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

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Abstract

Because healthcare systems are increasingly complex, a valuable skill for students in healthcare management is the ability to model aspects of systems elements in order to make strategic decisions. We have used the systems dynamics approach to first conceptualize and then develop quantitative models to support strategic decisions by our students. This paper demonstrates the application of this approach and an example from one of our healthcare professional graduate student teams.

1. Introduction

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

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

Systems dynamics is a technique that has been used to model large systems. This macro modelling approach can help organizations develop both strategic and operational decisions. It has also begun to be used in modeling aspects of the healthcare system (Hirsch, Gary B, Homer, Jack 2004, 2006; Brailsford, Sally C 2008)

This paper provides a method for teaching the modeling of healthcare systems through systems dynamics to make effective decisions in order to both solve operating problems and to select effective strategies.

2. Teaching Systems Dynamics Modeling

2.1 Course Description and Environment

Our university has several programs in the healthcare area including a specialized Healthcare MBA program. The program is a cohort model that brings in a new class every year. The typical students in our program are working healthcare professionals of which approximately 30% are physicians. Within the degree program students take this 3 credit course in Healthcare Systems which has a current health care topic as its focus such as quality or financing. Students analyze current policies, collect data and then develop models to identify the decision necessary to effectively apply these policies.

Embedded within the course is a systems dynamics project that is aimed at helping students understand the impact of choices on system behavior. The course therefore has two major components: The healthcare topic itself and the use of systems dynamics to make effective decisions related to this topic. Because the course comes at the back end of the MBA curriculum students will already had a statistics course. The course is taught in 8 weeks in a blended format (1.5 days on campus, the remainder on line.)

2.2. The Approach

Systems Dynamics is a technique that aspires to conceptualize and improve the performance of systems overall (Forrester 1954). The Systems Dynamics methodology is a particularly useful approach to engage healthcare professionals as it arises out of a biological paradigm.

> "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." (Jackson, 2003)

We have developed a five step approach to teaching systems dynamics to our students. This methodology builds on the work of Anderson and Johnson (Anderson, 1997) who provide a structure to teach systems thinking and the creation of causal loop diagrams. We have connected this methodology to stock and flow models (Meadows, 2008) which are then converted into Excel spreadsheets. The five teaching modules are as follows:

1. Creation of Causal Loops Diagrams
2. Development of the Flow model
3. Building a Computer Model
4. Calibration of the Model
5. Simulation for Results

None of these teaching methodologies independently are new concepts. Our approach is to use these concepts together to help individuals conceptualize, formulate and make strategic level decisions.

3. Causal loops diagrams

Senge (1990) would describe a business system as a series of elements that affect each other over time and are intended to operate toward a common purpose. Causal loop diagrams are graphical depictions that help students think strategically about their business systems or environmental systems in which their businesses operate. The causal loop diagram consists of two primary components: elements and edges. Elements represent the variables that are being analyzed for overall system performance. Edges are the links that represent a connection or a relationship between the variables in the model. Within the model, elements are linked with positive and negative relationships.

Figure 1 is a causal loop diagram which describes a system for the care of patients with End Stage Renal Disease. ESRD patients lose their kidney function and must either be maintained on dialysis or receive a kidney transplant. Even after receiving a transplant the organ may fail and the patient returns to dialysis. Most ESRD providers have a stable system as described in Figure 1.

This causal loop diagram is considered balanced as it continuously is “self- regulating and self-correcting itself” (Senge, 1994) in order to provide the needed services to its patients.

