of references with a brief comment on each, e.g. 1,000's of references. From memory it was published in Scotland in the 1980's.
[9] Jones,R.P. 1997 Admissions of difficulty. Health Service Journal, 27 March, pp 28-31.

sensible application of queuing theory via the use of the Erlang equation. By sensible we mean using numbers (i.e. arrival rate, LOS) appropriate to the seasonal, daily and organisational requirements.



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Queuing Theory, Poisson Statistics and the Erlang Equation

Queuing theory arose out of the development of Poisson statistics. This is the branch of statistics that looks at the randomness associated with events occurring in a given area of opportunity, e.g. per unit of time or space. For instance, raindrops per m^2, telephone calls per hour, GP referral requests per month, emergency admissions per day, etc. Although the average of a Poisson distribution can be non-integer (e.g. the average number of GP referrals to ENT is 4.6 per week) the outcomes are only ever integer values (e.g. you cannot get a fraction of a GP referral).

A unique feature of Poisson statistics is the fact that by definition the standard deviation is always equal to the square root of the expected average. As an approximation we can say that the maximum range in outcomes is the average ± 3 x standard deviation, hence, if we expect an average of 9 emergency admissions per day then we can get anywhere between 0 and 18 on any one day.

The implication to healthcare should be obvious. Let us imagine we have a ward with resources to handle our expected average of 9 emergency admissions per day. An NHS VIP is visiting today and all is in readiness. Unfortunately randomness is no respecter of persons and today of all days we get no emergency admissions in the whole day. The nurses do not have a lot to do and to the VIP it appears that this particular hospital 'just do not have their act together'. The day after the VIP's visit by some cruel twist of fate the unit receives 18 emergency patients and cannot cope. Several patients are forced to take a long ambulance journey to another hospital. One dies en route. A week later the Chief Executive receives a letter from the VIP suggesting that he close the unit to save money and simultaneously faces local public outrage over the disgraceful under-resourcing at the hospital.

Imagine what it must feel like for the nurses on a ward where the workload fluctuates so erratically. Why doesn't the management do something to make things better? It is always so frantically busy around here! The management responds with a study that shows they are receiving an average of 9 per day and this is exactly what was anticipated in the feasibility study.

Poisson randomness is the forgotten variable in most healthcare scenarios. In fact a consideration of Poisson randomness leads to the conclusion that the basic premise behind the current HNS performance agenda is flawed. The application of HRG's, activity-based costing & pricing and even resource allocation formulae all break down when attempting to extrapolate from large national averages to a much smaller local level[10].

Table Two: Percentage of English Trusts having various levels of turn-away (99/00 data)

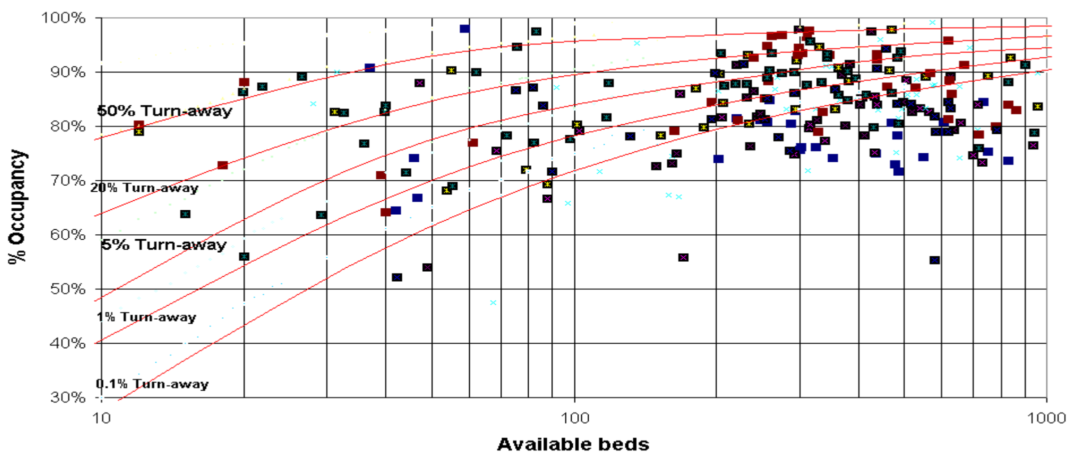
%Turn-away	Maternity	Paediatric	General & Acute	Mental Health	Intensive Care
Largest bed pool	163	300	1850	174	56
Average bed pool	55	49	355	30	13
Average occupancy	60%	59%	83%	90%	76%
>50%	0%	0.4%	0.3%	2%	18.2%
20% to 50%	0%	3.4%	1.1%	5.4%	21.2%
5% to 20%	5.4%	5.7%	9.7%	17.7%	36.4%
1% to 5%	13.6%	8.8%	15.2%	27.2%	18.2%
0.1% to 1%	16.3%	13.4%	15.2%	23.8%	4.2%
<0.1%	65.2%	67%	50%	23.8%	1.8%

