The right cot, at the right time, at the right place – evaluating the design and organisation of neonatal care.

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Aims

The aim of the project is to assess how we might improve design and organisation of neonatal care networks.

Methods

There are two main components: firstly a computer simulation of the neonatal network using neonatal care data and secondly an evaluation of different referral patterns to assess impacts on costs and survival.

A discrete event simulation model is developed to simulate the care of infants in the South West neonatal network. Infants are stratified into seven categories according to gestational age at birth or the requirement for specialised surgical/cardiac care. The model is validated by comparing predicted and observed occupancy and length of stay. Some assumptions used in the model are validated against neonatal patient group representatives.

The economic evaluation moves beyond service level objectives and predicts infant mortality as well as NHS and family costs. Predictions of infant survival are based on infant characteristics (gestation, gender and birth weight) and workload of the neonatal units (Manktelow et al. 2013, Tucker et al. 2002). Predictions of NHS costs are based on the level of care received and compared against micro costing based on nurse grade. The costs to families include travel time, vehicle operating costs and overnight stays.

The simulation is used to estimate the costs and outcomes of stepwise moves towards greater compliance with workload guidelines. The simulation also explores the extent to which these results change when referrals became more centralised.

Results

Preliminary analysis shows that greater centralisation achieves cost savings from more efficient allocation of on-duty staff, but imposes greater costs on families and increases transfer costs. Greater achievement of BAPM guidelines reduces mortality, but at a higher cost.

Conclusions

The project shows how models of service delivery may be developed to inform evaluation of different configurations of care. We discuss the challenges of applying incremental cost effective analysis to such models such as how best to assess the costs of units that close altogether. We also look at alternative approaches to evaluation such as cost benefit analysis.

Introduction

The aim of this paper is to assess how we might improve design and organisation of neonatal care networks.

The paper extends the application of discrete event simulation in healthcare. Though discrete event simulation has been applied to staffing of an intensive care network (Griffiths et al. 2005) it has not been applied to neonatal units or multiple units acting a coordinated network with a dedicated transport facility. Asaduzzaman et al. (2010 and 2011) have previously developed a mathematical model of a single neonatal unit and a network of five units. In Asaduzzaman et al.'s models it is assumed that units have a given number of cots available. Something that is missing from these models, however, is that under BAPM recommendations, nursing staff, rather than by the number of cots may become the constraint to taking on more infants. We seek here to develop a model where both cot number and nursing staff are used to judge when a unit cannot accept any more infants. Another sophistication of the discrete event simulation used here, that is absent in Asaduzzaman et al., is that we can incorporate other differences between hospital provider. For example, some units may not care for very low gestation age, even though they nominally provide intensive care.

Though initially the neonatal model is concerned with the delivery of care, the model has been conceived to move beyond service objectives to outcomes of interest to policy makers and patients, like mortality. Tucker et al. (2002) produced the widely cited result that overcrowding in neonatal units is associated with increased neonatal mortality. It has also been shown that transfers between hospitals may lead to critical incidents (Moss et al. 2005) and are inherently costly. Whilst for families the lack of a cot close to home may lead to potentially large financial costs. The model draws together all these aspects of neonatal care, and looks at ways which they might be minimised if resources at one or more hospital change or alter. We report here some of the preliminary findings of this model, though we are still in the process of analysing the data.