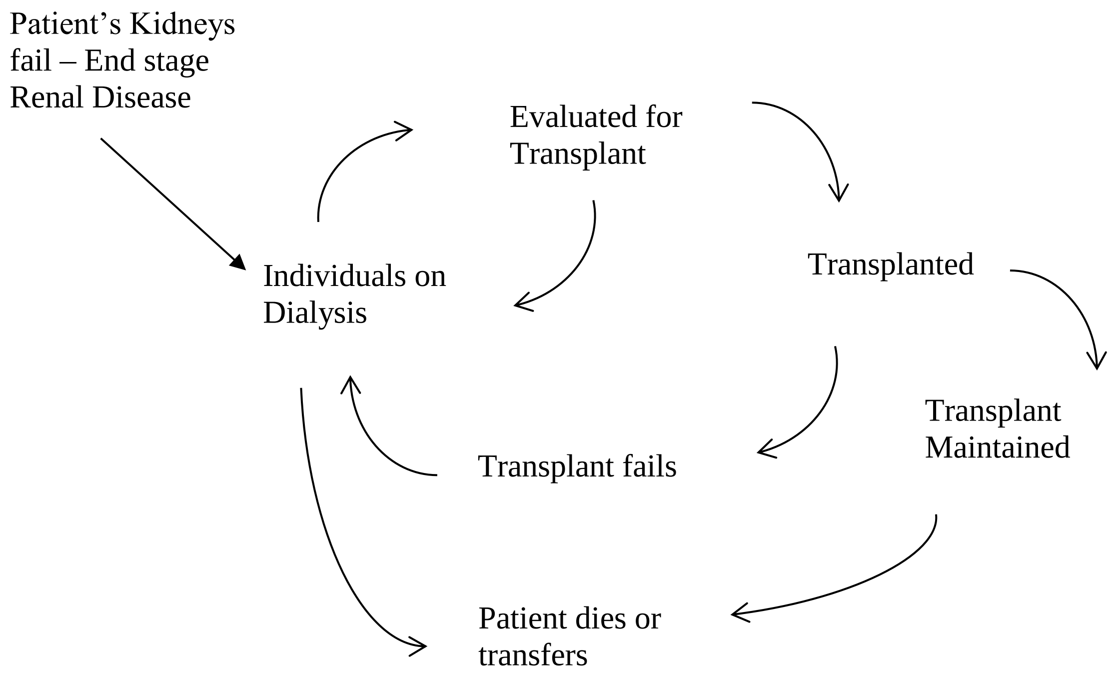


Figure 1 Patients with End Stage Renal Disease

3.1 Feedback

Causal loop diagrams also include feedback loops which influence the operations of the system. A feedback loop is formed when changes in status of an element affects the behavior of other elements. Time delays in feedback loops can cause problems in a system. For example in the ESRD diagram in Figure 2 consider the implementation of a new, more effective, immune-suppressive drug for 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 (Figure 2) now has a time delay in the flow of patients from transplant back to dialysis. It may take 6 months to a year for the ESRD provider to realize that they their dialysis population is not growing as fast as projected and they may have built too much capacity and will soon be out of balance.

