A Prescriptive Analytics Project For Maximizing Healthcare Value Generation At The Sir Mortimer B. Davis Jewish General Hospital

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Introduction

To maximize the healthcare value it generates, the Sir Mortimer B. Davis Jewish General Hospital investigated the appropriateness of performing hospital enterprise optimization by using a linear programming based analytics model to make decisions about patient inflow into its Emergency Department, its cancer treatment center, and its surgery programs.

To help others benefit from the results of this work, this paper describes the project. It starts by describing the hospital, and the needs the hospital wanted to address with the project. It next discusses how the abstract goal of maximizing healthcare value the hospital generates was translated into a linear programming model. The paper then discusses the data needed for the model, how it was collected, and the issues that arose while trying to collect it. The paper also discusses the potential and realized benefits of the modeling at the hospital level and at the community level, in both government funded and non-government funded healthcare environments. The paper concludes by suggesting future work to further take advantage of the modeling possibilities.

Project Motivation

The Sir Mortimer B. Davis Jewish General Hospital, located in Montreal, Quebec, is a full service university affiliated medical center that operates 537 beds and provides a broad range of inpatient and outpatient services. It has major tertiary and quaternary cardiovascular, neuroscience, oncology (including robotic surgery) and colorectal programs. Its surgeons perform 12,000 - 13,000 operative procedures each year, it admits more than 20,000 patients each year, and the Emergency Department (ED) discussed in this paper was seeing more than 60,000 patients each year before a new ED was opened in February 2014.

To a certain extent, the hospital has become a victim of its own success. That success includes improving flow through its ED to the extent that public knowledge of that improvement resulted in further increasing the flow into the ED, to the point that it has *by far* the largest patient visit rate of any ED in Quebec. Likewise, the hospital's Segal Centre has become so well known for its cancer research and treatment activities that more than half of its patients are from outside the hospital's catchment, even when those patients are otherwise readily treatable in a hospital closer to their homes.

This increase in incoming patient flows has not been matched with corresponding increases in government funding. This has led to the hospital needing and trying to maximize the healthcare value generated with its budget, without decreasing access to care or decreasing its quality of care.

Doing this maximization is challenging, particularly because of the complex interactions between patient flows in the different areas of the hospital, and because of the interactions between those flows and the use of limited hospital resources, including funding. As can be seen in Figure 1, patients flowing into the ED sometimes subsequently flow into inpatient units, and patients flowing into the cancer center sometimes subsequently flow into the OR or into inpatient units. Likewise, patient stays in the ED and the inpatient units lead to the consumption of pharmacy, lab, radiology and nutrition resources, and treatment of cancer patients consumes pharmacy, lab, radiology and radiation oncology resources.

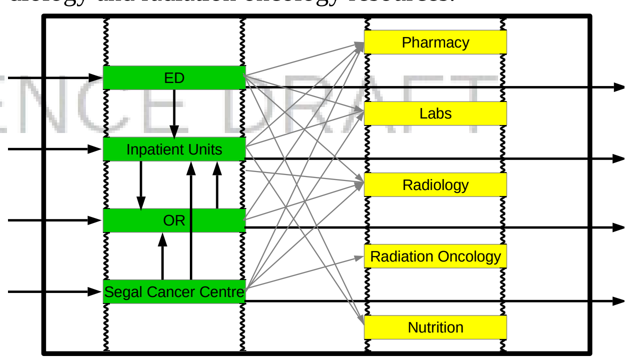

Figure 1 Sample Interactions between flows and resource consumption

To determine if the use of a large scale mathematical model of patient flow and resource consumption could help the hospital increase the healthcare value it generates without decreasing access to care or quality of care, the hospital initiated a proof of concept modeling project staffed by personnel from CGI, River Logic and TroyWare. This modeling effort was needed because the hospital did not otherwise have means to evaluate how patient flows and resource consumption in one area of the hospital would affect patient flow in other areas. The hospital also initiated an analysis/evaluation of all of its programs with respect to their value to community, efficiency, patient orientation, and fit to the hospital's strategic goals.