The average position can be very misleading. As can be seen from Table Two only 1.8% of English NHS Trusts have adequate ICU beds to avoid turn-away (with 40% having higher than 20% turn-away) while 65% of maternity and paediatric units have sufficient beds to avoid turn-away. For General & Acute beds some 10% of English NHS Trusts are operating above 5% turn-away. While the bulk of these Trusts have fewer than 100 beds there are still 12 larger acute trusts in this category. These Trusts will have almost no hope of achieving national inpatient waiting list targets by virtue of a severe shortage of beds relative to the local demand for beds.

However, returning to our theme of bed allocation - how do we apply this to predict bed requirements? A.K. Erlang was a Danish mathematician and telephone engineer. He was investigating the patterns of telephone traffic and the number of times there were insufficient lines to meet demand. He formulated an equation that included arrival rate and a service interval - the basis of what is called queuing theory.

Obviously the applications are far more diverse than hospital beds, however, Erlang's equation does allow us to predict the occupancy and turn-away associated with any given arrival rate (average admissions per day) and service interval (average LOS). The method has been extensively validated for hospital beds and is an excellent tool for predicting ICU bed requirements[11]

Figure Four: Turnaway for NHS Trusts - General & Acute beds



[10] See Jones,R.P (2001) Guaranteed urgent appointments? Health Service Journal, 111 (5778) 20-23 as an example of this principle for urgent appointments.
[11] Lamiell,J.M. 1995. Modelling intensive care unit census. Military Medicine, 160(5), 227-232.

One valuable feature of Erlang's equation is that the relationship between occupancy and beds results in lines of similar turn-away that are independent of LOS. Hence we can compare two very different organisations or specialties using a single chart. All that is needed is the number of beds and the occupancy. From these two numbers alone we can determine the turn-away associated with that bed pool. An example is given in Figure Four.

It is important to note that in this example the turn-away is calculated on the assumption that all beds are equally available to the next arriving admission. In most cases moving the data points to the left reveals the real situation experienced by the smaller sub-pools (e.g. Urology, T&O, etc) which comprise G&A.

The practical application of this equation is that it can be used at a strategic or operational level.

Use of the Erlang equation to gain a strategic overview

For example, at the strategic level we can look at the reported bed occupancy statistics for the NHS Trusts (as in Table Two) and derive an estimate for something that is not measured. In this approach we simply take national averages for different bed pools and use this to give a rough indication of the relative turn-away. Using this approach we see a disturbingly high turn-away rate is associated with particular types of provision, e.g. mental health secure units in particular and most non-acute bed types in general. Implications to the surrounding community systems can then be evaluated.

Alternately we can look within various regions and predict which regions will find it difficult to meet waiting list targets (i.e. a reduction in the number waiting or reduction in number of cancelled operations) due to high bed occupancy.