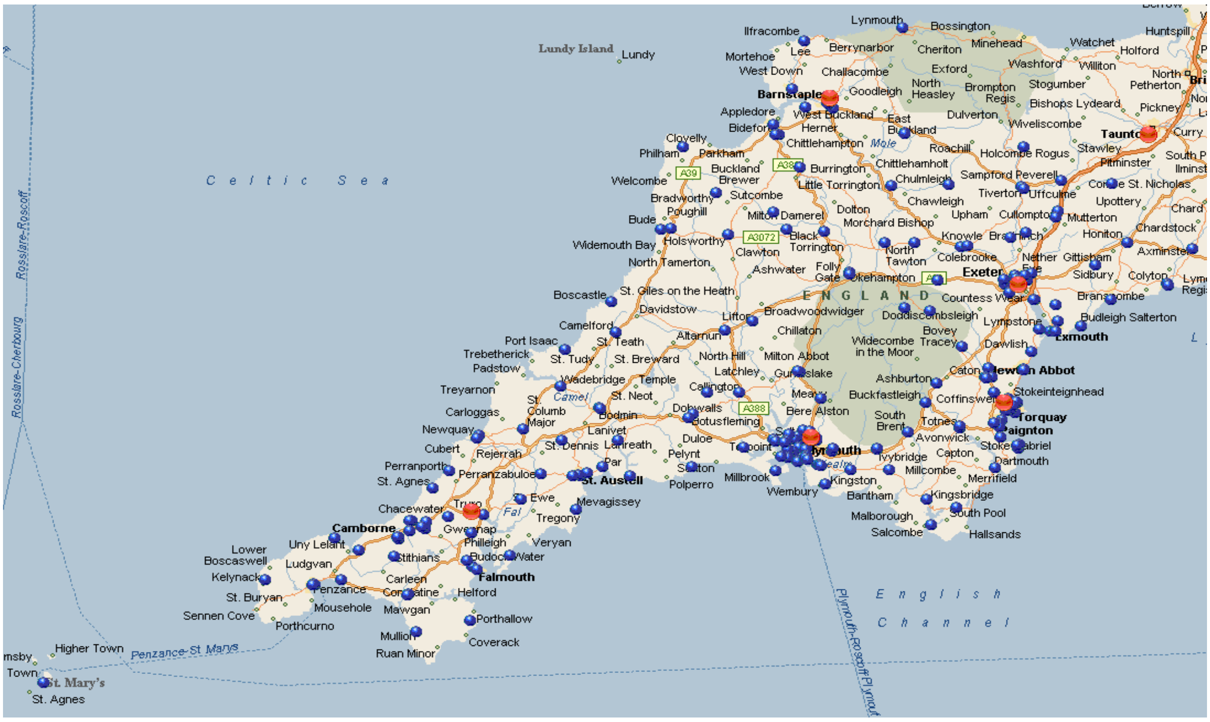
Methods

A discrete event simulation predicts movements of infants in the neonatal model in the South West of England, based on the location of the mothers, hospital provision, patient characteristics and expected patient pathway through the services. The model is based upon the Badger dataset of neonatal care for the Peninsula Neonatal Network 2010-2012, consisting of 9239 infants. Variables include length of stay in 4 levels of care, booked and actual place of birth, locations and times of transfers, GP postcode, gender, birth weight, gestational age at birth, mortality. Nursing data was available from a daily survey of ward nurses.

The economic evaluation moves beyond service level objectives and predicts infant survival as well as NHS and family costs. The simulation is used to estimate the incremental costs and outcomes of stepwise moves towards greater compliance with workload guidelines. The simulation also explores the extent to which these results change when referrals became more centralised.
The main elements of modelling approach and scenarios are described in detail below.

1. Location of mothers

Mothers are assigned a geographic location according to the location of their GP. The mean road distance between any two GP practices is 4.0km. There are 222 GP practices (patient nodes) across the Peninsula network with, on average, each GP practice having 12.6 births per year requiring care in a neonatal care unit.



2. Choosing between hospitals

The model attempts to place the infant in the closest hospital able to provide the required level of care, and with free capacity. Travel distances from each patient node to each hospital were obtained from Microsoft MapPoint which identifies the fastest route by road (a map of example routes is shown below).

The model first seeks to place the infant in the closest hospital within the mother's own network. If no suitable cots are available and free within the network the model looks for the closest free cot in other networks. In the Peninsula network all infants must travel outside of the network for the first period of specialist Cardiac or Surgical care.

Availability of cots may be limited by free cots or by the number of nurses. Nurse workload is calculated according to BAPM standards as ICU infants + HDU infants/2 + SCU infants/4 (if transitional care is modelled then we have assumed workload is increased by TCU infants/8, though there are no BAPM guidelines for transitional care). The unit may become closed to new infants when the workload exceeds a given proportion above BAPM recommended workload (for example the model may be set to limit workload to a maximum of 150% BAPM recommendations, though this figure may be varied between units if wished).

Transfers between hospitals may be required. If this occurs a delay in transfer may be set (other than that there is no constraint to transfers). Historically 13% of births were booked into a hospital that is not their closest neonatal care hospital, and another 13% of births used *in utero* transfer rather than neonatal transfer. The model reflects these (the percentages may be altered).

3. Patient categories

The model classifies infants into seven groups. These groups are used to sample from distributions describing the prevalence of twins, length of stay and flow into and between different levels of care.

Category	Gestational age at birth
1	<24
2	24 to <27* (or 24 to <28 for twins/multiples)
3	27 to <30
4	30 to <33
5	33 to <36
6	36+
7	Surgical/Cardiac (requires specialised care)

