A Simulation Model to Increase the Efficiency of a Hospital Maternity System

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Abstract

The objective of this study is to develop and test an analytical based simulation model, which can be used to plan for the Wesley Hospital's maternity unit. The efficiency of the system can be analysed along with the effects of increased demand and variation in parameters. The development of the unit to its optimum capacity with minimum investment is basically contingent upon the efficient use of resources. Ideally a unit must be planned so as to ensure that all the resources are used at all the available times and no patient is ever kept waiting. An ideal state of affairs is impossible to achieve in practice because of the unpredictable nature of problems such as earliness and lateness in arrival times, variability in operation period, break down of equipment, etc. There are basically two ways to achieve an approximation to such an ideal solution: improvements in operational methods; and investment in new-facilities for expansion. The analysis is carried out by the improvement in the operational methods. This can be achieved by creating scheduling techniques to improve accuracy of the booking system, the efficiency of the bed usage and synchronisation of the balance of each unit in a multi-unit environment such as the Wesley Hospital. If the desired level of service level is not achieved by these methods, then the second way to investigate infrastructure change is analysed. This can then be balanced against capital investment and operating costs for finding the optimal investment program for the Wesley hospital.

1. INTRODUCTION

Maternity units at hospitals experience problems in accurately booking and scheduling patients due to the inherently unpredictable nature of patient arrivals. Even with predicted dates of birth, any actual birth may well occur with an important deviation from the expected date. As a result, allocation of resources is generally left until shortly before those resources are actually required. This creates the potential for a patient to arrive at the hospitals to give birth only to find that the resources available at the time are inadequate.

The most important issue for hospitals is to provide quality health care in the most efficient and cost-effective manner possible, so analysis is carried out by considering improvement in the operational methods. This has be done by establishing an analytical based computer simulation model of the processes involved, in the Wesley Hospital's Maternity Unit, which will be used to analyse the efficiency of the system, along with the effects of increased demand and variation in other parameters.

In the literature, simulation models have been used to evaluate the impact of a variety of hospital policy decisions involving patient movement. Blewett et. al. (1972) employed simulation models to evaluate bed requirements in progressive care units. Kwak et. al. (1976) applied simulation to evaluate utilisation of operating and recovery rooms. Hamilton and Breslawski (1994) compared the factors considered "essential" or "important" for each of the First Come/First Served and Block scheduling strategies investigated in the previous article Hamilton and Breslawski (1991). Dexter (1996) proposes that rather than using mean or median times to predict the duration of operations in an operating room, the upper 95% prediction level gives a more accurate result with a better chance of all operations scheduled being completed on the appropriate day. McFadden (1996) developed simulation models for both existing and proposed systems based on assumptions of Markovian patient movement within a Maternity Unit in order to include bed capacities and operating costs in each care unit. Hersley et al (1989) modelled the flow of patients using a simulation model to estimate mean utilisation and service level for a finite service capacity.

2. MATERNITY SYSTEM

On the arrival at the Wesley of a "normal" patient in the early stages of labour, she is taken straight to a Delivery Suite in the Labour Ward and remains there until the baby has been born. If there are no vacant Delivery Suites on her arrival, she is taken to a bed in the Maternity Ward until one of the Delivery Suites is available. If the patient enters the final stage of labour and all the Delivery Suites are still occupied then a Recovery Bed can be used. Recovery Beds are generally used for mothers who have just given birth if there is another patient waiting to enter the Delivery

Suite, otherwise a patient will give birth in her bed in the Maternity Ward. A normal delivery is never performed in the operating theatre - this is reserved for either booked Caesareans or for emergencies. This process is shown in Figure 1. In this figure, options at each decision point are labelled in order of preference, with 1 representing the most desirable option at each stage of the process.