The Model

Modeling Needs

To address the maximization problem briefly described above, the hospital needed a model that included patient flows into the ED, inpatient units, one day surgery and oncology departments. Because of the interrelatedness of all hospital departments, the model needed to relate incoming patient flows to flows to other parts of the hospital and to resource consumption, including budget, within the hospital. The model also needed to relate flows to healthcare output so as to maximize the healthcare value generated by the hospital. It was decided in advance that the modeling effort would focus on aggregate planning for a one year cycle so that the hospital could use the model to identify tactical rather than operational opportunities.

Modeling Approach

In context of that decision, it was possible to use simple linear constraint equations to approximately model the interrelationships between patient flows in the different areas of the hospital to resource consumption in the hospital. This made it possible to model the problem using a linear programming capability.

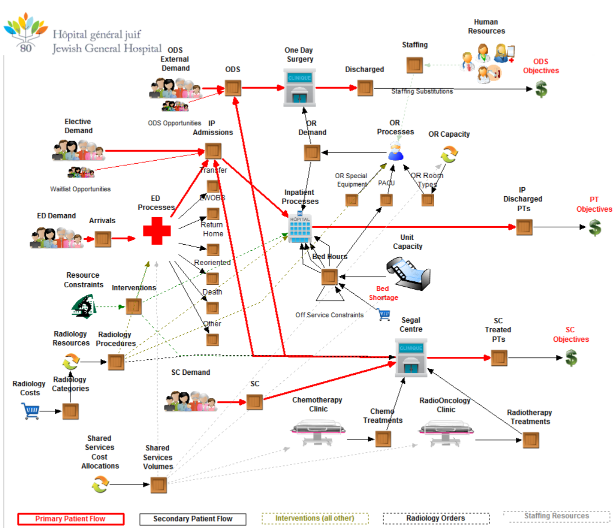

Figure 1 Model EO Diagram

The particular linear programming capability used for the project was River Logic's Enterprise Optimizer (EO). Without getting into the details of EO, one of its capabilities is that it uses a diagram to specify the nature of the relationships between flows and resources, instead of requiring analysts to formulate constraint equations. It then determines the equations, and the data needed to support these equations, from that diagram.

Model Variables

A critical part of building the model to meet the hospital's needs was determining the model's variables. Given that the model was oriented around patient inflows, the values of the decision variables were the quantities of the different groups of patient inflows into the hospital. These different patient inflow groups were determined based on improvement scenarios, found in Table 1, suggested by hospital clinicians. For the ED the resulting patient inflow groups that were used were:

- Divertable Non Admitted Nursing Home Patients (DNANHP)
- Divertable Medical Admission Nursing Home Patients (DMANHP)
- Divertable Segal Centre Patients (DSCP)
- Fast Track Patients (FTP)
- Frequent Flyer Patients (FFP)
- Other Patients (OP)

Scenario	What If Impact on Access, Quality and Cost
Discharge improvement	Can FSA days (waiting for nursing home placement) be reduced? Will LOS be reduced for a specific cohort of patients? Will making beds available reduce blocking in the ED?
Bed Turnover Process Improvement	Will reducing bed turn over time result in increased bed availability? Will beds become available sooner in the day? Will there be a reduction in ED, PACU, OR blocking?
Outreach to Nursing Facilities	Can we reduce admissions in the ED and hospital and keep patients healthier? Will beds become available and reduce blocking of other services?
Outreach for ED "Frequent Fliers"	If we keep FF out of the ED can we reduce hospital admits and keep patients healthier? Will ED load be reduced? Will there be a reduction in blocking?

Table 1 Clinician Suggested Improvement Scenarios

Patient inflows for inpatient units and surgery were grouped by Diagnosis Related Groups (DRGs), while patient inflows for the cancer center were grouped by a combination of their morphology and topography. Both types of grouping were problematic in that inpatient unit inflow groupings should most likely have included severity or co-morbidity classifiers, and the cancer center inpatient flow groupings should most likely have also included more information as to the type of treatment needed, which is often a function of patient genetics rather than just the type of cancer.

Model Objective Functions

Different objective functions were tried. The first of those, used with minimum patient inflow and outflow constraints (to ensure that all patients were fully treated), was to minimize costs. This resulted in the model identifying budget changes that would result from each of the clinician suggested scenarios.