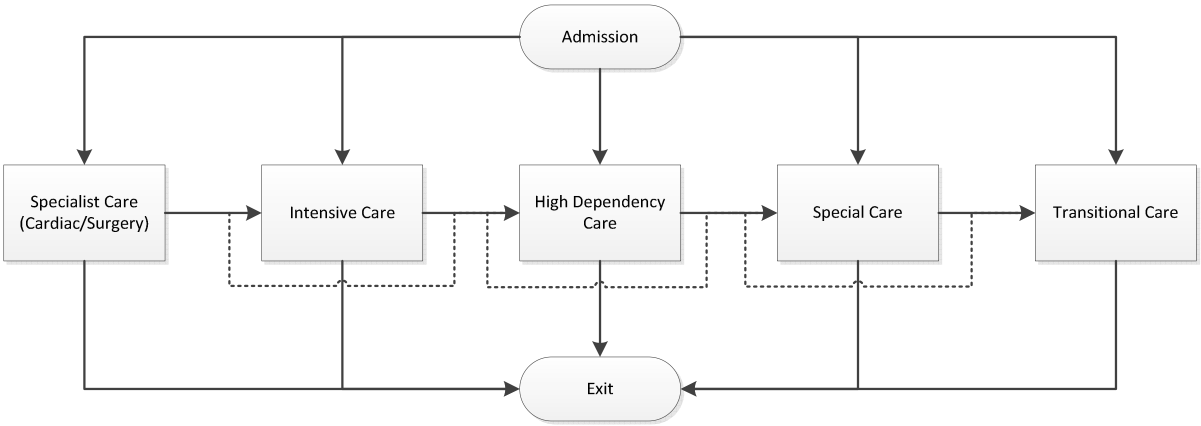
4. Patient pathway

As Badger does not report back the sequence in changes in level of care a working assumption is made that infant transition to lower levels of care over time. When modelling data it is assumed that any intensive care period comes first, then any high dependency care then any special care. The model has been constructed to allow for bi-directional changes in care level, but the working assumption with data available is that infants progress Specialist Care → ICU → HDU → SCU →TC. During model validation we have reversed this assumption so that all infants progress TC → SCU → HDU → ICU → Specialist Care and find that results (workload in each hospital, and average number of infants at each level of care in each hospital) are not changed ($r^2>0.99$).

Entry point and transition probabilities are sampled for each of the seven infant categories (see Appendix 5.2).

Lengths of stay are sampled from log-normal distributions with mean and standard deviations derived for each of the seven infant categories (see Appendix 5.3).

A schematic of the flow of patients is shown below (dotted lines show movements that can be made directly from one care level to another e.g. from intensive care to special care).



Note: Badger data is summarised for each day of care. The real spell length will be less than the total Badger care days as infants will have partial days at the beginning and end of care (unless they are admitted and discharged precisely at midnight). For analysis, and for modelling, the actual length of spell is used, and the Badger days are used to divide up the total length of spell into corresponding ICU, HDU and SCU periods in proportion to the number of days in each level of care.[1]

5. Mortality

Predictions of infant survival are based on infant characteristics (Manktelow et al. 2013) and measures of overcrowding/workload (Tucker et al. 2002). The infant characteristics are those found in most predictive models (i.e. gestation, gender and birth weight) and which account for most of neonatal mortality (Medlock et al. 2011). The mortality model is shown the appendix.

There are some challenges to replicating Tucker et al.'s workload measure. Tucker et al. use three workload measures, and report that occupancy was statistically significant. Tucker base occupancy

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[1] For example an infant admitted to HDU at midday on 1st January and discharged at midday on the 3rd of January has an actual length of stay of exactly two days, but will have three Badger days recorded (one for each calendar day the infant is present). If the infant has 1 HDU and 2 SCU days then the duration in each level will be adjusted in proportion to the total length of stay; so the infant will be recorded as having 0.67 days in HDU and 1.33 days in SCU.

on the maximum number of infants present in a unit over their study period but their measure is hard to operationalise. We define occupancy as the ratio of current nurse workload to nurse workload corresponding to 150 percent BAPM. Further, we measure occupancy at the moment of entry of infants to intensive care which contrasts with Tucker et al. (2002) who measured average occupancy using twice daily sampling over entire period of stay.

In applying the mortality model we simply add Tucker et al.'s workload measure to the Manktelow et al.'s 2013 model of infant mortality and make the following additional assumptions:

- mortality occurs to infants when in intensive care only (this assumption is broadly supported by our data).
- when infants have more than one stay in intensive care, mortality occurs in the first of these.
- when infants are discharged directly from intensive care it will be due to mortality (broadly supported by our data).

In the US it has been found that there is reduced mortality with increased centralisation (Phibbs et al. 2007) which is attributed to increased experience of staff in the more centralised units. However, this finding has not been replicated in a UK setting and is not modelled here. There may also be risks associated with transfers of infants to intensive care, but circumstantial evidence suggests that the mortality risks are quite small, and we have not modelled these risks here.

6. Costs

Predictions of NHS costs are based on two sources: the level of care received and a micro costing based on whole time equivalent (WTE) nurses. Unit costs for the level of care received are based on national reference costs 2011/12 and unit costs of WTE nurses is based on Curtis 2012. Though each band of nurses has a range of salaries attached to it, Curtis bases the cost on the medium salary within each band (i.e. the median full-time equivalent basic salary for Agenda for Change Bands of April-June 2012 NHS Staff earnings estimates for Qualified Nurses).

