Hospital Patient Flow Capacity Planning Simulation Model at Vancouver Coastal Health

Amanda Yuen, Hongtu Ernest Wu
Decision Support, Vancouver Coastal Health
Vancouver, BC, Canada

Abstract

In order to address certain operational questions for a hospital, Vancouver Coastal Health built a simulation model that captures the flow of all patients from multiple arrival streams all the way to discharge. For this model, historical data was analyzed to determine arrival rates, transfer rates between units, and processing times within each area of the hospital. Different patient types were created to represent the different needs and journeys of patients through the hospital. The actual inpatient bed capacities and operating room schedules were used, and additional process logic was created to simulate certain system dynamics such as surgical cancellations and the use of overflow capacity. This model helped address questions such as the impact of implementing protected surgical beds and discharging additional patients from certain units.

Keywords
Healthcare Systems, Discrete Event Simulation, Optimization, Resource Planning & Scheduling

1. Background
Similar to many OECD countries, the Canadian healthcare system faces the challenge of improving care while battling the increasing demands and costs associated with the aging population, new medical technologies, HR expenditures, etc. The Canadian healthcare authorities promote innovation to improve sustainability of the healthcare system.

Vancouver Coastal Health (VCH) is one of the five regional health authorities in the province of British Columbia. VCH operates the publicly funded healthcare systems in the cities of Vancouver, Richmond, North Vancouver, etc., covering a total population of over 1 million. Across the healthcare continuum, acute facilities or the hospitals bear the highest costs. The number of funded beds in the VCH hospitals has remained largely unchanged in the past 15 years. The hospitals are under constant pressure to serve the increasing demand using existing acute beds, and the fixed funding associated with the beds. Access and flow therefore becomes the top operational challenges that VCH hospitals face. Since 2015, the VCH Senior Executive Team introduced the concept of “Bed Gap” to operational management in order to raise awareness of the gap between fixed acute capacity and the demand on acute beds that are over the capacity, and the demand is increasing over time.

Lions Gate Hospital (LGH) is located in the city of North Vancouver. It is an acute site consisting of an Emergency Department (ED), Operation Rooms (OR), medical, surgical, maternity, cardiac, neurological, acute rehabilitation, palliative, and mental health inpatient units, and outpatient clinics. LGH has 255 funded acute beds, but the total inpatient census is usually between 275 and 290. Since 2009, ED visits have been increasing at an average of 4-5% annually. LGH management has worked on various improvement projects to effectively plan discharges, reduce non-value-added waiting time for the patients, and make capacity available for incoming patients.

To incentivize hospitals on patient access and flow, the provincial Ministry of Health and VCH founded Pay-for-Performance (P4P) programs. A small portion of the funding is withheld from the hospitals, and the hospitals need to meet targets on certain metrics to gain this portion of the funding back. Among other care quality and safety metrics, the access and flow metrics that LGH strives to work on are:

- ED 10hrs: The percentage of admitted patients who wait for less than 10 hours need to be above 55%
- Surgical waiting time: Patient wait time for non-emergent surgeries should be below certain targets

- Long Length-of-Stay (LLOS): The number of patients and their inpatient days staying in hospital for over 30 days need to be below certain targets
- Total census: The annual average daily acute census needs to be below the previous year's average

The P4P funding accounts for 2.2% of the total funding for LGH. However, with the tight overall budget, this 2.2% is critical for the hospital to "stay afloat" financially therefore achieving P4P targets is high priority for the hospital management. The P4P metrics are designed in such a way that there are trade-offs between them. For example, opening unfunded beds help the ED 10hr and surgical waiting time metrics but negatively impact the total census and likely the LLOS metrics. Due to the complicated inflow, outflow, and internal transfers between units, the decisions involved with managing beds and facilitating discharges in certain units may not have the intended outcomes. It is also challenging to estimate the quantitative impacts on P4P metrics. To this end, the hospital-wide patient flow simulation model is a powerful decision support tool for LGH management.