A switch was then made to an objective function that maximized activity volumes, while retaining the budget, patient volume, and quality constraints. To do so, weightings were assigned to additional elective procedure volumes of both day surgery and inpatient surgery patient groupings. These weightings were seen as a proxy for an "access" metric and could be adjusted to meet strategic goals, such as reducing wait times for specific procedures, or preferring procedures that the JGH has a particular skill for. The model was only allowed to choose from volumes of procedures for which there would be demand, either from the current catchment area or by absorbing volume from competing area hospitals.

By treating the objective function this way it became possible to answer the question as to how many additional patients could be treated with the same budget. This demonstrated that the model could be used to demonstrate budget reductions, improvements in access, or a combination of budget reductions and improvements in access.

Model Data

For the parts of the hospital that were modeled, the following types of data were needed by patient grouping:

- Annual volumes
- Processes
- Resources/interventions needed/performed for each process
- Disposition for each group
- Mappings between patient groupings and processes
- Mappings between patient grouping and processes to resources and interventions

For the ED, this necessitated collecting the data for which samples are displayed in tables 2, 3, 4, and 5. For the other areas of the hospital similar tables were needed, though the volume table was only needed for areas through which patients entered the hospital.

To collect the data, a preliminary data requirements document was prepared and used as a starting point for requesting data for a 15 month period spanning January 1, 2013 through March 31, 2014. As the hospital opened a new ED in February, 2014, in most cases only the first 12 months of data was used to ensure a full year's worth of data with the same ED. Data was initially requested and mostly received from the hospital's information management team, though in some cases it was necessary to go to other sources inside the hospital as either that team did not have access to that data, or they did not know how the data was organized.

Several issues arose while collecting the data. The most difficult of these included:

- Difficulty, particularly with cancer patients, determining when treatment episodes began and ended. This difficulty arose because individual patients occasionally had more than one cancer.
- Obtaining meaningful cost data for almost every type of service provided by the hospital as the hospital tracks costs departmentally rather than on an activity basis.
- Getting the appropriate individuals to provide the data.

DNAMHP	DMANHP	DSCP	FT	FF	O	Annual Volume
					x	31239
				x		2642
						36303
				x		1176
						152
				x		31
						30
		x	x	x		5
	x					460
	x			x		51
	x		x			3
	x	x				1
x						989
x				x		164
x			x			81
x			x	x		14

Table 2 Sample ED Arrival Rates By Patient Visit Groupings

DNANHP					
DMANHP					
DSCP	x	x	x	x	x
FT					x
FF				x	
O					
Area	POD	RAZ	Resuscitation	POD	FastTrack
Yield	95.0%	1.5%	3.5%	100.0%	100.0%
Mean LOS	18.7	3.8	27.2	18.8	4.6
Mean Nursing Hrs	4.7	0.8	13.6	4.7	0.2
Mean Lab Cost	$0.48	$0.00	$0.00	$0.00	$0.33
Mean Medication	$12.96	$0.00	$76.94	$2.87	$0.00
Admitted	22.1%	0.0%	71.4%	13.9%	0.0%
Deceased	0.0%	0.0%	0.0%	0.0%	0.0%
LWBS	0.0%	0.0%	0.0%	0.0%	0.0%
Reoriented	0.0%	0.0%	0.0%	0.0%	0.0%
Returned Home	77.9%	100.0%	28.6%	86.1%	100.0%
Transferred	0.0%	0.0%	0.0%	0.0%	0.0%

Table 3 Sample ED Process Characteristics By Patient Visit Groupings And ED Destination (Transposed)

Model Benefits

Immediate Benefits To Hospital

The first and most obvious benefit of the modeling was the ability to determine the extent to which clinician suggested scenarios would impact the hospital. This analysis included an assessment as to whether the data needed to support the scenario was available, whether or not the hospital would be able to implement the scenario, and the impact of the scenario on the hospital. The results of that analysis are displayed in Table 6.

A secondary result of the analysis was identification of the need for off-service beds. Keeping in mind that the analysis was an aggregate analysis across a year, it would have been expected that the need, aggregated across a whole year, to use beds for off-service patients would be relatively low but was instead found to be fairly high. (See Table 7.) Given that the use of off-service beds is likely to increase costs by using more expensive intensive care than needed, or decrease quality of care by using less specialized or less intensive care than needed, this suggests either the hospital reallocate beds to the different services or when possible adjust the number of patients admitted to each service.