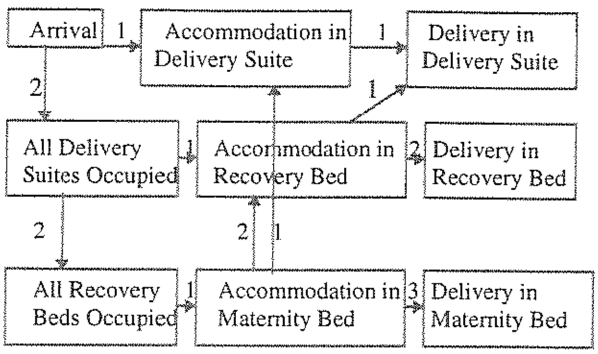

Figure 1: Resource Allocation Process

If the baby is well, it is not considered as a patient who has been admitted for hospital care. Mothers of well babies are transferred to the Maternity Ward after the delivery. The baby is admitted to the Special Care section if a medical treatment is required.

The Patient Process Flowchart in Figure 2 illustrates the progress of a patient through the system from her first telephone call through to her discharge. Refer to the notes following the chart for detailed explanations of the various stages in the process.

In the event that a patient requires an emergency Caesarean and the Labour Ward operating theatre is already occupied, the patient is simply taken to one of the other theatres in the Hospital for the operation and then transferred back to the Maternity Ward to recover as would normally happen for any Caesarean operation.

There are only two aspects of the birth process that can be controlled by the Hospital:

1. the date of delivery for an elective Caesarean; and
2. the length of stay / discharge date of the mother and infant after birth.

The hospital has no control over when labour commences, nor whether an emergency Caesarean will be necessary.

The following three possibilities for a birth are considered : Standard Vaginal Delivery; Elective Caesarean; and Emergency Caesarean. It is possible that other types of emergency may occur (for example excessive bleeding, respiratory failure, etc.) which may require the mother or infant or both to be transferred to another unit or to undergo processes other than those discussed. Unless these occurrences are extremely rare, they should be incorporated into the system for purposes of analysis.

3. THE SIMULATION PROGRAM

Simulation is defined as the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the maternity system. The simulation modelling procedure should begin by developing a description for the maternity system's processes. The model developed for this simulation analysis is based on the second section of patient process flowchart in Figure 2. The Wesley Hospital's maternity system has been adapted to a model by some parameters involved in the phenomena which influence the efficiency of the system. Each simulated period of the queuing operation is developed using a sample set of input values drawn from system properties.

The Siman simulation language is used and the maternity system is described in terms of the following components: Entities, attributes, resources, queues, and state variables (see Pegden 1990). Running the program many times produced various results due to different combinations of random numbers produced during the simulation. Therefore in order to perform sensitivity analysis and statistical interpretation on the data a substantial number of runs need to be produced. Thus in taking the average of these runs should result in reasonably accurate results to draw hypotheses and conclusions on.

4. VARIABLES AND PARAMETERS OF THE MODEL

To determine the overall arrival rate of patients and the arrival rates for each type of operation, the Hospital's database was analysed to obtain statistics for each set of data which were employed to fit theoretical distributions to the inter-arrival times, length of stay and duration of labour for patients anticipating Vaginal Delivery, Emergency Caesarean and Elective Caesarean.

Duration of a birth is the time between arrival of a labouring patient at the Hospital (or the scheduled start-time of an Elective Caesarean or Induction) and the time of birth of the child. The time spent in the Labour Ward would not be an appropriate indicator as a patient may not be admitted to the Labour Ward immediately on her arrival if all the Delivery Suites are full.

