Chapter 4

Computer Simulation of Grace Hospital

The Grace hospital simulation model consists of 2700 lines of GPSS/H code. It is a model of the inpatient flow through Grace Hospital that allows the user to investigate how changes in the hospital would effect the resource utilization. The data input for the model includes arrival rates, transfer tables, and holding time distributions for all the patient categories. The model assumes that for an infinite capacity hospital transfers and LOS depend only on a patient’s category and present location (and arrival time in some special cases), but not on their past history. However, as capacity is reached the occupancy of the various units will affect patient movements. As overflow, patients may transfer to different locations or have their LOS shortened (see section 4.3).

This chapter explains the inner workings of the model: the patient classifications, the physical divisions, and the logic used to create and run the model. See appendix C for a sample output, and appendix D for a complete listing of the code.

4.1 Classification of Adult Patients

Adults are classified in four ways. They are assigned a delivery type, a code for their place of residence, an antepartum condition, and a postpartum condition. There are on average 730 patients per month at Grace (620 patients who deliver and 110 AP-only or PP-only patients). The number following each category name gives the percent of this total that category represents.
4.1.1 Delivery Type

The following are the possible delivery types in the model.

1. spontaneous delivery - 50%

2. instrumental delivery (includes all forcep deliveries, vacuum extractions, and assisted breech deliveries) - 13%

3. elective caesarean section (includes day of surgery patients and regular arrivals) - 8.5%

4. emergency caesarean section - 13%

5. undelivered (PP-only) - 1.5%

6. undelivered (AP-only) - 14%

Abortions are ignored in the model because at Grace they represent only about one patient per month. A patient’s delivery type governs the admission procedure (see section 4.5.1), and all her transfers and length of stays in the delivery suite section. In addition, the distinction between patients who will deliver and AP-only patients is important in the AP section.

4.1.2 Geographical Region

Patients are classified according to their place of residence.

1. Vancouver School District # 37 - 54%

2. Greater Vancouver Regional Health District (not including school district # 37) - 36%
3. British Columbia (not including GVRHD) - 10%

The geographical region is assigned as function of the delivery type, and is used only to determine (in conjunction with the delivery type) a mother's AP category. The geographical code is important because mothers who come to Grace from far away tend to be more ill and thus are more of a burden on the hospital. Grace, as a tertiary care centre, is obliged to accept all "high risk" patients. The high/low risk distinction must be with a preliminary diagnosis which is not always a good predictor of a patient's future problems (in fact, the "high risk" diagnosis list is outdated and is presently under review at Grace). However, at Grace, once a patient arrives the low/high risk distinction is lost. Geographical residence is correlated with higher risk and this relationship is reflected when a patient's AP category is determined. Including the geographical region as a factor in the model allows for experiments to study the effect of increasing the proportion of patients not from Vancouver coming to Grace. This indirectly causes the "high risk" proportion to also increase.

4.1.3 Antepartum Complications

The following is a list of the antepartum conditions used in the model.

1. no antepartum complication or no significant AP complication (i.e. no AP complication that effects LOS in the hospital) - 39%

2. preterm labour - 6%

3. premature rupture of membranes - 13%

4. intrauterine growth retardation (IUGR) - 5 to 6%

5. pregnancy induced hypertension - 6 to 7%
6. diabetes (insulin dependent diabetic mother - IDDM & gestational diabetes) - 5 to 6%

7. antepartum hemorrhage - 5%

8. other significant antepartum complication (includes twins, triplets, renal disease, urinary tract infections and many others) - 19%

Antepartum conditions are randomly assigned by functions which depend on a mother's previously assigned delivery type and geographical code. The antepartum condition is used in the model to determine transfers and LOS while a mother is in the antepartum subsection of the hospital (see next section for clarification of the antepartum subsection). In addition the AP condition controls the destination of the initial transfer into Grace for all mothers except those who have either come as day of surgery patients or postpartum only patients.

4.1.4 Postpartum Complications

The following is a list of postpartum (PP) complications. A PP complication includes hemorrhages, infections, and other significant complications. 10 to 11% of patients who deliver have some PP complication. But, the percentage varies by delivery type. With instrumental and emergency C-sections having the highest rates.