In this application of the Erlang equation we take the number of beds and the reported occupancy and work backward to calculate the resulting annual average turn-away. This is give in Table Three where it has been assumed that Trusts with more than 100 General & Acute beds function as if it were a series of single specialty bed pools containing 100 beds. In most cases this is probably too high an estimate and hence the calculated occupancy and turn-away are probably conservative. In addition NHS statistics are for midnight occupancy rather than daytime occupancy and hence the figures are a conservative estimate. Finally the turn-away was calculated using the Erlang-B rather than the Erlang-C equation and once again will give a conservative result. A weighted average occupancy and turn-away is then calculated for each region.

Interestingly this is almost exactly the order in which regions are experiencing difficulty in meeting targets for the reduction in the number of patients on the waiting list. It is therefore not surprising that the newspapers (Tuesday 5th June) gave details of a leaked Audit Commission report indicating that 1 in 4 Chief executives admit to 'massaging' waiting list statistics. Seemingly high turn-away forecast using the Erlang equation is thus confirmed to be real.

Table Three: Average occupancy and turn-away for acute Trusts within various UK Regions. Analysis is based on bed occupancy data from 1999/00.

Region	Average Number of Acute Beds per NHS Trust	Average weighted Occupancy	Average weighted Turn-away
Trent	425	80%	0.8%
Northern	440	80%	1.4%
South & West	390	82%	2.0%
North Thames	330	85%	4.4%
Anglia & Oxford	260	87%	4.7%
West Midlands	350	87%	4.9%
North Western	380	85%	5.3%
South Thames	370	88%	6.5%

In conclusion, used in a strategic manner the Erlang equation has given us order of magnitude figures that could not be calculated in any other way. It points to a position where a significant percentage of patients are turned-away due to bed shortages. You may disagree that the figure in South Thames was

6.5% exactly but the usefulness of the method is that we know it is at least 8 times worse in one region than another. We also see that all but 2 regions in the entire NHS are probably intrinsically unable to achieve genuine reductions in the waiting list and hence are forced to resort to massaging the numbers in order to achieve a mathematically impossible mission.

Use at an operational level

At a more specific level we can use the Erlang equation to forecast the particular bed requirements of a specialty bed pool. To calculate turn-away we need the average LOS and admission rate and hence Figure Five gives actual results for a General Surgery bed pool over the past six years. Data is for combined elective and emergency overnight admissions.

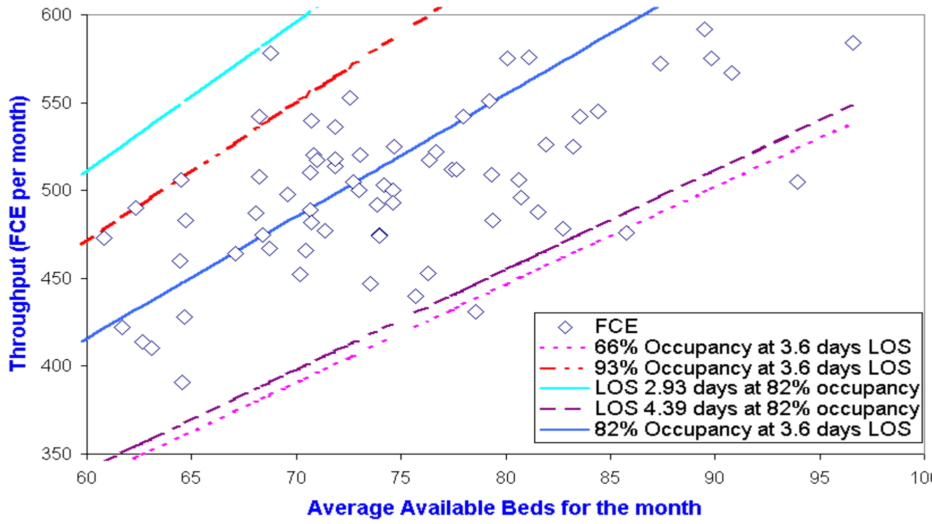
In this example average monthly length of stay varies between 2.93 and 4.39 days and occupancy varies between 66% and 93%. This wide variation has nothing to do with effective/ineffective management but is simply the outworking of Poisson randomness in emergency admissions and average LOS. These interact to give a wide range in monthly occupancy otherwise obscured by the use of annual averages.

