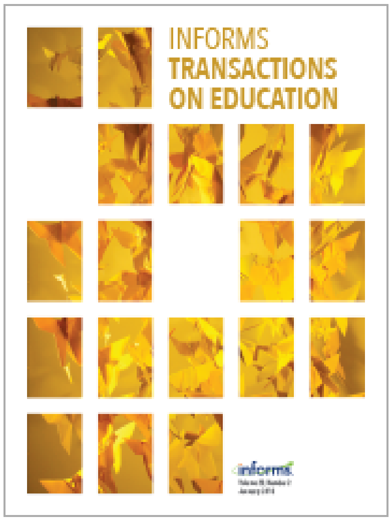

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Teaching the Use of Systems Dynamics for Strategic Decision Making in Healthcare

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Abstract. Having worked in the healthcare system and taught healthcare MBAs for over a decade, we have observed that healthcare systems and departments operate in independent silos. This paper shows how to use systems dynamics as a method to help students examine the big picture of how components fit together to form a system. We demonstrate the application of this approach and provide an example from one of our healthcare professional graduate student teams.

Keywords: systems dynamics • health care • excel modeling

1. Introduction

The healthcare care industry is one of the largest segments of any country's economy. Currently the U.S. healthcare system accounts for 17.4% of the GDP as reported by Centers for Medicare and Medicaid Services (2014). With the constant change in the environment, as well as healthcare policy and law, organizations have an increased need to understand the major cost and operational drivers of the system.

For several decades healthcare organizations have used many operational approaches to reduce overall healthcare costs including Lean, Six Sigma, and Optimization techniques (Koning et al. 2006, Nelson-Peterson and Leppa 2007). While effective, these approaches often provide improvement at a micro level of the organization.

Systems dynamics is a technique that has been used to model large systems. This macro modeling approach can help organizations develop strategic and operational decisions. It is also now being used in modeling aspects of the healthcare system (Hirsch and Homer 2004, Homer and Hirsch 2006, Brailsford 2008).

The use of systems thinking in business classes has become an increasingly important topic. Several authors have presented managerial and simulation tools that help students understand and effectively use systems related tools for decision making (Ritchie-Dunham et al. 2007, Atwater and Pittman 2006). Building on these studies this paper provides a method for teaching the modeling of healthcare systems through systems dynamics to make effective decisions to solve operating problems and to select effective strategies.

2. Teaching Systems Dynamics in a Healthcare MBA Program

2.1. Program Description

Program Structure. Our university offers several healthcare programs including a specialized Healthcare MBA that follows a cohort model, and which brings in a new class every year. Students complete the program in 2.5 years. Towards the end, they take an 8-week course on Healthcare Systems that is taught in a blended format, with 1.5 days on campus and the remainder online. This course is a combination of lecture and computer-based activities. Before this class students have already taken quantitative and qualitative analysis courses including statistics, operations management, management and leadership among others.

Embedded in our Healthcare Systems course is a systems dynamics project. The goal of this project is to provide students with a methodology to analyze complex healthcare systems and insights on how decisions impact system and strategic behaviors. Students analyze current policies, collect data, and then develop models to identify the decisions necessary to effectively apply these policies.

Student Profile. The majority of the students in our program are working healthcare professionals. The breakdown is approximately 50% clinical background including physicians, physician assistants, nurses, and chiropractors. Our students have on average 15 years of work experience and come from a variety of work places including hospitals, insurance companies, nonprofit organizations, wellness related organizations, and medical device manufacturers.

In terms of abilities, students are much stronger in management skills than quantitative skills. Informal surveys in each course indicate that most students have little experience in building Excel models; however, most are familiar with probability from the Introduction to Statistics course. When students take the Healthcare Systems course, virtually none have developed interactive spreadsheet, Monte Carlo or optimization models.

2.2. Classroom Environment

The classroom environment combines lecture and exercises. We adopt a simplified Forrester view of systems dynamics in that it is a technique that aspires to conceptualize and improve the performance of global systems (Forrester 1961). The systems dynamics methodology is a particularly useful approach to engage healthcare professionals as it arises out of a biological paradigm, as discussed by Jackson (2003, p. 5).