The costs to families that we can include at the moment in the model are travel time and vehicle operating costs. The unit costs applied to travel time is based on the Department of Transport non-business costs travel (TAG 2012)[2]. Travel for non-business is based on a study estimating the willingness-to-pay of travellers for shorter travel times (Mackie et al. 2003). This study found that travellers gave the same value to time in all modes of transport. The Department of Transport cost business travel at a higher rate, which varies between modes of transport based on lost workplace productivity and the wages of employees that typically uses that mode of transport. We do not apply these higher costs here, though it is recognised that travel may also take place in work time for spouses of women that have undergone caesarean section (and are recommended not to drive in the first 6 weeks) who may take off time to drive mothers to the units. The unit cost of vehicle operating costs is based on the AA and includes an allowance for car parking (AA 2012).

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[2] The DfT costs are recommended by the Treasury Green Book for economic evaluations of transport projects in England (https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent), but the approach appears useful for projects which affect journey times as a consequence of changes in referral policies.

7. Scenarios

In total 10 scenarios have been modelled which move progressively from localisation (all facilities exist locally) to centralisation (only Special Care available in Devon & Cornwall, intensive and High Dependency Care moved to hospital 6). Scenario 5 is closest to the current system where all surgical babies are treated by hospital 6.

Results

The model produced good predictions of occupancy and the absolute error in total workload is 0.4 (i.e. total number of nurses to meet BAPM guidelines). The absolute error in the number of infants in each care level is 0.7.

For the economic evaluation we estimate the costs and outcomes of stepwise moves towards greater compliance with BAPM workload guidelines based on the current system (scenario 5) using this model. As previously explained, a unit may become closed to new infants when the workload exceeds a given proportion above BAPM recommended workload. Most units in the South West are working at thresholds above the BAPM recommendations, with workloads of 120%-150%. In tables 6 and 7 we model the impact of restricting workloads to a maximum of 150%, 140% etc., so that the hospitals become increasingly compliant with BAPM. At a threshold of 100%, hospital workloads never exceed the BAPM recommendations. At thresholds below 100%, hospital workloads are lower than currently recommended by BAPM. Table 6 shows that transfers between hospitals and parental travel increases as the threshold is reduced (e.g. movement from 150% to 120% threshold). Table 7 shows that the mean NHS and family costs also increase but that the mortality reduces, and so raises the question about whether the increasing costs are worth the improved outcome, which we return to in the discussion.

We look at the impact of moving from localisation (scenario 1) to centralisation (scenario 10) setting the maximum BAPM workload threshold at 100%. For this analysis, we look at the cost implications only, as mortality is unlikely to be affected by centralisation if we set the BAPM threshold at 100%. Table 8 shows movements to centralisation (from scenarios 1 to 10) increase the mean distance and time travelled by parents whilst hospital transfers initially increase and then decrease. Table 9 shows the overall costs to families and the NHS remains broadly similar overtime (table 9).

A more accurate reflection of cost variation is found by looking at the network on-duty staff, which is more able to reflect the changing cost structure that arises from changing the referral pathway. At the writing of this paper this analysis assumes that infants are not transferred due to cot or nurse shortages; all transfers are in line with expected location of care. Table 10 shows the numbers of network on-duty staff to meet BAPM 80%, 90% and 95% of the time, which we cost using WTE of staff. Table 11 shows that greater centralisation reduces staff costs and so is likely to lower the unit costs of bed days, but imposes greater costs on families and increases transfer costs.

Discussion

We present preliminary work from a network model of neonatal care. Preliminary analysis shows that greater centralisation achieves cost savings from more efficient allocation of on-duty staff, but imposes greater costs on families and increases transfer costs. Greater achievement of BAPM guidelines reduces mortality, but at a higher cost.

We plan to extend the work in a number of ways. Changes in service configuration change the unit costs of bed day costs and more accurate costing of the staff is currently been sort from the network, to allow better estimation of these costs.

In this preliminary analyses we have been conservative in our estimates of family costs. For example, our estimate of family travel costs are well below those estimated by Bliss for families with experience of neonatal care (i.e. £401.71 for travel and £126.96 on car parks in 2006). Bliss based costs on all forms of transport, including public transport. In our model we estimate that basing travel on public transport would approximately double travel times. There are also other costs that are not yet incorporated into the model, including accommodation, childcare, lost earning (estimated to be £112.51, £104.96, £240.83, £1265.84 by Bliss in 2006). Bliss are currently collecting a nationwide survey of family costs, which will give additional disaggregated data on mode of travel and lost earnings, and which we aim to include. For example, there is also the possibility of including overnight stays for those in the early stages of care, or who live far from the hospital, with knock on affects for childcare costs.