1. spontaneous delivery without PP complication - 54%

2. spontaneous delivery with PP complication - 4.5%

3. instrumental delivery without PP complication - 12.5%

4. instrumental delivery with PP complication - 2.5%

5. elective C-section without PP complication - 9%
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6. elective C-section with PP complication - 1%

7. emergency C-section without PP complication - 12.5%

8. emergency C-section with PP complication - 2.5%

9. postpartum only - 2%

A mother’s PP category controls her transfers from and in the PP subsection, and her LOS in the PP subsection (see next section for a clarification of PP section). The PP category is determined by using the delivery type and randomly choosing a percentage of mothers to have some PP complication. The number of mothers in the PP-only category was too small to divide according to the presence or absence of a PP complication.

4.2 Classification of Babies

There are five categories of babies used in the model.

1. less than 2500 grams birthweight - 5%

2. greater than 2500 grams birthweight and less than 37 weeks gestational age - 10%

3. greater than 2500 grams birthweight and greater than 37 weeks gestational age - 79%

4. short stay (less than 2 hours in Grace) due to transfer to Children’s Hospital - 4%

5. pediatric (i.e. not a newborn, returning baby previously discharged from Grace) - 2%

A baby’s classification is a function of their mother’s AP category, and controls all the transfers and length of stays of that baby in the hospital. Twins and triplets are
assigned a category taking into account the lower birthweight of most multiple birth babies. Short stay is a special category that had to be included for very sick babies since they are immediately transferred to Sick Children's Nursery in Children's Hospital (located next to Grace).

4.3 Physical Divisions and Overflow Procedures

The physical divisions and overflow procedures used in the model resemble Grace Hospital as much as was feasible without going into unnecessary detail. Overflow refers to the situation of patient demand outstripping the resources of the simulated hospital. In most cases, the different areas in Grace have policies reflecting what occurs if a new patient requires care but there is no more space available. The overflow procedures were determined through interviews of hospital staff. There are three different overflow strategies used at Grace. A patient may go to an alternative location where they can receive similar care (HIGH and PAR use this strategy). Patients may temporarily stay in an overflow area, moving to the desired location as soon as possible (used in LOW and PP). Finally, as a last resort, overflows may cause the patient who has the least time remaining in the full area to be moved prematurely to their next location (used in LOW, HIGH, PAR, and PP). This bumping is rare in the regular operation of the hospital. If bumping increases significantly the model will still run, but patient services deteriorate. Patients may no longer be staying in their desired locations long enough to receive the care they need.

4.3.1 Antepartum modules

There are two antepartum modules: Holly with 26 beds, and Dogwood with up to 16 beds. Antepartum patients are first placed in Holly. Any additional patients arriving
take up as much room in Dogwood as required, displacing a PP patient in Dogwood to another PP module if necessary. If both Holly and Dogwood are full with AP patients (a rare occurrence), new AP patients are put in Evergreen, again displacing PP patients to another PP module if needed.

4.3.2 Low Risk

Low risk consists of two separate areas in the model: low risk delivery area with 11 rooms, and the assessment area (ASESS) with 4 rooms. If the 11 rooms in low risk are full, patients are put in one of the assessment rooms temporarily until a low risk room is free. If both low risk and the assessment rooms are full a new patient is temporarily placed in the PAR. If low risk, AESS, and PAR are full when a new patient arrives the patient presently in low risk who has the least time remaining will be prematurely moved to their next location.

4.3.3 High Risk

The model groups all the high risk beds together with the intensive care beds for a total of 8 places in high risk. If all the high risk beds are occupied a new patient will be sent to low risk instead. If both high risk and low risk are full when a new patient arrives the patient presently in high risk who has the least time remaining will be prematurely moved to their next location, thus freeing up a spot for the new patient.

4.3.4 Operating Rooms

As in the Grace, the model has 3 operating rooms. There is no overflow area for the OR, but all non emergency procedures (including all antepartum and postpartum OR visits, and non emergency deliveries) are delayed if there are fewer than 2 ORs free. Any
delayed surgical patient waits in their present location until enough ORs are free.