> An open system, such as an organism, has to interact with its environment to maintain itself in existence. Open systems take inputs from their environments, transform them, and then return some sort of product back to the environment. They depend on the environment for their existence and adapt in reaction to changes in environments.

In the course, we use four modules to help students learn materials related to systems dynamics and to apply these concepts to the semester long project. Elements of this methodology build on the work of Anderson and Johnson (1997) who provide a structure for teaching systems thinking and the creation of causal loop diagrams. Stock and flow diagrams (Meadows et al. 1972) are then created to convert conceptual ideas into more concrete models. Finally, these models are converted into Excel spreadsheets to enable students to conduct "what-if" analyses. The four teaching modules used to illustrate systems dynamics concepts are:

1. Creation of Causal Loops Diagrams with Feedback Loops,
2. Development of the Stock and Flow model,
3. Building an Excel Model, and
4. Scenario Analysis and Decision Making.

Independently, none of these teaching methodologies are new concepts. We use them together to help students conceptualize, formulate, and make system level decisions. Each of these teaching modules is taught over a 3-hour class period. We describe each module in the next sections.

3. Module I: Causal Loops Diagrams with Feedback Loops

The first teaching module is causal loop diagrams and feedback loops. To help students conceptualize causal loop diagrams we adapt Senge's (1990) view of a business system as a series of elements that affect each other over time and that are intended to operate toward a common purpose. The conceptual model that provides students with a framework to construct the initial causal loop diagram is based on Forrester's original research in systems dynamics (Forrester 1961). This seminal work was one of the first attempts to model complex business systems mathematically and graphically using computer models to improve performance.

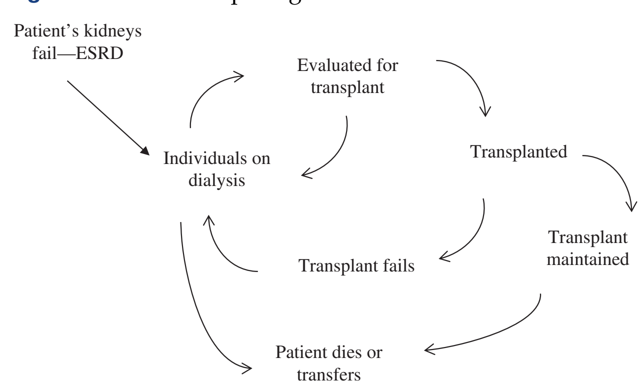
Causal loop diagrams are graphical depictions of conceptual models. They help students understand the business or environmental systems in which their organizations operate. The causal loop diagram has two primary components, i.e., elements and edges. Elements represent the variables that are analyzed for overall system performance. Similar to arcs in network diagrams, edges are the links that represent connections between the variables in the model. These connections can indicate a positive or negative relationship between two variables.

Figure 1 is an example of a causal loop diagram of a system for the care of patients with End-Stage Renal Disease (ESRD). ESRD patients lose kidney function and must be maintained on dialysis or receive a kidney transplant; even after receiving a transplant the organ may fail and the patient returns to dialysis. The causal loop diagram helps students develop a higher level view of how the variables in ESRD systems are related. The first step in teaching systems dynamics is getting students to understand the complexity of the environment: Causal loop diagrams achieve this through a simple graphical format.

3.1. Feedback Loops

We introduce feedback loops after the causal loops are created. Feedback loops are created when changes in the status of an element affect the behavior of other elements. Effective feedback loops include time delays as well as the elements impacted. For example, Figure 2 shows the ESRD diagram redrawn to show the impact of a new, more effective immune-suppressive drug for

Figure 1. Causal Loop Diagram of Patients with ESRD



transplant patients. Transplant patients return to dialysis when their transplants fail due to rejection by the body. Because of the efficacy of this new drug, the system now has a time delay in the flow of patients from transplant back to dialysis. The time delay, if not recognized, could create unnecessary expenditures due to new capacity created at the dialysis center that is now not needed.

Healthcare systems are rife with time delays in feedback loops such as reimbursement cycles and drug interventions that have tremendous impact on overall system measurement. The addition of these feedback loops help students to understand the time sensitive nature of decisions.