We plan to run further analyses to decompose mortality by gestation to show more clearly the impact of occupancy upon mortality of the very young. We also aim to run bootstrap analysis to establish the confidence intervals around the incremental cost effectiveness and consider the impact of reducing the number of hospitals providing neonatal care.

The preliminary analyses have raised some questions about how we take this work forward that we would welcome discussion on. Firstly there is a potential mismatch with our model and the secondary data sources of mortality. We assume that mortality occurs to infants in intensive care only, which is broadly reflected in our data. In contrast, Manktelow et al.'s (2013) estimates of mortality is for infants entering NICU units before 33 weeks and where there may have been mortality among the older of these infants from high dependency. Similarly, for the relationship between occupancy and mortality, it is not clear which levels of care the Tucker et al. (2002) occupancy measure applied to. Secondly, changes in service configuration change the unit costs of bed day costs. This suggests a need for greater clarity in the components that make up national reference costs for neonatal care bed days, so that we can adjust these figures accordingly to reflect changing unit costs and then apply these costs to episodes of care. Thirdly, the impacts of reducing the number of hospitals providing neonatal care will need to be considered as the expected saving from disinvestment are not always achieved (Mortimer 2012). Moreover, hospitals services are jointly provided and closing one service has potential knock on effects for other services. For example, maternity and paediatric services in the hospitals in the South West currently use neonatal units for infants requiring stabilisation. If a hospital no longer provides neonatal care it will be necessary to still provide this service, for example, through a practice nurse (band 8). But is it that simple? There are clear cross subsidies of other staff across the maternity and neonatal services, including midwives, which would suggest the need for a model that captures both maternal and neonatal care jointly. Finally, there is the overriding problem that there is no clear decision rule for whether the additional costs justify the additional benefits using mortality estimates. So in cases where the expected outcome is mortality/survival, rather than actual quality of life or length of life changes, is there a case to move towards cost benefit analyses to try to establish if the service is likely to be cost effective.

There are some limitations to the analysis. The relationship between occupancy and mortality is taken from Tucker et al. (2002) but the definitions of levels of care and BAPM guidelines have changed since the time of their study. Little is reported about how best to combine the workload measure into a model of neontal mortality. For example, Tucker et al. (2002 and 2000) do not report whether the coefficients on the infant characteristics change when the workload measure is added.

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Tables

1. Categories of care

Category	Gestational age @ birth	% of infants requiring care	% Infants who are twins	% of deliveries requiring care**	% deliveries that are twins
1	<24	0.30	24.0	0.27	13.64
2	24 to <27*	0.83	20.0	0.78	11.11
3	27 to <30	1.83	17.5	1.74	9.61
4	30 to <33	5.25	23.0	4.86	13.01
5	33 to <36	16.24	21.2	15.17	11.85
6	36+	72.92	4.4	74.52	2.27
7	Surg/Card	2.63	7.2	2.65	3.74

*Or multiples <28 weeks

** Delivery of twins = 1 delivery, 2 infants

2. Entry point and transition probabilities between levels of care

Category	Entry point					Exit from ICU					Exit from HDU					Exit from SCU					Exit from TC				
	ICU	HDU	SCU	TC	Exit	ICU	HDU	SCU	TC	Exit	ICU	HDU	SCU	TC	Exit	ICU	HDU	SCU	TC	Exit	ICU	HDU	SCU	TC	Exit
1	94.74	0.00	0.00	5.26	0.00	0.00	22.22	0.00	0.00	77.78	0.00	0.00	75.00	0.00	25.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	100.00
2	100.00	0.00	0.00	0.00	0.00	0.00	80.43	0.00	0.00	19.57	0.00	0.00	81.08	0.00	18.92	0.00	0.00	0.00	23.33	76.67	0.00	0.00	0.00	0.00	100.00
3	93.41	6.59	0.00	0.00	0.00	0.00	94.12	0.00	0.00	5.88	0.00	0.00	90.70	0.00	9.30	0.00	0.00	0.00	57.69	42.31	0.00	0.00	0.00	0.00	100.00
4	50.34	35.27	14.38	0.00	0.00	0.00	86.39	6.80	0.00	6.80	0.00	0.00	97.83	0.00	2.17	0.00	0.00	0.00	66.79	33.21	0.00	0.00	0.00	0.00	100.00
5	8.77	29.99	59.86	1.38	0.00	0.00	80.26	17.11	0.00	2.63	0.00	0.00	99.07	0.31	0.62	0.00	0.00	0.00	77.53	22.47	0.00	0.00	0.00	0.00	100.00
6	6.32	10.61	73.73	9.34	0.00	0.00	44.02	47.88	0.00	7.34	0.00	0.00	95.26	2.91	1.82	0.00	0.00	0.00	53.26	46.74	0.00	0.00	0.00	0.00	100.00
7	100.00	0.00	0.00	0.00	0.00	0.00	64.20	11.11	0.00	24.69	0.00	0.00	90.00	0.00	10.00	0.00	0.00	0.00	27.94	72.06	0.00	0.00	0.00	0.00	100.00
7* (Surgical unit)	100.00	0.00	0.00	0.00	0.00	47.37	11.70	39.77	1.17	0.00															