Intervention	Cost
CONSULT Asthma Nurse	?
CONSULT Diabetes Nurse	?
CONSULT Discharge Planning Nurse	?
CONSULT Nutrition Support	?
CONSULT Occupational Therapy	?
EXAM Abdominal Series (A/S)	?
EXAM Angio:	?
EXAM Ankle (Stress View)	?
EXAM Barium Swallow	?
EXAM Bladder scan	?
EXAM C.Spine (Cervical) Spine	?
EXAM C/SC	?
EXAM CARDIO (Cardiac Echo) Transthoracic Echocardiogram (TTE)	?
EXAM CARDIO Exercise Stress Test (EST)	?

Table 4 Sample ED Interventions With (Unknown) Costs

DNANHP	DMANHP	DSCP	FT	FF	O	Area	Intervention	Mean / Visit
	x			x		Resuscitation	EXAM CXR (PORTABLE)	1.0
	x					Resuscitation	EXAM CXR (PORTABLE)	0.9
x				x		Resuscitation	EXAM CXR (PORTABLE)	0.7
				x		Resuscitation	EXAM CXR (PORTABLE)	0.6
		x				Resuscitation	EXAM CXR (PORTABLE)	0.6
					x	Resuscitation	EXAM CXR (PORTABLE)	0.5
x		x				POD	CONSULT Physiotherapy	0.5
x						Resuscitation	EXAM CXR (PORTABLE)	0.5
	x					RAZ	CONSULT Physiotherapy	0.3

Table 5 Sample Mean ED Interventions Per Visit By Patient Visit Groupings And ED Destination

Potential Benefits To Hospital

As briefly mentioned earlier, in parallel to the modeling effort, the hospital had simultaneously initiated an analysis/evaluation of all of its programs with respect to their value to the community, their efficiency, their patient orientation, and their fit to the hospital's strategic goals. When completed, the result of that effort is to include a set of scores for each program, which could be used as objective function coefficients for optimizing the model subject to budget and other resource constraints. To facilitate hospital optimization, these scores could be weighted as to their importance, or instead a multi-dimensional efficiency frontier could be determined using them. The potential result of this analysis would be the selection, in a process very similar to that used by Data Envelopment Analysis, of programs and program operating levels that would maximize the hospital's outputs subject to its resource and budget constraints.

Program Scenario	Access to Care	Quality of Care	Estimated Savings	Data	Ability to Achieve	Program Impact
Eliminate excessive (>7) FSA days	7 Beds	-40% FSA Bed Days	$1M			
Reducing bed stays by using a discharge planning system	84 Beds	-16% Bed Days	$13M			
Appropriate ED Oncology Orders	0 Beds	-200 CTScans	$10K			
Reducing ED Frequent Flyers	14 Beds	-2000 ED Visits	$3M			
Reducing treatments of out of catchment cancer patients	20 Beds	Treatment nearer home	$18M			
Cancer: Increase Study Patients	4 Beds	Increased study patients	($0.4M)			
Cancer: Weekend Drop-Iin Clinic	0 Beds	-100 ED Visits	$0.2M			
Eliminating ed visits of divertable nursing home patients	26 Beds	-500 admissions, -1800 ED visits	$5M			
Earlier PICC Lines	3 Beds	-1100 Bed Days	$0.4M			
Combining FSA reductions & elective procedure increases	1000 Procedures	Earlier surgery	$0			

Table 6 Analysis Results (red – stop, yellow – caution, green - go)

Potential Benefits To The Community

A much greater benefit of using the model could come from extending it to the group of healthcare institutions that would be integrated by a bill currently being discussed by the Quebec government. Given the governing party's majority in the Quebec National Assembly, it is extremely likely that the bill will be passed. When it does it is likely to become possible for the executive director of the integrated set of institutions, which will include the Jewish General Hospital, to specify the levels of each type of service to be performed in each of the institutions. At that time, an extended version of the model could be used to more effectively allocate and balance these services in context of either providing, in a cost effective manner, all health services needed by individuals living in the region's catchment, or of maximizing the healthcare provided to those individuals.