When causal loop diagrams are introduced to the classroom it is important to stress conceptual/macro thought. Anecdotally we have observed that many students struggle to understand the large economic principles that drive their business. Most students, especially those with a technical background, focus only on detailed micro level analysis of the organization. For example, a healthcare system might have a strategic goal of reducing overall costs related to chronic pain. Many students with technical or financial backgrounds will focus on balance sheet and income statement activity to reduce costs. A causal loop diagram of the chronic pain situation may reveal a significant issue such as inappropriate use of emergency services by chronic pain patients that leads to inflated costs. These issues would not be easily detected by examining the financial statements of the organization. We revisit this setting in Section 7.

4. Stock and Flow Models

Although the causal loop diagrams with feedback loops graphically illustrate global healthcare issues, the lack of data and measurement limits the insights that stock and flow models provide. These models help students transition from a conceptual model to decision making (Sterman 2000, Chapter 6).

Causal loop diagrams are conceptual in nature and use macro level variables: This makes it difficult to create an Excel model. Specifically, the causal loop diagrams are missing the measurement of input and output variables and the relationship between those two variables over time.

Stock and flow models share some similarities with other flowchart methods such as process maps and network diagrams. They are similar in that they demonstrate flow and loops in the system. They differ in that their focus is entirely on macro level flow and not on micro level analysis, which would include decision points and quality control.

4.1. ESRD Stock and Flow Diagram

The stock and flow diagram depicts the movement of entities in the system. Figure 3 shows a simplified stock and flow model of ESRD patients (corresponding to the Figure 2 causal loop diagram, with the delays removed for simplicity). The model below has four parts:

1. Patients develop ESRD;
2. Patients are maintained on dialysis or immediately receive a kidney transplant;
3. Some patients on dialysis will also receive kidney transplants; and
4. Transplanted patients and those on dialysis occasionally leave the system through death or transfer to another provider system.

In this model, the entities in the system are patients. Stock and flow models have valves (analogous to water valves) that control the flow of entities between stocks. These valves are the rules or policies that dictate flow in the system. The entities then flow between the stocks

Figure 2. Dialysis Patient Population Declines Due to Improvement in Longevity of Transplants Because of More Effective Drugs

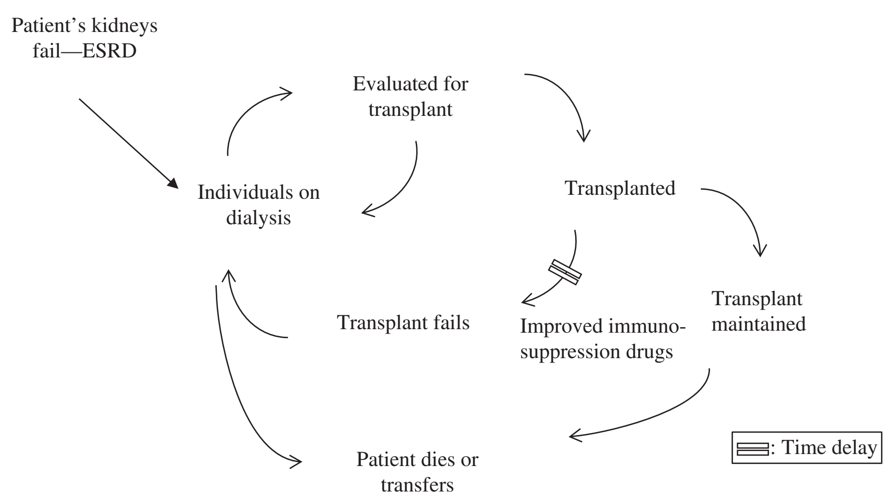
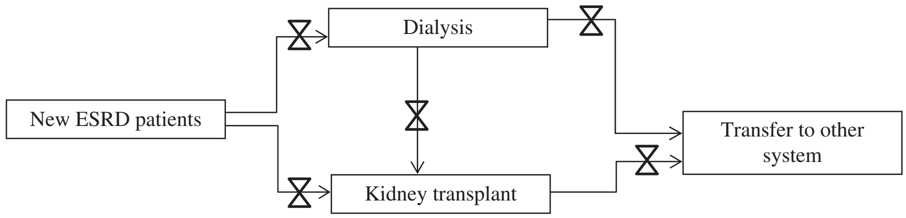


Figure 3. Stock and Flow Diagram of Annual Movement of Patients with ESRD



based on the settings of the valves. Flow is expressed in time intervals to demonstrate how changes in values longitudinally impact other stocks. A critical element of a stock and flow model is that it depicts the overall movement of entities and not the detailed analysis of entity flow. In our experience students often build stock and flow models with unreliable data sources, thus limiting the effectiveness of the model. The data students use to construct the initial stock and flow model should be scrutinized to assure validity before making any decisions from the output of the model.