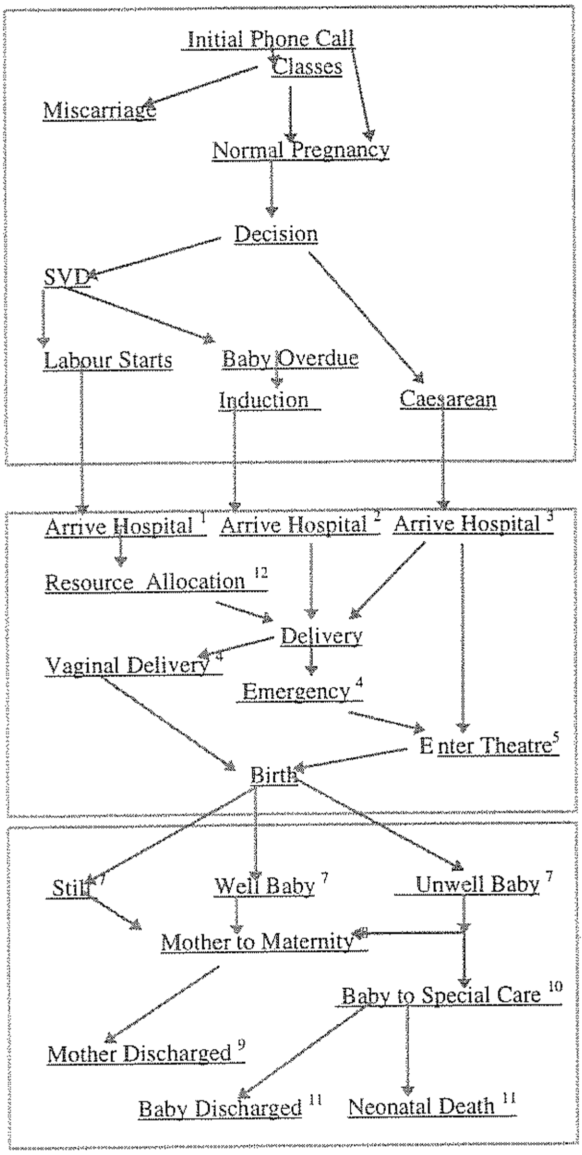

Figure 2: Patient Process Flowchart

Notes Accompanying Flow Chart

1. Arrive Hospital (1). Arrival time and date for "normal" patients, i.e. those anticipating standard vaginal delivery (SVD). The date will be used to determine the arrival distribution and the time will be used as the "start time" for calculating duration of the operation for SVD patients with and without an emergency Caesarean operation.

2. Arrive Hospital (2). Arrival time and date for patients having induced labour - these booked for a set time and date, so they generally arrive on a weekday morning; however, the time will still be important for determining the duration of an induced labour.

3. Arrive Hospital (3). Arrival times for elective Caesarean patients. As with patients for inductions, these are booked in advance and so generally arrive in the morning of a weekday. In order to calculate the duration of the Caesarean operation, the time of entry to theatre may be a more appropriate "start time".

4. Vaginal delivery / Emergency (SVD and induction only). This will probably take the form of an indicator variable used to represent whether a patient who does not anticipate giving birth by Caesarean will require an emergency Caesarean operation.

5. Enter Theatre. Time at which a patient for elective or emergency Caesarean actually enters the operating theatre - this will be used to determine duration of Caesarean operations.

6. Birth. This point will generate the "finish times" for all four operations under consideration, i.e. SVD, induction, elective Caesarean and emergency Caesarean.

7. Still / Well Baby / Unwell Baby. This is an indicator variable representing the health of the infant. As still births are a very rare occurrence, it may be possible to ignore this possibility without greatly jeopardising the integrity of the model; however it is still necessary to consider whether or not the baby requires special care since the Special Care Unit operates in conjunction with the Labour and Maternity Units and so the systems are in constant dependence, particularly in terms of staffing requirements. There may also be dependencies between duration of birth, requirement for an emergency Caesarean and requirement for special care since firstly a difficult birth may influence the health of the baby, and secondly multiple births (twins etc.) are likely to take longer, to require an emergency Caesarean and to require special care for the infants.

8. Mother to Maternity. This will represent the date on which the mother enters the Maternity Unit after giving birth and will be used as the "start date" for calculating the Length of Stay of the mother.

9. Mother Discharged. The date on which the mother leaves the Maternity Unit, used as the "finish date" for Length of Stay.