Out of interest this General Surgery department has the second lowest HRG adjusted LOS in the NHS, i.e. they are highly LOS efficient. To calculate the turn-away we simply use the monthly averages and see that at (say) 75 beds turn-away fluctuates between 45% (at 93% occupancy) and 0.06% (at 66% occupancy) with an average of 4% at 80% occupancy. This implies a minimum of 20 cancelled operations in the month, i.e. roughly in line with actual performance.

Figure 5 is intended to illustrate the importance of the rational use of information when forecasting real bed needs. Annual average FCE and LOS simply do not tell the true story. Although not perfect, a monthly view gives a much better understanding of the real bed needs.

To understand the resulting complexity in the interactions requires the use of techniques such as Monte Carlo simulation coupled with the Erlang equation.

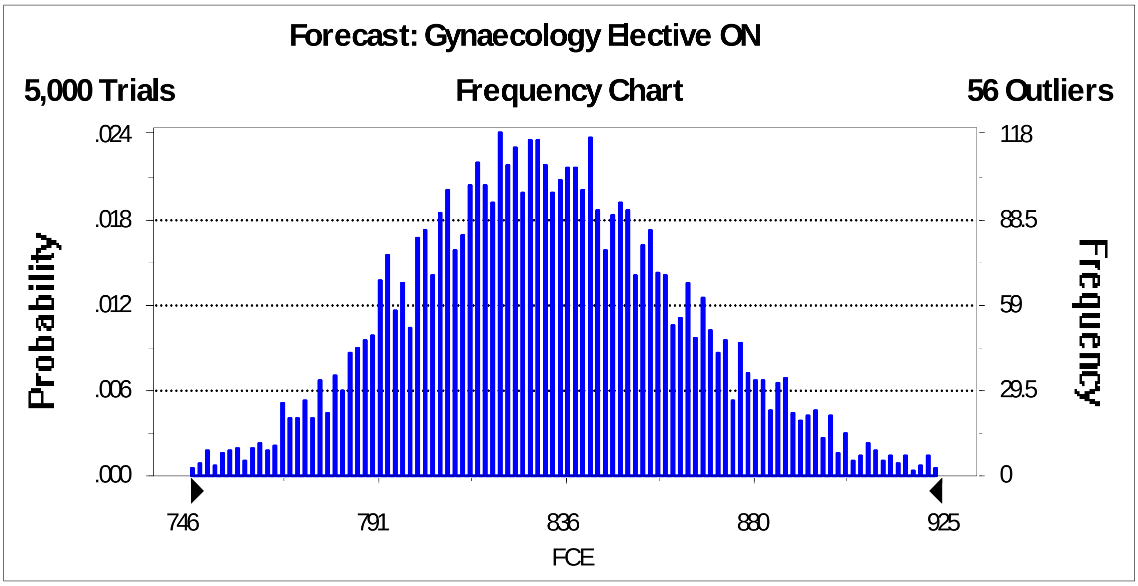
Figure Five: General Surgery monthly statistics



One interesting outcome of this approach has been to run the model in reverse and forecast the number of FCE's which arise from a given bed pool size. This generates the equivalent to Figure Six with the additional knowledge of the associated turn-away that results from operating a fixed bed pool at various levels of occupancy. As expected, there is an enormous range in possible activity – an uncomfortable fact that explains why contracting does not work in a NHS context.

The only reason that the equivalent to contracting works in the USA is because they have excess beds (compared to the UK) and hence do not experience high turn-away (as cancelled operations). It then becomes far easier to guarantee a certain level of activity.

Figure Six: Potential elective throughput for a 16 bed Gynaecology unit handling emergency and elective overnight patients. Average daytime occupancy of 66% gives 130 cancelled operations per annum.



82% Occupancy as a benchmark

Our final use of the Erlang equation is to investigate the adequacy of the recently proposed 82% occupancy figure arising from the National Beds Inquiry (NBI).