2. Business Problem

The intention of developing the simulation model was to quantify the impact on P4P metrics. After the first draft of the model was developed in SIMIO and presented to hospital management, the operational leaders saw the value of the model and started using the model for various projects and initiatives. These initiatives included:

2.1 Communicating the impact of discharge planning

Conceptually, the frontline care team and staff members understand the pressure of access and flow. They may not necessarily understand the difference that their daily work could make. Is it worth the effort to discharge one more patient in a day? Does it even make a difference? Showing the cumulative impacts of the improvements on discharges can inspire and motivate the frontline care team because they can see the actual impact of their efforts.

2.2 Protecting surgical beds

One standing patient flow challenge faced by LGH is "off-service" demand, i.e., beds are occupied by patients whose required care is different from the unit. This issue is particularly challenging for the surgical units, where a portion of surgical beds are occupied by non-surgical patients (mostly medical patients). This is caused by a higher demand of medical patients admitted through ED and the medical units are usually full.

Medical patients staying in surgical beds pose care and safety challenges because the skills of the care team and supplies in the surgical units may not be well-equipped to provide care for these patients. When a higher number of surgical beds are occupied and the units are full, it impacts the downstream flow of surgical patients from the OR. Under more challenging circumstances, the hospital may need to cancel scheduled surgeries, adding to the already long surgical wait times. On the other hand, if the surgical units are "protected" only for surgical patients, the hospital would lose the flexibility of moving admitted patients from ED, adding to the already long ED wait times. Since ED wait times, surgical wait times, and the total hospital census are part of the P4P program, performance in these areas affects funding received by LGH. The hospital management would like to find an optimal number of surgical beds protected for surgical patients only, in order to achieve overall best results for patient flow, quality and safety, and the P4P results.

3. Model Development

3.1 Data Sources

The scope of the simulation model includes all operating areas of LGH, which uses different data systems to record emergency department visits, acute inpatient stays, and operating room procedures. We extracted and analyzed historical data from these sources for the full 2015 calendar year. The analysis provided model data inputs such as patient arrival rates, patient types, transfer rates between different units, and length of stays in each area.

The model uses an hourly arrival schedule to closely approximate the demand for ED in reality, which varies by hour of day and day of week. Average hourly arrivals for each day of the week are entered into the model, which randomly generates inter-arrival times using the exponential distribution over the course of the simulation. Hourly arrival schedules are derived for 5 different arrival streams:

1) Patients who arrive at ED and are admitted into inpatient units.

2) Patients who arrive at ED and are not admitted into inpatient units.
3) Non-surgical patients who are directly admitted into inpatient units.
4) Surgical patients who are admitted into inpatient units.
5) Surgical patients who are not admitted into inpatient units (daycare surgeries).

Upon creation, model entities (patients) are assigned patient types based on their point of origin. For patients who originate from one of the 3 admitted streams, they are also assigned patient specialties and the acute unit that they will be admitted into based on historical probabilities.

Once patients are admitted into inpatient units, certain patients may be likely to transfer to another inpatient unit before the end of their hospital stay. Using historical data, we determined which units are most likely to see transfers to and from other units and assigned probabilities to simulate the movement between units in the model. For example, of all the patients who are admitted into ICU, 23.5% have transferred into a medical unit, 18.7% have transferred into a surgical unit, 17.6% have transferred into a cardiac unit, 12.3% have transferred into a neurology unit, 1.4% have transferred into a palliative unit, and the remainder were directly discharged from ICU.