3. Lengths of stay

Category	LoS (Mean Days)				% CV			
	ICU	HDU	SCU	TC	ICU	HDU	SCU	TC
1	22.62	46.62	18.32	0.90	143	21	81	0
2	25.33	42.84	26.71	4.05	97	96	45	75
3	12.88	19.59	31.04	3.13	95	79	45	68
4	6.13	6.84	22.73	3.15	125	97	45	66
5	2.75	3.07	9.52	2.45	82	126	72	71
6	3.10	2.39	3.29	1.59	104	195	130	79
7*	12.83	18.57	10.97	1.86	132	106	132	116
7* (Surgical unit)	5.80				100			

*Surgery LOS split between surgical unit and home network (or closest ICU to patient home)
Surgical unit LoS = Out of network LoS for Peninsula surgical cardiac

Surgical unit ICU LoS from...
David M Burge, Melanie Drewett (2012) Workload and costs associated with providing a neonatal surgery service. Arch Dis Child Fetal Neonatal Ed 2012;97:F179-F181
(Surgical unit LoS: 5.6 dyas ICU, 7.0 days HDU, 2.6 days SCU; HDU and SCU days not included in model - assumed transfer back to network after ICU)
LoS taken from patients will full data (all spells accounted for)

4. Scenarios

	Hospital type	Surgical provision	Care for <24 weeks?*	Care for <27 weeks?*	Care for <30 weeks?	Max permitted predicted ICU LoS (days)	Max permitted predicted HDU LoS (days)	ICU transfers in allowed	Cots (maximum level of care)			
									ICU	HDU	SCU	TC
1	Special care unit (SCU)	0	0	0	0	0	2	0	1	0	1000	1000
2	Local neonatal unit (LNU)	0	0	0	1	2	9999	0	1000	1000	1000	1000
3	Local neonatal unit + (LNU+)	0	0	0	1	28	9999	1	1000	1000	1000	1000
4	Intensive care Unit (ICU, also known as Network neonatal unit)	0	1	1	1	9999	9999	1	1000	1000	1000	1000
5	Surgical unit (Surg)	1	1	1	1	9999	9999	1	1000	1000	1000	1000

	1	2	3	4	5	6	7	8	9	10
Hospital 1	SURG	ICU	ICU	ICU	ICU	ICU	ICU	LNU+	LNU	SCU
Hospital 2	SURG	ICU	LNU+	LNU+	LNU+	LNU	SCU	SCU	SCU	SCU
Hospital 3	SURG	ICU	LNU+	LNU	SCU	SCU	SCU	SCU	SCU	SCU
Hospital 4	SURG	ICU	LNU+	LNU+	LNU+	LNU	SCU	SCU	SCU	SCU
Hospital 5	SURG	ICU	LNU+	LNU	SCU	SCU	SCU	SCU	SCU	SCU
Hospital 6	SURG	SURG	SURG	SURG	SURG	SURG	SURG	SURG	SURG	SURG

5. Unit costs 2011-12 prices

Cost components	
Micro costing by number of nurses on wards	
Nurse (Band 5) Unit costs (costs including qualifications in brackets)	£35 (£41) per hour £85 (£100) per hour patient contact
Nurse trained in speciality (band 6) Unit costs (costs including qualifications in brackets)	£43 (£50) per hour £105 (£121) per hour patient contact
Costing by national reference costs	per day
Neonatal Critical Care, Intensive Care	£ 1,117
Neonatal Critical Care, High Dependency	£ 795
Neonatal Critical Care, Special Care, without External Carer	£ 480
Neonatal Critical Care, Special Care, with External Carer	£ 387
Neonatal Critical Care, Normal Care	£ 440
Neonatal Critical Care, Transportation	£ 1,253
Costs of travel	
Cost of travel per mile	45 pence
Cost of travel time per hour in non work time (by base year 2011). Mothers likely to be passengers, due to caesarean so need to multiply this by two	£4.68 per hour per person travelling
Cost of travel time per hour in work time (by base year 2011).	£26.93per hour car driver and £19.80 per hour passenger