4.2. Data for Stock and Flow Models

One of the challenges students face in the process of creating their own systems dynamics model is estimating the parameters. In healthcare, most clinical and administrative data are readily available in data warehouses and other computer driven systems. Although not a course objective, many students have had to learn how to retrieve large data sets to calculate model parameters . The exercise of data retrieval often enhances the student's ability to understand the complexities of systems dynamics since data is not often collected for macro level analysis. In addition, a unique feature of stock and flow models in healthcare is that the data used in the models are often a combination of internal and external data. Secondary data are often used to calibrate the model including publicly available databases and data from a review of scientific literature. For example, the detailed data for the model described in Figure 3 can be obtained from recent publications (Patzer et al. 2014, Onuigbo 2013).

5. The Spreadsheet Model

To facilitate decision making the stock and flow models are converted into a spreadsheet model. Spreadsheets have become a widely used technique to teach modeling concepts (Ragsdale 2001, Carraway and Clyman 2000). Students are expected to have basic Excel skills including creating formulas, naming variables, and graphing results. An initial model is created in the computer lab in class to give students an example of how to create a step by step stock and flow model. This model is posted on our learning management system to serve as a template for students as they create their own projects.

Figure 4 is a snapshot of a how we constructed the stock and flow diagram included with this paper. For this example, we use the following data to develop the initial Excel model:

New patients entering the system per year = 70,
percentage of patients to dialysis = 90%,
percentage of patients to transplant = 10%,
percentage of patients from dialysis to transfer = 10%,
percentage of patients from Kidney transplant to transfer = 5%, and
percentage of patients from dialysis to transplant = 5%.

Figure 4 shows the Excel worksheet for the ESRD stock and flow model described by the stock and flow model created in Figure 3. It includes the performance over time graph generated by the spreadsheet. Figure 5 shows the formula's view of a portion of the spreadsheet. It is important for students to understand that not all of the data for these models originate from internal data warehouses. Because some of the data is external to the organization it may not correspond exactly to the system being analyzed. In healthcare this often is a difficult reality for clinical students to grasp since their educational background focuses on perfect data. Students must understand that the goal of systems dynamics modeling is to enhance appreciation of larger system behavior, not build perfect models.