We also used the historical data to derive the amount of time that patients spend in each inpatient unit. Using data analysis, distributions based on historical length of stays were determined for each unit and entered into the model, which randomly generates patient length of stays in each unit as the simulation runs. The LOS distributions by unit:

Table 1: Length of Stay Data for Inpatient Units

Inpatient Unit	**Time Unit**	**Mean**	**Std Dev**	**Distribution**
Cardiac	Days	6.06	7.88	1 + Random.Exponential(5.07)
ICU	Days	8.16	11.2	1 + Random.Exponential(7.16)
Maternity	Days	2.29	1.8	0.5 + Random.Gamma(1.72,1.04)
Medicine	Days	13.4	17.4	1 + 142 * Random.Beta(0.44, 4.32)
Mental Health	Days	13.5	19.6	1 + Random.Exponential(12.5)
Nursery	Days	2.82	3.91	0.5 + Random.Lognormal(0.3,0.91)
Neurology	Days	8.4	14	1 + 178 * Random.Beta(0.398, 7.78)
Palliative	Days	8.21	8.64	0.5 + Random.Exponential(7.71)
Pediatrics	Days	2.79	4.27	0.5 + Random.Lognormal(0.15, 1)
Surgery	Days	6.45	9.56	1 + 160 * Random.Beta(0.529,17.4)

To determine the length of stays in the emergency department, operating room, and post-anesthetic recovery areas, we determined distinct distributions based on patient type:

Table 2: Length of Stay Data for ED, OR, PAR

Patient Type	**Area**	**Time Unit**	**Mean**	**Std Dev**	**Distribution**
ED Patient (non-admitted)	ED	Minutes	216	174	8 + Random.Gamma(2.09, 99.5)
ED Patient (admitted)	ED	Minutes	289	221	2 + Random.Gamma(1.93, 148)
	OR	Minutes	103	59.3	Random.Gamma(3.17, 32.5)
	PAR	Minutes	323	420	1 + Random.Exponential(322)
Scheduled Surgical Patient (inpatient)	OR	Minutes	103	59.3	Random.Gamma(3.17, 32.5)
	PAR	Minutes	323	420	1 + Random.Exponential(322)
Scheduled Surgical Patient (daycare)	OR	Minutes	42.7	30	9 + Random.Exponential(33.7)

3.2 Model Structure

As mentioned, the simulation model includes all operating areas of LGH, which encompasses the emergency department, inpatient units, and operating rooms. The emergency department accepts patients coming in from arrival streams #1 and #2. These patients spend a certain amount of time in ED (randomly determined by the distributions in Table 2) before moving on. The admitted patients continue onto a reception area in the model where they wait for a bed to become available in their destination unit, while the non-admitted patients leave the system. A process is built into the model to reflect the reality that the longer a patient waits for an inpatient bed, the more likely that they will be discharged directly from ED. Based on historical data, we created the following algorithm: the patient has a 15% chance of being directly discharged from ED if they have been waiting between 1.5-2 days, 30% chance if they have been waiting between 2-3 days, and a 40% chance if they have been waiting more than 3 days. In order to simplify the model, the inpatient units are grouped as follows:

Table 3: Inpatient Unit Groupings

Unit Groupings	**Inpatient Units**
Cardiac	2E Med-Post Coronary Care, ECC Enhanced Cardiac Care
ICU	Intensive Care Unit
LD	LD Labor & Delivery
Maternity	3W Maternity
Medicine	4E Acute Medicine, 4W Subacute Medicine, 5E Rehab
Mental Health	MIU Mental Health Inpatient Unit
Neurology	7E Neuroscience, NCU Neuro Critical Care Unit
Nursery	NSY Newborn Nursery, SCN Special Care Nursery
Palliative	7W Palliative Care
Pediatrics	3E Pediatrics, 3PO Pediatric Outpatient Observation
Surgery	6E Surgical, 6W Orthopedics, IPS Inpatient Surgery, SCO Surgical Close Observation

Each unit grouping has a bed capacity, which determines the maximum number of patients that can be in the unit at any given time. When patients enter through ED, through direct admission, or through OR, they will need to wait to be admitted into an inpatient unit if there is no available capacity, just like in reality.