10. Baby to Special Care. If the baby requires special care (i.e. if the indicator variable from Note 7 corresponds to the option "Unwell Baby") this will be the date on which the baby is admitted to Special Care, or the "start date" for the baby's Length of Stay.

11. Baby Discharged / Neonatal Death. The date on which the baby dies or is discharged (whether it is well enough to be sent home or requires further care at another institution is basically irrelevant as far as modelling the Length of Stay is concerned) will be the "finish date" for the baby's Length of Stay in the Special Care Unit. It may be unnecessary from a mathematical perspective to consider discharge of the baby and neonatal death as two separate possibilities, since the aim is to model the distribution of Length of Stay actually within the Unit and the reason for leaving the system may not have any great effect upon this value.

12. Resource Allocation. See Figure 1.

In considering the duration of the various operations undertaken in the Maternity and Labour Wards, the following need to be considered as different operations: Standard Vaginal Delivery; Elective Caesarean Section; Induced Labour; and Labour followed by Emergency Caesarean Section

Details of the type of operation can be found in the Register of Births. It is probably unnecessary to consider forceps births, vacuum extraction or breech births as separate from Standard Vaginal Delivery or Induced Labour.

The age of the mother has very little effect upon the duration of the birth. Generally, a woman's first child tends to take longer to deliver than subsequent children, but this cannot be relied upon as other factors influence the time taken far more than this, for example the size of the baby and the mother's state of mind at the birth. Aside from the fact that the number of previous births is an unreliable indicator of the duration of labour, this information is not available to the Hospital before the mother is admitted and so is not likely to be usable as a factor in predicting the duration of operations.

An exponential distribution with a mean of eight hours has been obtained from the available data for the duration of labour. An exponential distribution has been determined with a mean of two hours for an Elective Caesarean which includes anaesthesia and operation set-up times. Duration of an Emergency Caesarean is much shorter than an Elective Caesarean and an exponential distribution with a mean of half an hour has been used for the model.

The length of the mother's stay in the Hospital can be determined from the dates of the mother's discharge from Labour (and admission to Maternity) and discharge from the Maternity Ward. Using this information the length of stay for patients for a normal vaginal delivery has been determined as a triangular distribution with a lower bound of five, a mode of six and an upper bound of seven days. A triangular distribution has been determined for Elective Caesarean birth with a lower bound of seven, a mode of eight and an upper bound of ten days. Emergency patients generally stay slightly longer than Elective Caesarean patients and the distribution has been again determined as triangular with lower bound seven, mode nine and upper bound ten.

Often, a patient who has just given birth to her first child stays a little longer than an experienced mother although this tendency is unpredictable since many mothers who do have other children prefer to stay in the peace and quiet of the Hospital while they are recovering. Length of stay does not vary noticeably with seasonal demand.

Difficulties encountered in obtaining long term data from hospital led us to make decisions with limited information. It has been estimated that labour patients arrive according to an exponential distributions with an average number 3.214 patients per day and the times required for Caesarean operations also follows exponential distributions with mean 3.0 patients per business day. An average 10% of patients anticipating vaginal delivery require an emergency Caesarean section.

Service rates are determined from the hospital's database and number of servers (at each series station) are simply the resources available in the Maternity Unit, i.e. Delivery Suites, Maternity Beds and so on.

Service discipline is determined by hospital policy. This is essentially a FIFO system backed up by a priority system so as to allow firstly for emergencies and secondly for the fact that one woman may give birth before another even if her labour started earlier.

Calling source is assumed infinite as it potentially consists of all women in Southeast Queensland. Change in population on the health care system will alter the arrival rates of patients, although it is unlikely to effect the nature of the distribution.

The physical resources are defined as the number of beds, theatres and delivery rooms in the Labour and Maternity Wards. There are four Delivery Suites, one Operating Theatre and two Recovery beds in the Labour Ward. There is total 31 beds in the Maternity Ward (1 deluxe suite, 24 private rooms and 3 shared rooms).