4.3.5 Post Anaesthetic Recovery Room

The post anaesthetic recovery area has 4 beds. Overflow from the PAR goes to high risk if possible. If high risk is also full the patient with the least time remaining in the PAR is prematurely moved to their next destination.

4.3.6 Postpartum Modules

Postpartum consists of 6 individual modules (Arbutus, Balsam, Cedar, Dogwood, Evergreen, Fir) with 15 or 16 beds each, and a 6 bed treatment room called TREAT (in the hospital each module has a treatment bed). Overflow from the PP modules is rerouted to TREAT. Patients stay in TREAT only until a bed becomes free in the PP modules. If the PP modules and TREAT are full, the next scheduled to leave is prematurely sent to their next destination thus freeing up a bed in the PP modules.

4.3.7 Observation Nursery

The observation nursery (OBN) has 10 bassinets. Babies arriving to find the OBN full cause the baby with the shortest time remaining to be prematurely sent to its next location.

4.3.8 Low Risk Nursery, High Risk Nursery, Postpartum Nursery

The low risk nursery (LRN), and the high risk nursery (HRN) are very flexible in terms of the number of babies they can accommodate. In the model they have places for 11 and 8 babies respectively (the same as low risk and high risk delivery areas). The postpartum nursery (PPN) is similar: it is divided into six different nurseries (one for
each PP module) with 15 or 16 bassinets each. LRN, HRN, and PPN have no overflow procedures because they are never totally full. Babies stay in LRN and HRN for only short periods of time, and the PPN has the flexibility to add more bassinets if it becomes busy.

4.4 Logical Division of Grace in the Model

The simulation model divides Grace into three logical units: antepartum (AP), the delivery suite (DS), and postpartum (PP). This is similar to the physical division of Grace, but some additional distinctions are made to account for differences in LOS between patients in different phases of maternity. Low risk and high risk are logically divided into low/high risk for deliveries and low/high risk moving next to antepartum. In addition it was necessary to logically partition the OR and PAR depending on whether a mother is delivering, moving next to the antepartum subsection, or proceeding to postpartum. This logical partition means a mother’s stay in low/high risk or the OR or PAR uses the same facilities and overflow procedures but the LOS and transfers are governed by a different criterion. For example, a mother entering low risk from the antepartum subsection (perhaps for false labour, i.e. she will not delivery this stay), has her LOS and subsequent transfer controlled by her AP classification. On the other hand, patients entering low risk to deliver have their LOS and transfer controlled by their delivery type.

All transfer and LOS functions were created empirically from the data gathered at Grace. This way both the transfers and LOS functions could reflect some very rare events simply by assigning them a low probability. Many of the LOS distributions could have been successfully approximated by a normal curve, but the normal distribution would have had to be truncated at the low end (since LOS cannot be negative). Thus for simplicity and uniformness all functions were created empirically.
4.4.1 Antepartum section

The antepartum subsection in the model consists of the antepartum modules (Holly and Dogwood) and the delivery suite areas APLOW, APHIGH, APOR, and APPAR for patients returning to one of the AP modules (see Figure 4.2). In the AP modules transfers and LOS are controlled mainly by a patient’s AP classification. A distinction is also made between patients who will deliver before being discharged and AP-only patients because these two groups have markedly different transfers and LOS times. AP-only patients are discharged to home from the AP section whereas mothers who will deliver must pass through the delivery suite and postpartum before leaving the hospital. In addition, because undelivered mothers are often in the AP subsection at an earlier gestational age than mothers who will deliver, undelivered mothers tend to have a longer LOS in the AP section.

Patients in the AP subsection but not in an AP module (i.e. in APLOW, APHIGH,
APOR, or APPAR) have their transfers and LOS controlled solely by their AP complication. No distinction is made between delivered and undelivered because transfers are similar by definition (transfer must always return patient to the AP module before leaving the AP subsection), and LOS is very similar.