Unlike the inpatient unit bed capacities, which stay constant, the OR bed capacity varies by time of day and day of week to reflect the actual OR slate. Patients enter OR through arrival streams #1, #4, and #5. We also incorporated a process in the model to simulate OR cancellations, which is a real issue for ORs. This process is triggered when the following conditions are met: available capacity in OR and other downstream inpatient units is low, and the number of patients waiting in ED is high. When all conditions are met, patients are placed in a virtual holding area and counted as cancelled cases. When the conditions no longer apply, these patients are placed back in the OR queue.

Another process included in the model involves newborns. In reality, patients are admitted into the Labour & Delivery unit to give birth. Therefore, newborn babies are created in the model when the new mothers exit the unit. The mothers are then transferred to Maternity while the newborns are transferred to Nursery. Newborns are not included in the reported statistics to be consistent with standard reporting practices.

3.3 Validation

The validation process is an important part of the model development and can take even longer than the model building process. Validation involves testing the model to ensure that it simulates the real system as accurately as possible. We examined the model data inputs, compared simulated versus actual metrics, and performed sensitivity analysis to ensure that the model performs as expected.

The model is validated based on the following model outputs:

- Percentage of ED patients admitted within 10 hours
- Average daily census at the facility level
- Number of off-service surgical patients.

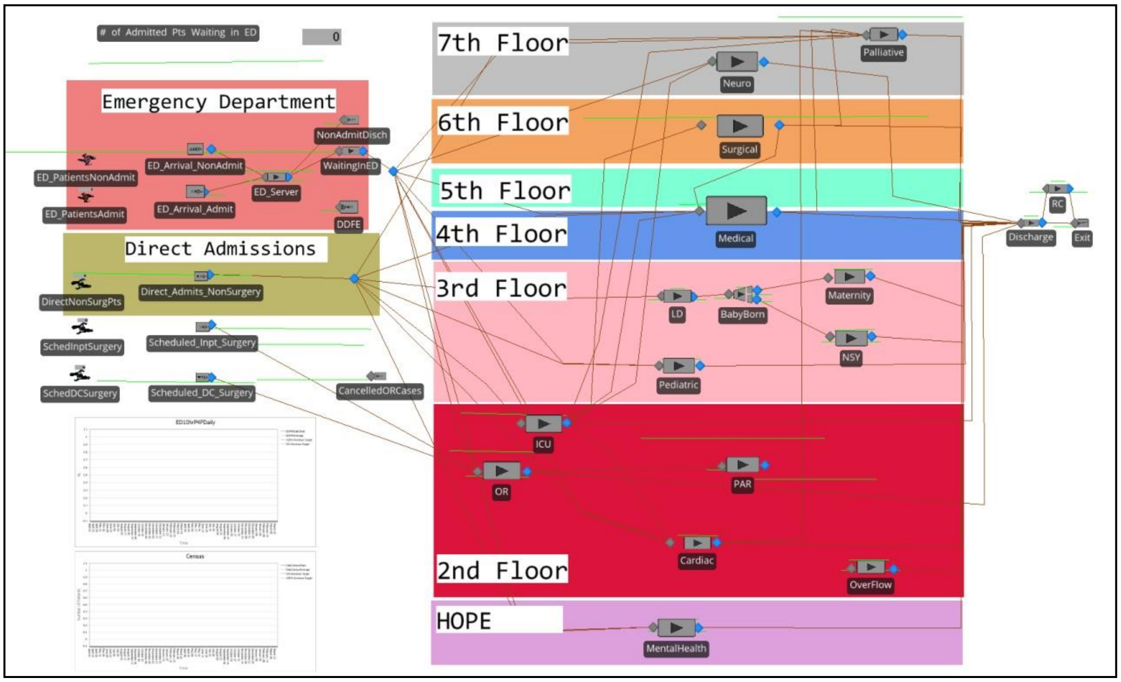

Figure 1: Simulation Model in SIMIO

4. Model Outputs

Returning to the business initiatives described in Section 2, the model was used to generate results that helped provide insights to support decision making. With regards to discharge planning, we approached the problem by asking, what if we target one additional discharge each day? The results confirm that as we achieve more discharges, we can free up more space and therefore improve the flow from ED. The outputs are presented below:

Table 4: Discharge Planning Scenario Results

	Overall Census	**ED 10hr%**
Actual	283	52.2%
Model Baseline	280	52.3%
Model Scenario		
One additional discharge each day at 4E&2E	269	54.5%
Two additional discharge each day at 4E&2E	269	57.0%
One additional discharge each day at 4E,2E,6E,6W&7E	257	61.6%
Two additional discharge each day at 4E,2E,6E,6W&7E	242	67.0%

For the second business initiative described in Section 2, we approached the problem by asking, what if we implement protected surgical beds? Specifically, what is the impact of reserving x number of the total surgical beds for surgical patients only. Here are the results:

Table 5: Protecting Surgical Beds Scenario Results

	ED 10-Hr	**Overall Census**	**# Off-Service Surgical Patients (1 year)**

0 protected beds	45.70%	275	474
35 protected beds	45.30%	276	464
40 protected beds	48.60%	278	487
45 protected beds	48.10%	279	453
50 protected beds	47.70%	277	460
55 protected beds	47.50%	274	365
58 protected beds	46.00%	271	248
60 protected beds	41.50%	264	0

Outputs of the model show protecting 45 beds seems to be a well-balanced decision with regards to the flexibility of patient flow, the right level of care provided by the surgical unit, and the ED and surgical waiting time. Total census and the number of off-service patients are relatively stable till 50+ beds are protected.

The LGH surgical program leaders valued the analysis from the simulation model. They asked for more scenarios to be tested, and outputs are used in their operational decisions.

5. Lessons Learned and Next Steps

It is more intuitive to simulate a flow system with a clear layout and scope, i.e., to replicate the actual physical activities in a specific unit/area. For a larger system such as patient flow through a hospital with 280-300 beds, determining the right level of detail where the simulation model needs to be developed became a critical decision for the project team. It has to be detailed enough to add value to the business challenges by presenting the variances in volume, Length of Stay, and the complicated flow patterns, while being abstract enough so that the development and validation workload is manageable. As an example, the project team went back and forth in deciding the type of patients to be included in the model. The existing clinical patient categories, either at a higher or detailed level, did not work for this model. The project team eventually defined a new patient categorization method that fits the practices at LGH and serves the purpose of bed planning decisions that this model supports. Another lesson learned is the importance of communicating with the business leaders. It is essential to help them understand the model, and the concept of simulation, while managing their expectations on model usage.

Potential next steps are determined by how the model is used to support the strategic priorities of VCH and LGH, including the funding-related improvement programs e.g. P4P. LGH is going through a long-term planning process to determine the capacity in 2035 and beyond. Many scenarios are to be run using this simulation model. ED visits and flow is a highly visible section of the healthcare system. We are also building a detailed simulation model for ED patient flow, using the actual layout and resources such as nurses, physicians, allied health, and lab/diagnostic imaging schedules. The OR is another potential area that could use a detailed model.

6. Conclusion

The Decision Support department at VCH developed a SIMIO simulation model to support patient flow and bed capacity planning. To the best of our knowledge, this model was the only discrete event simulation model in the province of British Columbia that covers all patient flow activities in an entire hospital. It was used to communicate the quantitative impacts of patient flow improvement initiatives to the larger staff members. More importantly, the model runs scenarios to support strategic and operational decisions regarding bed planning. This paper shows one of the decisions supported by the simulation model, how many beds in the surgical unit should be protected for surgical patients only, so that the hospital-wide patient access and flow, and the related P4P program results could be optimized. The model was well received by the hospital management, and will be used and expanded to further support healthcare improvement decisions at LGH and VCH.

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