Potential Benefits To For-Profit Healthcare Systems

While the current project applied optimization to a publicly funded healthcare system, the underlying approach used in the modeling effort could also be used for profit oriented healthcare systems, either by strictly maximizing profit, or my maximizing a combination of profit and healthcare provided to those systems' catchments.

Off Unit Patient Bed Usage	Bed Hours Used
4E patients to 4EHC	127,578
4NW patients to 5NW	35,487
5NW patients to 8W	66,844
6W2M patients to 7NW	42,033
7W patients to 8NW	118,824
8NW patients to 6W2M	76,116
3SDU patients to 4NW	25,809
3NW patients to 4NW	12,018
8W patients to 3W	61,225
4EHC patients to UTT	67,423
6NW patients to 8NW	94,562
3W patients to 7W	129,156
6W2M patients to 6N	87,445
2NE patients to 3SDU	47,118
4W patients to 6W2M	16,185

Figure 7 Off Unit Patient Bed Usage

Future Work

During the proof of concept project, several potential actions to enhance application of the model were identified. These include:

- Episode identification - When patients flow into the hospital, they often do so needing care that either started before or after their particular visit to or stay at the hospital. To make more effective decisions using the model it is necessary to accurately identify the whole scope of each episode of care. While doing this would require a centralized episode identification system, in addition to being of use for individual healthcare institutions, such a system would be of even more benefit when optimizing care across integrated institutions.
- Time Driven Activity Based Cost Data. For the current analysis, an analysis similar to that of activity based costing was performed to approximately allocated departmental costs to individual groups of patients. While this provided the project team with initial data for the analysis, a much better approach would be to use Time Driven Activity Based Costing, as it better reflects the actual time needed for each activity, which in turn would identify areas of the hospital where resource utilization is less than reasonable.
- Evaluate the use of more physicians in the ED – In Quebec, physician fees for services in the hospital are paid for directly by the government, rather than by hospitals. As such it is not incentive compatible for ED physicians to work at less than 100% utilization levels as doing so reduces their earnings per hour. Consequently it seems likely that patient stays in the ED are extended because of increased waiting due to high utilization of physicians. This suggests the potential benefit of evaluating the reduction in costs, obtained by the reduction in patient waiting, that would be achieved by the use of more physicians in the ED.
- Improving the grouping of flows into inpatient units to reflect the severity of their diagnoses and the resources required for their care.
- Improving the grouping of cancer patients to better reflect the resources required for their treatment.
- Analysis of the non-linear benefits of reducing patient length of stay in the ED – Particularly for older patients, long length of stays in the ED can result in severely reduced patient mobility as care in the ED is generally not oriented towards keeping these patients mobile. This in turn can result in the need for mobility rehabilitation for those patients after their hospital stays are complete. This suggests the potential benefit of evaluating programs to further reduce the length of stay in the ED of older patients not only in reducing ED costs, but in also reducing the system wide costs, including rehabilitation costs, of those patients.

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Biographical Sketch

Dr. Troy is a quantitative healthcare process and decision support systems consultant for Les Entreprises TroyWare in Montreal, Quebec. He earned a Bachelor of Science degree in Engineering Science and a Master of Science degree in Quantitative Business Analysis at The Pennsylvania State University, and a doctorate in Operations Research from Yale University. His analytical skills include queuing theory, Monte Carlo Simulation (including discrete event simulation), optimization, systems analysis, and software development. Dr. Troy focuses his efforts on analyzing, simulating and making recommendations for improving healthcare processes. Past efforts include an analysis of the surgical beds needed for an Intensive Care Unit, the development of a simulation based optimization model for a proposed presurgery screening clinic, the development (in progress) of an enterprise simulation model of a hospital's peri-operative processes, and the development of a touch screen based data collection tool for a Post Anesthesia Care Unit. Dr. Troy has presented his work at the Winter Simulation Conference, the Mayo Clinic on Systems Engineering and Operations Research in Health Care, the Central Surgical Association, the International Workshop On Healthcare In Operations Management, and the Society For Health Systems Conference; he has also published articles in Surgery and in the Journal of Revenue and Pricing Management.