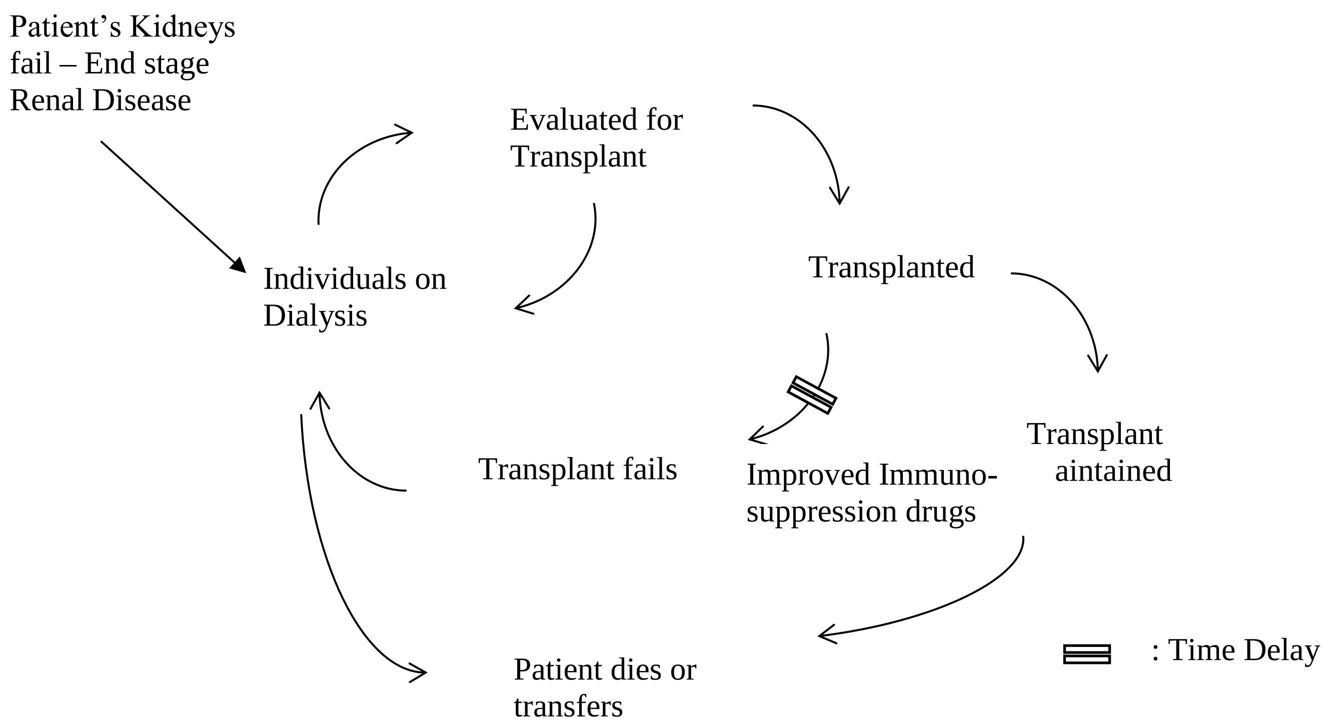


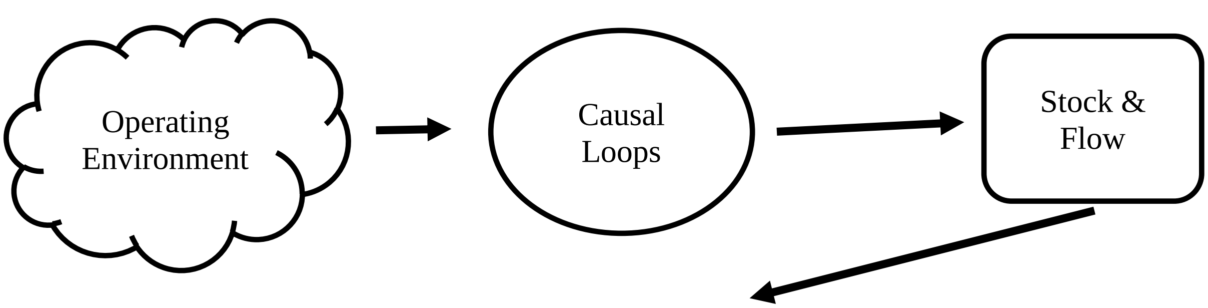
Figure 2. Dialysis patient population declines due to improvement in longevity of transplants because of more effective drugs

When teaching this material our approach is to provide an explanation of the impact of system elements in the creation of a causal loop diagram. Students are then formed into teams and instructed to create causal loop diagrams for contemporary health policy initiatives or predominant operating issues in the healthcare system.

3.2 Causal Loops - From Micro to Macro

When teaching systems dynamics it is important to stress conceptual/macro thought in the classroom. Our observation is that many students struggle with understanding the large economic principles that drive their business. The focus of most students, especially those with a technical background, is to only look at detailed micro level analysis of the organization. For example, a health system might have a strategic goal of reducing overall costs. Most of the students with technical background will focus primarily on balance sheet and income statement activity. A causal loop diagram that originates from an issue found in the balanced scorecard can reveal a significant issue such as the inappropriate use of emergency services by chronic pain patients. One of our student teams undertook this modeling and it is summarized at the conclusion of this article.

The causal loop diagram is the first step on the journey to effective decisions making. Figure 3 shows the progression of these tools. Each tool is described in the remainder of this article.



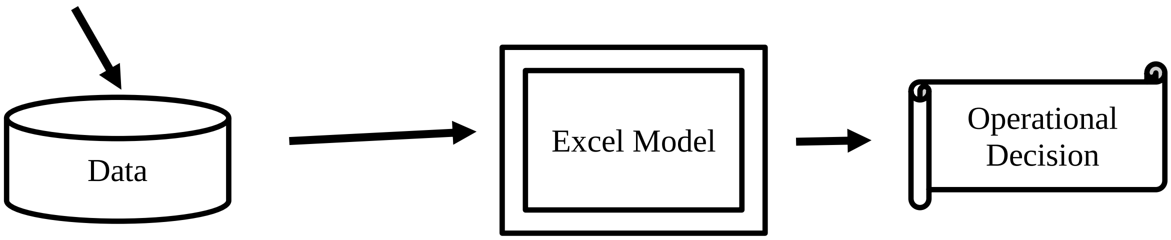


Figure 3 The Use of Systems Dynamics Tools to move from conceptual concepts to practical decision making

4. Stock and flow models

The next step in developing system dynamics models is to develop a stock and flow model based on the causal loop diagram (Sterman 2000, Chapter 6).