If the type of accommodation requested by the patient is unavailable on admission she will be placed in another bed in the maternity ward and upgraded to her requested accommodation style as soon as possible.

Staff resources in the maternity ward consist almost entirely of full-time Wesley staff. Occasionally an external doctor will book the operating theatre for a patient requiring tests or similar, but these patients are nearly always accommodated in the shared room facilities and the doctor must have a specific accreditation granted by the Wesley Hospital. Most patients arrange in conjunction with their doctors to give birth in the Wesley, but once they arrive at the Hospital, they are attended to by midwives and nurses permanently employed in the Ward. Aside from the fact that external doctors are not actually permitted to perform the delivery (although they are allowed to be present for emotional support to the patient) it is impractical for doctors to attend on all births of their own patients because of the unpredictability of the date and time of a birth.

The Labour Ward has 16 permanent full-time staff. In the event that there are insufficient staff to attend to the arrivals on a shift, staff rostered in the maternity ward come into the Labour Ward to assist.

Each staff member on a maternity ward shift is generally assigned four patients to attend to, although of course if a shift is very busy staff may have five patients and occasionally if one patient requires significantly more care than usual her staff member may only have three patients.

During a shift, nurses use the condition of each of their patients to predict how much time they will each require in the next shift so that each staff member for the next shift can be allocated an appropriate combination of patients.

5. RESULTS AND CONCLUSION

Each simulation with different parameter values for the model, which are described in Section 4, have been carried out for a total of twelve runs with a time period of 60 days (30 days warming period) to obtain average and maximum values for the following identifiers: waiting time and utilisations for beds and Delivery Suites. Average values of these results for each set of twelve simulation runs for these quantities are summarised in the second column of Table 1. The efficiency of the system has been analysed along with the effects of changes in arrival rates, number of beds, length of stay and service rates. From this analysis of the behaviour of the system of the maternity unit at the Wesley, it appears that the major variable to cause concern should be the time spent by patients waiting for admission to a bed in the Maternity Ward after delivery of a baby. Other variables of interest did not show such noticeably sensitive reactions to the changes in parameters investigated. However, as seen in Table 1 and Figure 3, changes in the arrival rates of patients produced important changes in the expected times spent by patients waiting for admission to a bed in the Maternity Ward. Changes in the number of beds available in the Maternity Ward affected the bed waiting time seriously as well. However changes in the average length of stay of patients after delivery had the most significant effect of all the changes investigated upon the waiting times for beds in the Maternity Ward.

Scenarios:		*Change in Arrival Rates*				*Change in Maternity Beds*			*Change in Length of Stay*		
Identifier	*Mean (a)*	*+10% (b)*	*+20% (c)*	*-10% (d)*	*-20% (e)*	*+10% (f)*	*-10% (g)*	*+20% (h)*	*+10% (i)*	*-10% (j)*	*-20% (k)*
Arrivals in Labour	86.4	99.67	105.6	79.58	74.40	84.25	88.33	88.80	94.42	87.42	84.2
Suite Wait Time(min.)	6	3.6	5.40	1.20	3.6	1.80	1.80	4.20	3.60	1.80	1.2
Av. # Emergency Caesarean	8.75	10.42	8.20	7.75	6.80	8.33	8.42	8	10.00	9.42	9.6
Av. # not Admitted to suit	0.50	1.08	1.60	0.42	0.80	0.58	0.42	0.4	0.83	0.58	0
Av. # External Caesareans	1.33	2.33	2	1.50	0.80	1.50	1.58	1.2	1.58	1.58	1.4
Av. # Elective Caesarean	58.58	63.52	70	54.92	47.6	61.17	61.08	61.4	61.08	58.50	61.6
Av. Bed Waiting Time(hr)	23.55 .	34.77	41.21	16.02	8.76	14.83	37.72	7.90	42.23	13.02	4.99
Max Wait for Bed (hr)	63.54	70.83	71.92	56.67	38.29	52.49	80.52	40.77	87.17	52.40	31.99
Av. Suite Utilisation (%)	26.0	29.80	33.50	23.50	23.0	23.50	26.5	26.0	27.80	24.50	23.0
Av. Bed Utilisation (%)	96.1	98.01	99.03	94.01	91.06	92.60	98.00	92.0	98.00	94.70	82.0