Transfers from AP modules are normally governed by their AP category, but if a transfer is to the delivery suite then the exact location in the delivery suite is determined by a mother’s delivery type (see Figure 4.6).

4.4.2 Delivery Suite

The delivery suite (DS) consists of low risk (LOW), high risk (HIGH), the operating rooms (OR), the post anaesthetic recovery room (PAR), and day of surgery (DOS) beds in postpartum for mothers, and the low risk nursery (LRN), and the high risk nursery (HRN) for babies (see Figure 4.3). DOS patients arrive for scheduled elective C-sections and stay briefly in one of the postpartum modules (Arbutus if it is free) awaiting their surgery. In the DS all the LOS and transfer functions for adults are determined solely by a patient’s delivery type. Transfers and LOS for babies in the DS are controlled by their health classification.

4.4.3 Postpartum section

The postpartum section (PP) in the model consists of the 6 PP modules (Arbutus, Balsam, Cedar, Dogwood, Evergreen, Fir), the OR and PAR (called PPOR and PPPAR) if there for a PP complication, the 6 nurseries associated with the 6 PP modules (PPN), and the observation nursery (OBN) (see Figure 4.4). The PPOR and PPPAR are mostly used to perform sterilizations, but occasionally a mother returns to the OR after delivering due to some PP complication (eg. hemorrhage). The transfers and LOS for adults in the PP modules are governed by a patient’s PP category. In the PPOR and PPPAR
Figure 4.3: Delivery Suite Showing Patient Flows

Figure 4.4: Postpartum Section with Patient Flows
all transfers are the same, and the LOS is controlled by a single function for all patients since there was not enough data to separate out the different PP categories. Babies in the PP section have their transfers and LOS controlled by their health classification.

4.5 How the Model Runs

This section explains the admissions process, how all transfers and length of stays are determined, and the discharge procedure. For all these tasks, the model uses empirical functions that randomly assign outcomes based on their likelihood of actually occurring at Grace.

4.5.1 Admissions

As discussed earlier, Grace hospital limits the number of patients who arrive to deliver each month to about 625. To simulate this, at the start of each month the model determines how many mothers to be will arrive using a function with a small variance (between 617 and 625 patients per month). This cap on mothers indirectly also limits the number of babies born in Grace per month. However the cap has relatively little effect on the number of patients arriving for undelivered visits (either AP-only or PP-only), since if a patient has been approved to deliver at Grace or has already delivered at Grace and develops a complication she will automatically be admitted, regardless of the number already admitted that month. Similarly, the number of pediatric babies admitted per month can vary significantly. Newborn babies, on the other hand, are admitted when their mother delivers (see next section).

At the start of each month the model determines the number of patients who will arrive to deliver, each patient is assigned a delivery type (spontaneous, instrumental, elective C-section, DOS emergent C-section) and all the patients not in the DOS category
Figure 4.5: The Admissions Process
are assigned a random arrival time in the month. All DOS patients are assigned an arrival time strongly favoring the mornings Monday to Thursday. These patients then wait until their assigned arrival time to enter the hospital. The undelivered AP-only, the undelivered PP-only patients, and the pediatric babies arrive randomly throughout the month, according to an exponential interarrival time function, moving immediately into the hospital. This procedure is shown in Figure 4.5. When a new adult patient enters the model they are assigned a geographical residence, an AP category, and a PP category. The geographical residence is a function of a patient’s delivery type. The AP category is determined by both the delivery type and the geographical residence. And the PP category follows almost directly from the delivery type.

4.5.2 Determining an Adult Patient’s Path Through the Hospital

All the initial transfers of adult patients, except PP-only and DOS patients, into the hospital (from admitting) are either to the antepartum section or to the delivery suite. AP-only patients almost all enter the AP section, whereas only a certain proportion (depending on their AP category) of the patients who will deliver go to the antepartum section. DOS patients proceed directly to a day of surgery bed in PP to wait for their surgery. PP-only patients go directly into the PP modules.