Since causal loop diagrams focus on strategic thought they are conceptual and cannot be directly converted to an Excel model as they are missing two key components:

- Variables that effect the performance of the system
- The outcomes of the system performance over time.

The stock and flow diagram is the formal exposition of the causal loop diagram which can now be converted into an Excel model and be used for decision making.

Although stock and flow models share some similarities to other flowcharting methods they contain attributes not commonly found in process maps:

- the value of one stock in the model can influence the performance of another stock in the model
- Time delays are included in the model and affect system performance over time.

4.1 ESRD Stock and Flow diagram

The intention of the stock and flow diagram is to depict the movement of entities in the system. Figure 4 shows a simplified stock and flow model of patients who develop End Stage Renal Disease.[1] The model below contains four parts:

1. Patients develop End Stage Renal Disease,
2. Patients are either 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 either death or transfer to another provider system.

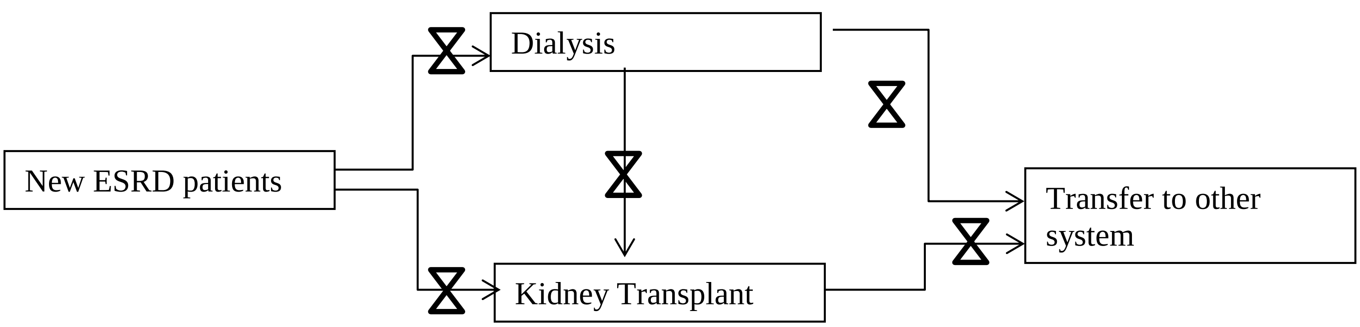


Figure 4. Stock and Flow diagram of annual movement of patients with End Stage Renal Disease

In this model the entity in the system are patients. Stock and flow models have valves (analogous to water valves) that control of the flow of entities between stocks. The entities then flow between the stocks based on the settings of the valves. Flow in these models is always

[1] No delays are included in this model (as shown in figure 2) in order provide a concise example.

expressed in time intervals. A critical element of a stock and flow model is that that it depicts the overall movement of entities and not the detailed analysis of entity flow.

4.2 Data for Stock and Flow models

One of the challenges students have in the process of creating their own systems dynamics model is calculating the parameters that initialize the system. In healthcare, most clinical and administrative data are readily available in data warehouses and other computer driven systems. Although not a learning objective of our course many students have had to learn how to retrieve large data sets to calculate the parameters of the model. The exercise of data retrieval often enhances the student's ability to understand the complexities of system 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 publically available databases and data from a review of scientific literature. Since medical practice is based on the use of scientific data, these sources are readily accepted. For example, the detailed data for the model described in Figure 3 can be obtained from recent publications (Patzer, Plantinga, Krisher and Pastan 2014, Onuigbo 2013).

5. The Excel model

Spreadsheets have become a widely used technique to teach modelling concepts (Ragsdale 2000, Caraway and Clyman 2000). To facilitate better decisions and illustrate impact we develop an Excel model in class.

We expect our students in this class to have basic Excel skills. This include creating forumulas, naming variables, and graphing results. We use the computer lab to work step by step to create a Excel model of the stock and flow model we put together in class. This model is posted on our learning management system (BlackBoard) to serve as a template for students as they create their own projects.