The danger is that Regional Offices and Health Authorities will use a simplistic interpretation such that 82% is blindly applied as the standard occupancy. The NBI merely concluded that occupancy should not exceed 82%. It did not say that occupancy should equal 82%. Obviously 82% is better than the de facto 85% standard of past years and is immeasurably better than >90% as experienced by around 70 HNS Trusts in 1999/00.

We have already noted that most NHS hospitals have a size well below 300 general & acute beds. It is not correct to combine all the general and acute beds to give one large bed pool. In fact most single specialty bed pools within the general & acute umbrella will be smaller than 100 beds.

Table Four demonstrates why 82% is not appropriate in most cases. Quite simply as can be seen in Figure Seven for a single specialty with 100 beds an average occupancy of 82% gives 3.5% turn-away. For a surgical specialty this would imply that 3.5% of the throughput (emergency + elective) would experience turn-away, some form of delay. In practice such delays are not overly long and hence 82% is a good figure for a bed pool of size 100 beds. Unfortunately the bulk of UK hospitals have surgical bed pools much smaller than 100 beds! The key message is to use the Erlang equation to give each specialty the number of beds giving each the same level of turn-away, i.e. all experience the same operational pressure.

To understand the real bed needs of an acute hospital therefore requires a far more scientific approach that has hitherto been adopted.

It is important to note that there is always a queue to admission, however, the average delay experienced say from GP telephone call to admission or as a trolley wait can range from 20 minutes to 12 hours depending on the combination of beds and average occupancy.

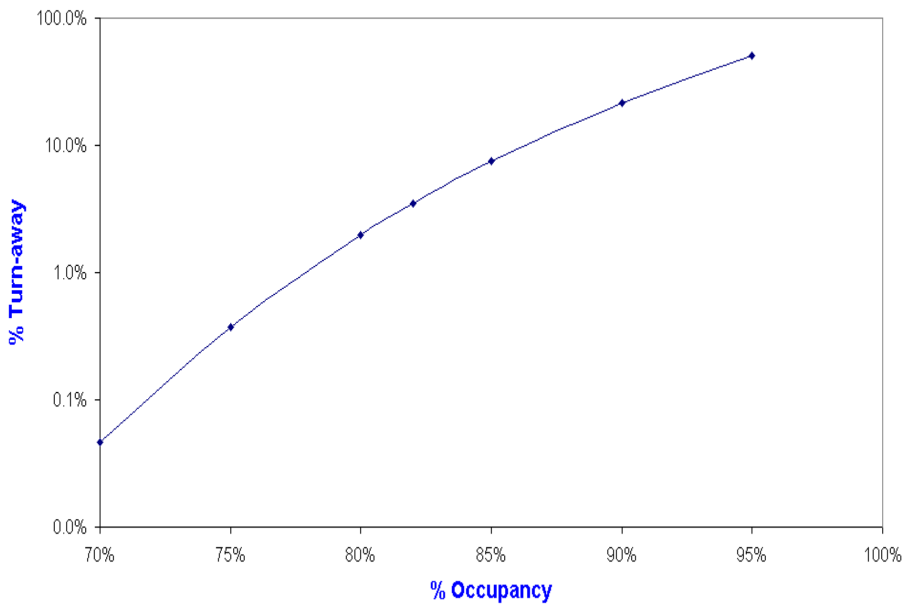
Table Four: Turn-away, queue for emergency admission and the average delay to admission for different size bed pools at a range of average occupancy.

Beds	Average Occupancy	Turn-away	No in queue	Average delay (hours)
50	82%	12.1%	5	6.7
100	70%	0.0%	2.3	2.0
100	75%	0.4%	3	1.2
100	80%	2.0%	4	1.5
100	82%	3.5%	5	3.4
100	85%	7.5%	6	2.0
100	90%	21.7%	9	4.0
100	95%	50.7%	19	12.0
150	82%	1.1%	5	2.2
200	82%	0.3%	5	1.7
250	82%	0.1%	5	1.4
300	80%	0.0%	4	1.0
300	82%	0.1%	5	1.2
300	85%	0.4%	6	1.4
300	90%	4.6%	9	1.9
300	95%	28.0%	19	4.8
500	82%	0.0%	5	0.7
1000	82%	0.0%	5	0.3

Increasing throughput per bed

This paper has already demonstrated that a consequence of increased throughput is higher turn-away. So how can we increase throughput per bed? The traditional NHS approach to this problem has been to reduce LOS. While this will indeed increase throughput in some less efficient specialties within some hospitals it needs to be stated that HRG's are still a very blunt and often inaccurate tool to discerning those who are supposedly less 'efficient'. Indeed in many cases a reduction in throughput is the more desired outcome due to the need to reduce turn-away.