6. Current referral pathway (scenario 5) by BAPM threshold level

	BAPM threshold level								
	25%	50%	75%	100%	110%	120%	130%	140%	150%
NHS									
Mean stay for those infants in ICU	8.06	8.30	8.16	8.13	8.06	8.12	8.15	8.07	8.10
Mean stay for those infants in HDU	6.58	6.65	6.64	6.55	6.64	6.77	6.69	6.54	6.63
Mean stay for those infants in SCU	6.28	6.25	6.28	6.28	6.27	6.27	6.30	6.25	6.25
Mean stay for those infants in TC	1.89	1.85	1.89	1.90	1.89	1.90	1.89	1.89	1.89
Total number of transfers	238,878	232,602	175,254	99,906	79,704	62,460	53,886	46,404	41,790
Family									
Mean distance travelled by parents (kms), sd*	1,857 (3,981)	1,330 (2,998)	929 (2,254)	660 (1,824)	592 (1,759)	541 (1,682)	515 (1,607)	483 (1,527)	470 (1,431)
Mean parents travel time (hrs), sd*	22 (46)	16 (34)	11 (25)	8 (21)	7 (21)	7 (20)	7 (20)	6 (19)	6 (18)

*based on a daily return visit to the hospital from home

**based on 168,657 infants

7. Current referral pathway (scenario 5) by BAPM threshold level

	BAPM threshold level								
	25%	50%	75%	100%	110%	120%	130%	140%	150%
NHS costs									
Mean costs bed days, sd	£5,679 (£11,641)	£5,717 (£11,850)	£5,704 (£11,861)	£5,679 (£11,594)	£5691 (£11,725)	£5,697 (11,828)	£5,724 (£11,846)	£5,667 (£11,506)	£5,672 (£11,654)
Mean cost of transfers	£1,775	£1,728	£1,302	£742	£592	£464	£400	£345	£310
Family costs									
Mean cost distance travelled, sd*	£519 (£1,113)	£372 (£830)	£260 (£630)	£185 (£510)	£166 (£492)	£151 (£470)	£144 (£449)	£135 (£427)	£131 (£400)
Mean cost travel time, sd*	£103 (£215)	£73 (£158)	£52 (£118)	£38 (£98)	£35 (£96)	£32 (£95)	£31 (£92)	£29 (£87)	£29 (£83)
Mean total NHS and family costs	£8,076	£7,890	£7,318	£7,244	£6,484	£6,344	£6,299	£6,176	£6,142
Probability of mortality (%)	0.88	0.92	0.98	1.01	1.02	1.07	1.08	1.07	1.04

*based on a daily return visit to the hospital from home.

**based on 168,657 infants.

8. BAPM threshold of 100% and centralisation (moving from scenarios 1 to 10)

	1	2	3	4	5	6	7	8	9	10
NHS										
Mean stay for those infants in ICU	7.90	8.01	8.13	8.02	8.13	7.98	8.03	8.17	8.10	8.19
Mean stay for those infants in HDU	6.57	6.73	6.61	6.62	6.55	6.61	6.69	6.61	6.61	6.56
Mean stay for those infants in SCU	6.27	6.26	6.27	6.27	6.28	6.28	6.26	6.29	6.28	6.29
Mean stay for those infants in TC	1.89	1.90	1.89	1.89	1.90	1.89	1.89	1.89	1.88	1.90
Total number of transfers	91,944	81,534	94,356	91,338	99,906	103,938	129,570	117,468	97,680	79,476
Family										
Mean distance travelled by parents (kms), sd*	590 (1,139)	605 (1,292)	620 (1,656)	600 (1,846)	660 (1,824)	707 (2,362)	960 (3,169)	989 (3,500)	1,009 (3,673)	1,041 (3,942)
Mean parents travel time (hrs), sd*	7 (13)	8 (15)	8 (19)	8 (22)	8 (21)	9 (28)	12 (38)	12 (42)	13 (44)	13 (46)

*based on a daily return visit to the hospital from home

**based on 168,657 infants

9. BAPM threshold of 100% and centralisation (moving from scenarios 1 to 10)

	1	2	3	4	5	6	7	8	9	10
NHS costs										
Mean costs bed days, sd	£5,649 (£11,332)	£5,690 (£11,681)	£5,690 (£11,608)	£5,660 (11,474)	£5,679 (£11,594)	£5,684 (£11,708)	£5,671 (11,666)	£5694 (£11,729)	£5,685 (11,768)	£5,685 (£11,693)
Mean cost of transfers	£683	£606	£701	£679	£742	£772	£963	£873	£726	£590
Family costs										
Mean cost distance travelled, sd*	£165 (£319)	£169 (£361)	£178 (£463)	£168 (£516)	£185 (£510)	£198 (£660)	£269 (£886)	£277 (£979)	£282 (£1,027)	£291 (£1,102)
Mean cost travel time, sd*	£34 (£61)	£35 (£68)	£36 (£140)	£36 (£102)	£38 (£98)	£42 (£130)	£57 (£177)	£58 (£194)	£59 (£204)	£60 (£215)
Mean total NHS and family costs	£6,531	£6,500	£6,605	£6,543	£6,644	£6,696	£6,960	£6,902	£6,752	£6,626