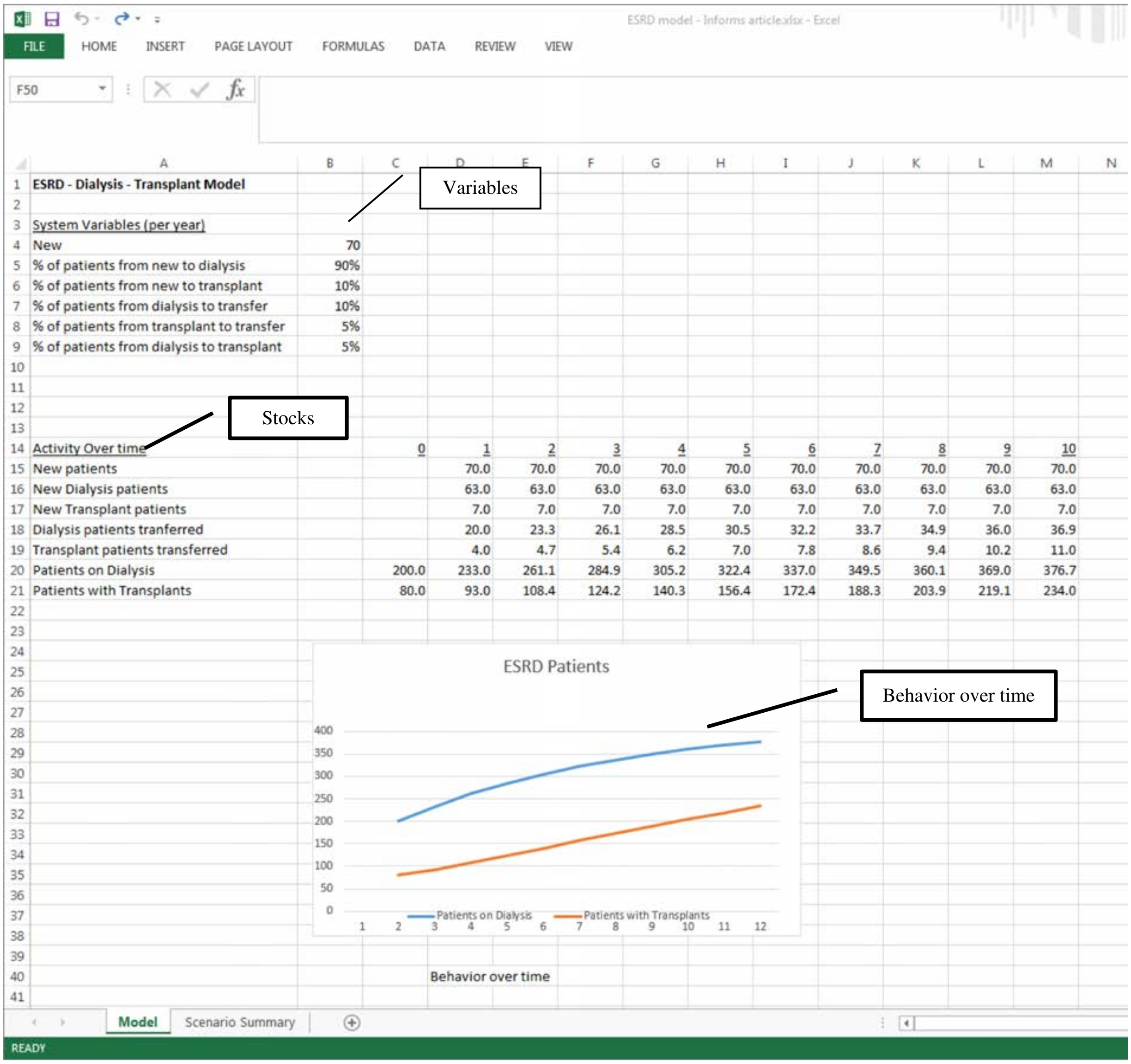
When developing the spreadsheet model, examining the impact of the variables over time helps guide the students to consider large scale practical decisions such as expanding or opening a new clinic to handle a projected increase in demand. At this point, the students have moved from the conceptual level of causal loops to a specific probability- based model that provides a platform for real world decision making.

6. Scenario Analysis and Decision Making

To facilitate better decisions, students use the model to construct "what-if" scenarios. One of the best tools to outline the impact of these different situations is the scenario manager in Excel Markham and Palocsay (2006).

For example, assume that the local affiliate of the National Kidney Foundation ran an extensive media campaign that increased the availability of donated organs. The model could now be run with higher rates of transplant, which would reduce the occupancy of

Figure 4. ESRD Stock and Flow Model Converted Into an Excel Worksheet



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	ESRD - Dialysis - Transplant Model												
3	System Variables (per year)												
4	New	70											
5	% of patients from new to dialysis	90%											
6	% of patients from new to transplant	10%											
7	% of patients from dialysis to transfer	10%											
8	% of patients from transplant to transfer	5%											
9	% of patients from dialysis to transplant	5%											
14	Activity Over time		0	1	2	3	4	5	6	7	8	9	10
15	New patients			70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
16	New Dialysis patients			63.0	63.0	63.0	63.0	63.0	63.0	63.0	63.0	63.0	63.0
17	New Transplant patients			7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
18	Dialysis patients tranferred			20.0	23.3	26.1	28.5	30.5	32.2	33.7	34.9	36.0	36.9
19	Transplant patients transferred			4.0	4.7	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.0
20	Patients on Dialysis		200.0	233.0	261.1	284.9	305.2	322.4	337.0	349.5	360.1	369.0	376.7
21	Patients with Transplants		80.0	93.0	108.4	124.2	140.3	156.4	172.4	188.3	203.9	219.1	234.0

the dialysis center (Figure 6). Although the impact on patients in this example is positive, it can have significant negative financial consequences for the dialysis center, which may be forced to adjust its strategy from an expansion mode to stable operation.