The procedure used to determine a patient’s movements in each of the three areas: antepartum, delivery suite, and postpartum is the same except that in each area a different factor controls all the actions. In the antepartum section actions are controlled by a patient’s AP category and whether or not she will deliver. In the delivery suite all transfers and LOS are governed by the delivery type, and in PP everything is controlled by a patient’s PP category.

Once a patient has moved to a new location her length of stay and next destination are determined randomly assigning probabilities to each event that reflect the empirical
data. She then tries to find a place in the desired location, following the overflow policies set forth in section overflow if necessary. Once the prescribed time has elapsed, the patient moves to her next destination again determining the LOS and next transfer etc. until she is discharged from the hospital.

Babies are born, in the model, when a mother visits an OR while in the DS section (so long as they have not delivered already), or when a mother is in LOW or HIGH risk and will transfer next to PP. Note, the model will not allow C-section patients to transfer to the PP without first visiting the OR to insure that all caesareans occurring in an operating room. In addition, a proportion of all the deliveries result in a stillbirth. In this case, no baby enters the model and the mother will stay her PP LOS in the AP modules so that she does not have to be around other patients who have just delivered healthy babies (this policy is also used at Grace for compassionate reasons).

Since an operating room must always be available for emergencies, all elective surgical procedures will be delayed if fewer than 2 ORs are free. The only elective surgery patients not delayed are those who were prematurely moved out of their previous location due to overcrowding. This exception is allowed only for model simplicity.

4.5.3 Determining a Babies Path Through the Hospital

The logic used to move babies is very similar but simpler than the procedure used for the adults because the babies are classified in only one way. All movements and LOS are controlled by a baby’s health category (see section 4.2). Figure 4.7 is a flow chart showing the logic used to move babies through the model.

4.5.4 Discharges

The majority of patient discharges from Grace occur from the morning to early afternoon. This discharge pattern causes a load peak in the mid-morning since patients arrive more
Figure 4.6: Adult Patient Movement Procedure
Figure 4.7: Baby Movement Procedure
or less uniformly throughout the day and night.

Discharges from Postpartum

To simulate this mid-morning peak in the PP modules the model generates a mother’s PP LOS in a special manner taking into account a patient’s arrival time in the PP section. Since most discharges occur shortly after 10 a.m. this time was used as a starting point. In the PP modules a patient’s LOS is determined by adding together three separate times. First, the difference between the current time of day (in the model) and the next 10 a.m. is calculated. Added to that is the number of days (24 hour periods) the patient has been assigned. Then, so that not all the patients are discharged at 10 a.m., a random amount of time to reflect their actual discharge time is added (not greater than 24 hours, and usually between 0 and 4 hours). Both the number of days, and the additional random time after 10 a.m. are determined from the empirical functions built up from the hospital data. For example, a patient who arrives at 3 a.m., is to stay 3 days, and is to be discharged at 12 noon will be assigned an LOS of $(600 - 180) + (3 \times 1440) + (720 - 600) = 4860$ minutes.

To simulate the flag system at Grace (see section 2.4 for details) the model discharges some patients early from the PP modules if there are less than 15 beds unaccounted for PP. The model will discharge 50% (the rest were deemed to be medically or otherwise unable to be discharged early) of the patients in these last 15 beds starting with the patients who are next to leave normally.

Discharges From All Other Locations

All the other discharges including undelivered mothers from antepartum, all baby discharges, and the occasional patient discharged directly from DS simply follow when a patient’s LOS in that location is finished (i.e. in the model they will tend to occur at
random times). The direct discharges from the DS are small in number and occur randomly throughout the day at Grace as in the model. In the AP modules the model does not stagger the discharge times as in Grace. As a result, the model does not create an mid-morning peak in the AP modules and underestimates the 10:30 census (see validation section). To include this effect in the model would have increased the complexity of the already complex functioning of the AP section and as a result was set aside as a possible future improvement.

Mothers and babies are usually discharged together at Grace. Thus the postpartum nurseries have a mid-morning peak like the postpartum modules. In the model, again for simplicity sake, mothers and babies are treated separately once the baby is born. The PP nurseries were not a pressing bottleneck at Grace and as result the model’s underestimated 10:30 census in PPN was of little consequence.