Right cot, right place, right time: improving the design and organisation of neonatal care networks – a computer simulation study

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Scientific summary

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Background

There is a tension in many health-care services between the expertise and efficiency that comes with centralising services, and ease of access for patients. Neonatal care is further complicated by the organisation of care into networks where different hospitals offer different levels of care. Infants cared for by the network may be moved either to access the required level of care or because of local demand pressures. Previous modelling and simulation of neonatal units and networks has been performed, but our model built on previous work in various significant aspects:

- The model views the system from the perspectives of both the service provider (looking at capacity utilisation, nurse requirements, transfers and cost) and of parents (distance of location of care away from home).
- The model allows capacity to be constrained by a combination of physical cots and the nursing workforce caring for the infants (nursing load varies depending on the acuity mix of the infants in care).
- The model allows a high degree of customisation of the capabilities of each hospital (such as gestational age limits on care).
- The model allows for multinetwork analysis.

This project used the Peninsula network as the main basis of analysis and modelling. The Peninsula network covers Devon and Cornwall, is over 200 km across and comprises five units. Approximately 2800 infants are cared for each year in the neonatal units, representing about 15% of all births. On average there were 71 infants in care, representing a workload of 23 nurse equivalents using British Association of Perinatal Medicine (BAPM) guideline staffing levels.

Objectives

- To develop a computer model to mimic the current performance and costs of a neonatal network, and to predict costs and performance of alternative configurations.
- To model the minimum network resources (cots and nurses) and costs required to meet BAPM/Department of Health (DH) guidelines [including 1 : 1 care in intensive care (IC)] 80%, 90% and 95% of the time.
- To use modelling to identify configurations and costs of resources that reduce the occurrence of overcrowding and increase the probability of an appropriate cot being available locally.
- To develop a primary economic analysis which will focus on costs of neonatal care using differing network configurations. A secondary analysis will consider ways in which this analysis might be developed to look at longer-term economic impacts of differing models of care.
- To develop a model that allows multinetwork analysis.
- To develop a pilot national model that will identify the best locations, and estimate travel distances for parents, for any given number of hospitals.
- To improve user (parent) involvement in health-care simulation and assess its value in planning and to elicit feedback on what is important to parents.

Methods

Design

A descriptive analysis of the current situation, an economic analysis and a discrete event simulation (DES) model.

Setting

The analysis and modelling focused primarily on a network of five neonatal units caring for approximately 2800 infants per year.

Participants and interventions

Analysis and modelling was based on historical secondary data. No patients were recruited for this project.

Parent involvement

During the research two meetings with parents were held to present findings and to obtain feedback. Parents particularly stressed the impact that large travel distances had on their lives.

Main outcome measures

Ability to meet nurse staffing guidelines, cost of service provision, number and distance of transfers, travel distance for parents.

Data sources

Anonymised neonatal data for 7629 infants who were admitted into a neonatal unit between January 2011 and June 2013 were accessed from Badger patient care records. Nurse staffing data were obtained from a daily ring-around audit. Further background data were accessed from NHS England National General Practice Profiles, Hospital Episode Statistics, Office for National Statistics and NHS Connecting for Health. Access to patient care records was approved by the Research Ethics Committee and the local Caldicott Guardian at the point of access to the data.

Results

- The simulation model produces very good estimates of unit workload, transfers and distances from the parents' home to the location of care.
- The models predicted network demand (expressed as either total infants or total nurse workload) to within 3% of the observed demand.
- The mean absolute difference between the predicted number and observed number of infants in each care level in the network was 0.5.
- The number of transfers predicted was within 2% of the observed number.
- The average distance from the parents' home to the location of care was predicted to within 2 km.
- For total number of infants at each hospital between the model and the observed data, the average absolute error in the number in each unit was 1.5. The average absolute error in the nurse workload in each unit was 0.4.
- The coefficients of determination (R^2) between the observed and modelled numbers of infants or the nurse workload in each unit were greater than 0.94. When results were examined at each care level at each hospital, R^2 was 0.87. The absolute error in the average number for infants in each care level in each hospital was 0.8.
- Some discrepancies between observed and modelled data could be explained by differences in lengths of stay between different hospitals. The model allows for these differences to be incorporated, but the results described here are for a general model that assumes length of stay is independent of hospital.

Demand for neonatal care in the Peninsula region, at 15% of all births, was higher than the national average (reported to be ≈ 10%). This may partly reflect deprivation of this area being higher than the national average. Demand had a geographic pattern: typically 30% or more infants from inner-city Plymouth GPs required neonatal care. Rural areas generally had lower admission rates.

Smaller units had higher relative variability in both the number of infants and the nurse workload present. The peak nurse workloads (90th percentile) in the two smallest units were three to four times those of the trough workloads (10th percentile), whereas in the larger hospitals the peak workloads were 1.5–2 times the trough workloads.

The workload per nurse varied significantly between hospitals, from working at an average of 51% of BAPM-recommended workload for the nursing staff present through to working at an average of 127% BAPM guideline capacity. Similarly, hospitals ranged from 1% to 85% of days over BAPM guidelines. The highest utilisation was at the network intensive care unit (ICU), the unit that arguably should work at the lowest utilisation. The network ICU should be most resilient to workload fluctuation, as it is receiving infants who cannot be cared for elsewhere in the network. This unit, caring for the sickest infants, is also where risk of mortality is highest, and this risk has previously been found to be related to the average percentage occupancy of a unit.

From modelling we estimate that there is approximately a 20% shortfall in the number of nurses required across the network if unplanned transfers are to be avoided, and if units are to work to BAPM guidelines 90% of the time. The shortfall is focused especially on the network ICU, which has the lowest resilience to workload fluctuations.