Table 1. Simulation Results

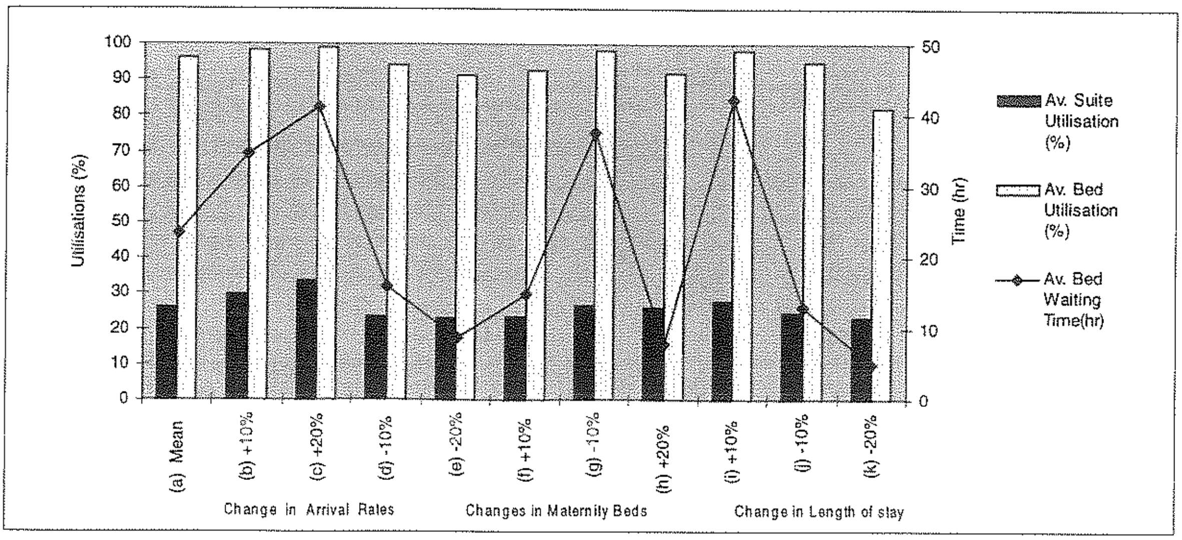

Figure 3. Graphical Analysis of Simulation Results

The objective of this research is to provide the Wesley Hospital management team with a versatile and comprehensive tool that will enable them to evaluate the maternity ward system operations and the effects of changes in hospital policies and operational strategies upon maternity unit performance. The effect of changes in parameters and variables upon the waiting time for admission to a Maternity unit should be more closely investigated, when more accurate distribution functions have been obtained. An analytical based computer simulation model is used to achieve this objective. The model allows management to anticipate the impact of changes, as well as to evaluate the effectiveness of current practices.

It should be necessary for the maternity unit to develop a computerised booking and record keeping system. As a current manual system will become more time consuming. While data for each patient is stored in the central computer records, this system can be improved for use in the Hospital as a whole.

Patients throughput time and variation from the desired level of customer service can be calculated using simulation outputs. Using these outputs a cost function may be derived to facilitate an accurate analysis of the relationship between the cost of supplying extra resources and the cost of unsatisfied customers. This cost function could then be optimised either by incorporation into the simulation model developed here or using analytical models. This can then be balanced against capital investment and operating costs to find the optimal investment program for the Wesley hospital in order to optimise the use of scarce resources. Then, the best strategy will be determined, which provides either the maximum present value of net benefits or the minimum present value of total costs over the planning perspective. This part of the research is left to future studies.

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