7. Student Example—Chronic Pain Management

A good example from one of our student teams was a project to model the treatment of patients with chronic pain in a regional healthcare system in Minnesota. From the project:

> Historically, most people visit their primary care provider looking for effective relief and care of their chronic pain and related symptoms. Few patients have access to the coordinated interdisciplinary therapy that is needed to effectively treat their ongoing pain symptoms. Unfortunately, most patients find themselves in an endless cycle of seeing multiple health care specialists in an uncoordinated attempt to deal with their challenging issues. These chronic pain patients end up with unnecessary trips to the emergency department, more hospital admission, and longer hospital stays.
>
> Fortunately new approaches have been developed and this project's model includes methods to decrease unnecessary utilization by utilizing health care coaches, enrollment in the Medical Home where their condition and medication management can be coordinated and identification of these patients early so the care they receive is coordinated and effective from the start.

Figure 7 shows the stock and flow model that the team developed of this new system.

The system parameters were calibrated with data from the healthcare system's electronic health records and two journal articles (Gore et al. 2012, Mashari et al. 2012).

Figure 5. Excel Worksheet for the ESRD Stock and Flow Model (Formula's View)

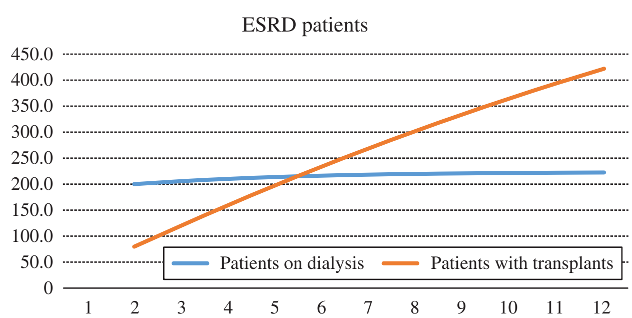
	A	B	C	D	E
1	**ESRD - Dialysis - Transplant Model**				
2					
3	System Variables (per year)				
4	New	70			
5	% of patients from new to dialysis	0.9			
6	% of patients from new to transplant	0.1			
7	% of patients from dialysis to transfer	0.1			
8	% of patients from transplant to transfer	0.05			
9	% of patients from dialysis to transplant	0.05			
10					
11					
12					
13					
14	Activity Over time		0	=C14+1	=D14+1
15	New patients			=New	=New
16	New Dialysis patients			=D15*NtoD	=E15*NtoD
17	New Transplant patients			=D15*NtoT	=E15*NtoT
18	Dialysis patients tranferred			=C20*DtoX	=D20*DtoX
19	Transplant patients transferred			=C21*TtoX	=D21*TtoX
20	Patients on Dialysis		200	=C20+D16-D18-(C20*DtoT)	=D20+E16-E18-(D20*DtoT)
21	Patients with Transplants		80	=C21+D17-D19+(C20*DtoT)	=D21+E17-E19+(E20*DtoT)
22					

Note the negative feedback loop of patients who are not effectively served and who recycle into the Emergency Department. This is a major driver of system performance. However, if the system performs as expected, the team's spreadsheet model predicts a net patient care cost reduction of $1.729 M per year.

Dr. Matthias (2015), who is the Vice President of Medical Affairs of the St. Cloud Hospital (a part of CentraCare) was part of the student team. He provided this overview of the impact of the project:

> We decided to create this model due to our hospital's concern about the overuse of emergency services by patients with chronic pain. Of the top 100 frequent users of our Emergency Department 37 were pain patients. To address this issue our team developed a stock and flow model of patient flow. It was calibrated with data from our Electronic Health Record and a review of the medical literature. This model has enabled us to understand the operating issues in our current system and to simulate new and more beneficial methods to manage patient flow for these patients. We are currently in the process of developing the alternative pain treatment clinic which will be a key component of the full model once it becomes operational.