Figure Seven: Occupancy and turn-away for 100 beds



Looking to blur the distinction between day case and overnight stay may still however make some marginal gains. Table Five gives some figures for consideration.

Table Five: Percentage of overnight admissions that do not stay overnight (LOS = 0) or stay for only one night (LOS = 1)[12]

Specialty	Elective	Emergency
Gastroenterology (LOS = 0) (LOS = 1)	40% 22%	74% 5%
Haematology	36% 42%	7% 20%
Anaesthetic & Pain Management	31% 18%	40% 16%
Oral Surgery	24% 53%	9% 29%
General Medicine	15% 47%	13% 20%
Thoracic Medicine	14% 86%	11% 9%
General Surgery	11% 40%	21% 22%
Trauma & Orthopaedic	10% 18%	10% 27%
ENT	9% 79%	12% 29%
Urology	9% 22%	12% 24%
Gynaecology	8% 18%	45% 26%
Ophthalmology	8% 68%	26% 30%

The figures in this table (which exclude any day case admissions) show that it may be possible to increase hospital throughput via the provision of more day bed type facilities. Day bed type facilities may include additional trolleys for emergency assessment units or larger daybed units used in a more flexible way. For instance, selected overnight and emergency operations could be channelled through a day bed unit with intensive postoperative care and earlier discharge should the patient prove fit. Those not fit for discharge could then be moved into the overnight bed pool at the point the day bed unit closes at the end of the day.

There are some obvious problems with this suggestion around moving patients from one location to another, etc. However in particular instances the entire bed pool for a specialty may be in one location and hence the number of beds classed as ‘overnight’ or ‘day case’ would be adjusted to meet the needs of randomness in emergency admissions, and the split between overnight and day case operations. Refer back to Figure Two for further consideration of this concept.

Rather than offering false hope it is probably safe to say that most large acute hospitals will see a reduction in throughput per overnight bed due to the need to reduce both % occupancy and hence turn-away. Throughput can be increased via a reduction in LOS although in some instances patients are discharged early due to bed shortages rather than on strict clinical grounds.

Table Six: Percentage occupancy giving rise to different levels of turn-away for different size beds pools

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%

[12] Data comes from the RBBH

Conclusions

This article has sought to demonstrate the use of the Erlang equation as a method for improving the validity and usefulness of bed forecasts. While it does not forecast bed requirements *per se* it is the only method available to forecast the consequences of a chosen bed allocation policy.

Turn-away is a useful concept because it contributes to the ability to achieve performance targets such as inpatient waiting time (via number waiting), cancelled operations and trolley waits. It also contributes to more subtle quality indicators such as the proportion of patients located in the correct specialty bed pool. Lastly it contributes to the hidden costs of not having sufficient beds. These hidden costs are never declared when a business case is presented. All that is ever shown are the cost savings arising from supposed reductions in the required bed pool. The Erlang equation tells us that these hidden costs will escalate in an exponential manner. Hence at 100 beds the consequence of being 10 beds too small is to go from 2% to 20% turn-away. One suspects that many business cases will require urgent revision!

Healthcare Analysis & Forecasting uses a mixture of proprietary forecasting tools, simulation software and novel adaptations of the Erlang equations to solve resource allocation and financial risk issues within healthcare, namely, how many beds does a specialty or hospital need, how many urgent, soon & routine appointment slots are required to guarantee targets, how much activity needs to be in a contract to guarantee achieving a target, what are the seasonal profiles behind activity and waiting lists, what is the financial risk behind decisions, etc.