*based on a daily return visit to the hospital from home

**based on 168,657 infants

10. Nurses on-duty to meet BAPM

	Scenarios									
	1	2	3	4	5	6	7	8	9	10
Network infants	74	73	73	73	72	73	72	69	65	54
Network workload	27.2	25.9	26.0	26.0	25.8	26.1	25.8	22.9	19.0	13.4
Network on-duty staff to meet BAPM 80% time	33	32	32	31	31	31	30	27	22	16
Network on-duty staff to meet BAPM 90% time	38	36	36	35	35	35	34	30	25	19
Network on-duty staff to meet BAPM 95% time	41	40	39	39	38	38	36	33	27	20
Staff utilisation to meet BAPM 90% time	73%	72%	73%	74%	74%	75%	77%	76%	76%	73%

Use results from MA table steering group Oct 2013

11. Costs of nurses on-duty to meet BAPM*

	Scenarios									
	1	2	3	4	5	6	7	8	9	10
Network infants	74	73	73	73	72	73	72	69	65	54
Annual cost of network on-duty staff to meet BAPM 80% time	2,455,296	2,380,893	2,380,893	2,306,490	2,306,490	2,306,490	2,232,087	2,008,878	1,636,864	1,190,446
Annual cost of network on-duty staff to meet BAPM 90% time	2,827,310	2,678,504	2,678,504	2,604,102	2,604,102	2,604,102	2,529,699	2,232,087	1,860,073	1,413,655
Annual cost of network on-duty staff to meet BAPM 95% time	3,050,519	2,976,116	2,901,713	2,901,713	2,827,310	2,827,310	2,678,504	2,455,296	2,008,878	1,488,058
Mean cost per infant of on-duty staff to meet BAPM 90% time	£1,006	£953	£953	£926	£926	£926	£900	£794	£662	£503
Mean costs of transfers	£2	£70	£86	£124	£191	£279	£390	£404	£496	£574
Family costs										
Mean cost distance travelled, sd*	£90 (£227)	£105 (£292)	£114 (£351)	£117 (£351)	£123 (£364)	£134 (£382)	£161 (£518)	£190 (£768)	£236 (£878)	£350 (£1,329)
Mean cost travel time, sd*	£20 (£47)	£23 (£58)	£25 (£74)	£26 (£73)	£27 (£77)	£30 (£82)	£37 (£114)	£42 (£158)	£51 (£181)	£71 (£257)

*The micro costing of nurses was based on two main types of nurses included in the model: qualified in speciality or not. Those nurses qualified in speciality are assumed to be band 6 and those without are band 5 (http://www.nhscareers.nhs.uk/explore-by-career/nursing/pay-for-nurses/ accessed 3/10/2013). The staff survey on which these figures are based, do not record consultants nor administrative support or matrons, but the Curtis 2012 costs include an administrative oncosts and training costs. The calculations are based on the assumption that 70% of registered nurses are qualified in specialty (following markers for good practice, Toolkit for high quality neonatal services 2009) and are band 6, whilst the remainder of registered nurses band 5

12. Appendix

12.1. Mortality estimate

We estimate the probability of survival to be:

$$\mathrm{logit(p)} = -10.28 + 0.46X_1 - 0.47\frac{1}{(X_2)^2} + 0.45X_3 - 0.28X_4 - 0.086\frac{X_5 - 50}{10}$$

where
p=probability of survival
X_1=gestation
X_2=birthweight
X_3=gender
X_4=gestation less than 24 weeks
X_5=occupancy
Mankelow et al. Pediatrics 2013 estimates the impact of infant variables upon survival (variables X_1 to X_4) and the UK neonatal staffing study group (Lancet 2002) looked at the impact of workload upon mortality (variable X_5) and reported that for every 10% increase in percentage of maximum occupancy at admission the odds of mortality increased by 1.09 (1.01-1.18). So in a logistic regression predicting the probability of mortality, the regression coefficient is log(1.09)=0.0861

We can convert a regression that is in terms of mortality, to survival probability, by the following rearrangement :

$$\mathrm{logit(1-p)} = \log(\tfrac{1-p}{p}) = \log(\tfrac{p}{1-p})^{-1} = -\log(\tfrac{p}{1-p}) = -(\beta_0 + \beta_1 X_1 + ..) = -\mathrm{logit(p)}$$

So, including in the impact of occupancy upon survival will be found by taking the negative of the coefficient in a regression looking at the impact of occupancy upon morality, and so an estimated impact of -0.086.