Neonatal networks have the option to move infants between hospitals as an alternative to each unit having the spare capacity to meet its own fluctuation of workload. Modelling showed that this strategy comes with a price: transfers start to increase rapidly above about 70% of network maximum permitted workload. Each time local capacity is breached, two transfers are required: one to the hospital absorbing the breached capacity and then a return from that hospital when possible. As the number of transfers increases, the average distance parents have to travel also increases (and the number of parents requiring temporary accommodation is likely to increase). The model predicted, for example, that the number of transfers doubles between 60% and 80% of maximum permitted workload (assuming a maximum workload of 150% BAPM guidelines), and doubles again as workload rises from 80% to approaching 100% of maximum permitted workload. At the same time, the average distance parents have to travel rises from 22 km to 25 km and then 34 km at 60%, 80% and 100% of maximum permitted workload, with 7%, 11% and 19% of infants over 50 km away from their parents' home location.

Centralisation of services can reduce the degree of workload variation and can thus reduce the number of nurses required to meet BAPM standards 90% of the time. Achieving these savings is difficult, however, if some local neonatal care capacity must be maintained at every major birthing centre. Savings are likely to require a co-ordinated consolidation of maternity services.

With the geography of the Peninsula region, centralisation of services would lead to a significant increase in the average travel distances for parents and an increase in the number of parents more than 50 km away from the location of care. For example, if all IC and high-dependency care (HDC) were consolidated into a single site the number of intensive and high-dependency care cots and nurses could be reduced by ≈ 15% (compared with each of the three units currently offering intensive and high-dependency care cots having sufficient spare capacity to deal with local fluctuation in workload). However, the average distance for parents whose children are in IC and HDC increases from 28 km to 55 km, and the proportion of parents over 50 km away from the location of care increases from 15% to 60%.

The expected travel cost to parents rises from ≈ £200 per infant in a localised system to ≈ £550 per infant in a centralised system. At the same time, NHS transport costs rise from an average of about £83 per infant in a localised system to about £820 per infant in a centralised system.

The cost of nursing depends on the target for meeting BAPM standards. If there is a target of meeting BAPM standards (i.e. the nurse workload calculated by BAPM recommendations does not exceed the number of nurses available) 80% of the time, then predicted nursing costs per infant are ≈ £4500. To meet BAPM standards 95% of the time, the expected nursing costs per infant increase to £5500.

Calculating nurse requirements using BAPM 2011 guidance produced requirements of 10–15% fewer nurses than using BAPM 2001 guidelines.

Following parent involvement, we performed additional analysis on public versus private travel times. We found that, on average, public transport times were 2.5 times as long as private transport. This may be significant when considering how many parents may need temporary accommodation because care is distant from their home location.

Using DES we were able to model the behaviour of a local neonatal network. This type of network model has significant advantages over single-hospital models, and we believe opens up the possibility of using this type of model on a national level to help inform decisions on the national provision of neonatal care.

An outline analysis of national locations of neonatal units showed that distance between hospitals varies widely between networks. The effect of consolidation/centralisation on parent travel distances and costs may be significantly greater in the Peninsula region than in other networks. Nationally, on average, units are separated by 23 km (road distance). The London networks had average interunit distances of 7–9 km. The Peninsula region had the greatest interunit distance, of 60 km. Although we recommend development of a more detailed national model that would also take into account expected travel times (rather than only distances), it may be possible that the economies of centralisation may be achieved in other networks without such a large effect on parents.

An algorithm was used to investigate the relationship between the number of units (of any particular type) across all of England and the travel distances for parents. The location of those units was identified using a 'greedy algorithm' which minimises average and maximum travel distances (units were chosen from a list of existing units). There were diminishing returns in adding more units. The average distance (straight line) between parents and their closest unit was 35 km with 10 units, 14 km with 50 units, 10 km with 100 units and 7 km with 150 units.

Conclusions

Our simulation model was able to replicate the current network configuration and performance, and could be used to explore alternative configurations. The model predicted that nursing costs could be reduced by centralisation of services, but that this must be offset against the increased parent travel distances calculated and the increased need of transfers. As parent travel distances increase, the number beyond a reasonable daily travel distance increases, which opens up the question of how best to accommodate these parents, and what local hotel capacity, if any, should be planned for. In the model, the maximum cost reduction of services was achieved only with unit closures. As neonatal care is frequently tied up with maternity and childbirth services, this raises the question of how joint planning of neonatal and maternity services is best achieved.

Neonatal networks have the ability to move infants to other hospitals when local capacity is exhausted. Our modelling showed that, while this may reduce the number of nurses required to cope with local fluctuations in workload, the number of transfers and the travel distance for parents start to rise significantly above $\approx$70% network capacity utilisation.

The BAPM and the Department of Health provide guidelines on the number of infants nurses may care for at each level. The model demonstrated the increasing costs associated with complying with these guidelines either 80% or 95% of the time.

Recommendations for further work

This work raises two main areas of potential further work:

1. Application of the model at a national level. This would be performed in collaboration with the Neonatal Data Analysis Unit, Imperial College, London, which holds a national set of Badger data that is suitable for modelling at a national scale. We have developed the model to allow for multiple networks to run simultaneously, and so we have high confidence the model could work at a national level. This would significantly assist in planning of national neonatal care provision.
2. Expanding the model to encompass all perinatal and neonatal care. Such a model would include births, postnatal episodes of care and neonatal care, and builds on both our neonatal modelling work and previous modelling we have published on labour wards and midwife requirements. We hope such an extension might provide a useful shared framework to inform discussion of how maternity services and neonatal care strategies influence each other.

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