Figure 6. ESRD Performance Over Time Graph Based on Increased Organ Availability (New Patient to Transplant = 20%, Percent of Patients from Dialysis to Transplant = 15%)



8. Conclusion

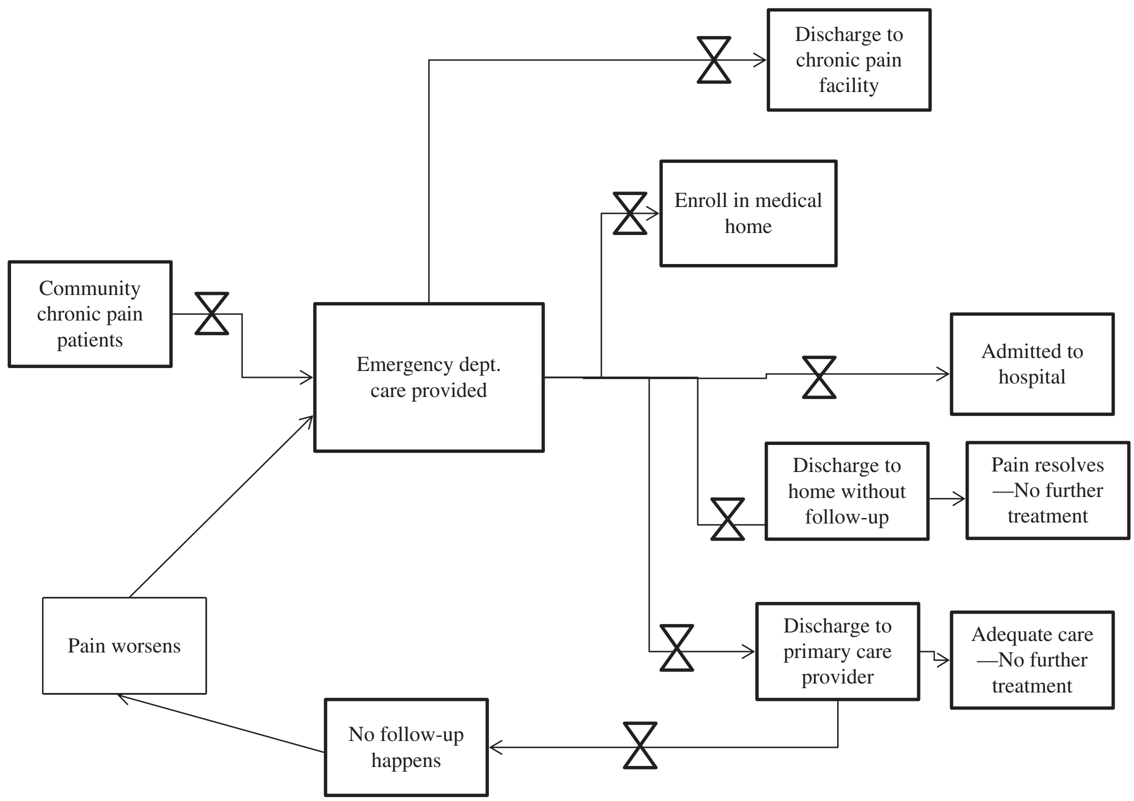
Teaching effective decision making using systems dynamics presents a number of challenges:

- Some students have difficulty conceptualizing systems at the highest level (e.g., Causal Loops).
- Students enter the class with varied levels of Excel skills; it is difficult to remedy this shortcoming during the class.
- Students are creating real projects with data from their workplaces; data acquisition and data quality are difficult for some students.
- Students with a medical background will focus on obtaining perfect data.
- Once a model is built and calibrated, manipulation of the key variables may not provide scenarios that can be used for practical decision making.

Our experience indicates that most of these problems can be resolved by team interactions and strong support from the instructors.

Integrated systems that operate in silos leads to decisions that are often suboptimal. Systems dynamics is a powerful conceptual and modeling tool that can be used by healthcare management students to understand the many complex interactions of elements in

Figure 7. Student Project—Stock and Flow Model of Chronic Pain Management



the system. The combination of real data and systems dynamics provides students with a much broader viewpoint from which to identify and solve problems and helps them to develop new strategies to improve the healthcare system.

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