We can illustrate this concept using the stock and flow diagram in figure 4. For this example we use the following data in development of the initial Excel model:

New patients entering the system per year = 70

% of patients to dialysis = 90%

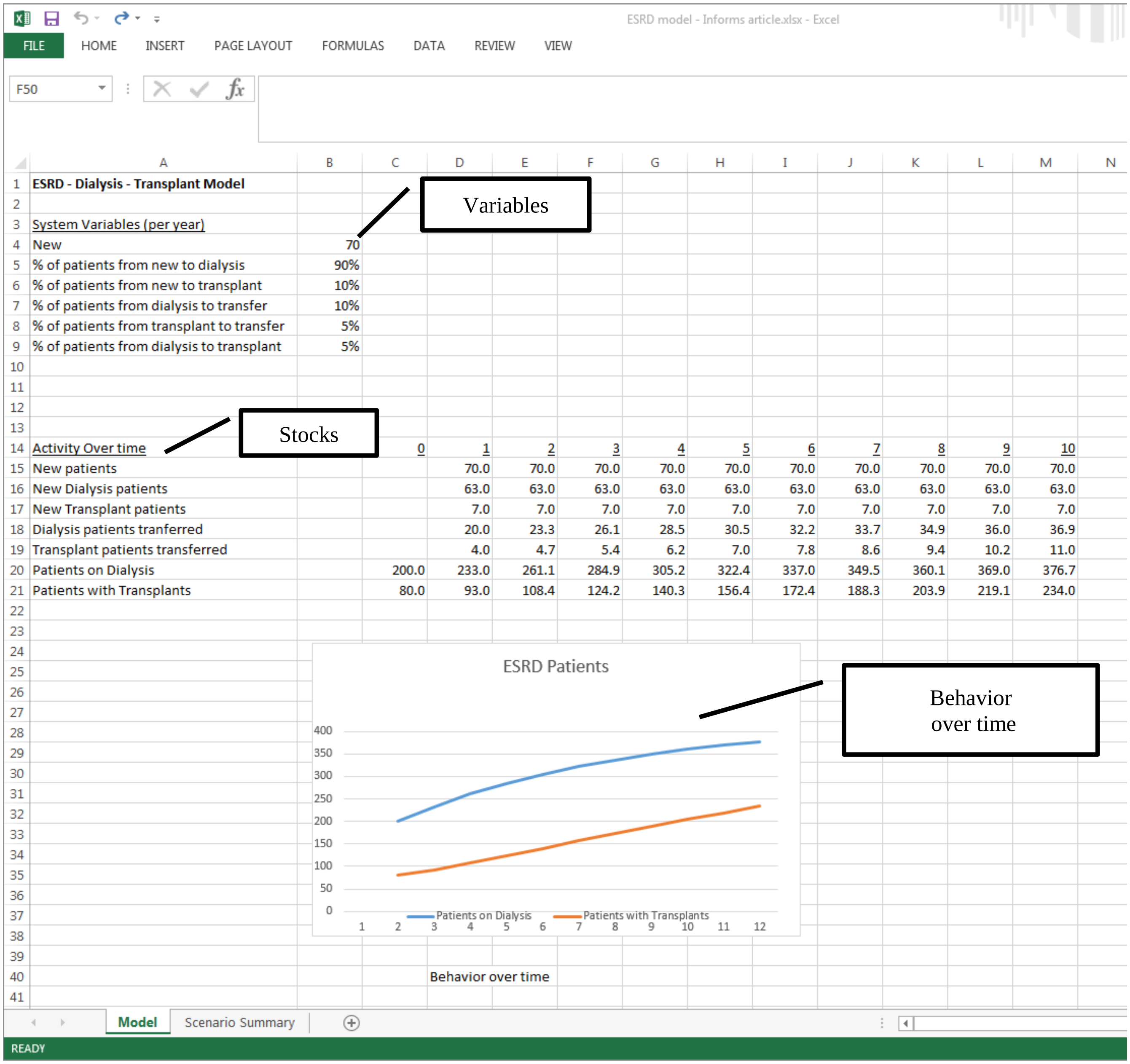
% of patients to transplant = 10%

% of patients from dialysis to transfer = 10%

% of patients from Kidney transplant to transfer = 5%

% of patients from dialysis to transplant =5%

Figure 5 shows the Excel worksheet for the ESRD stock and flow model described by figure 4.



ESRD model - Informs article.xlsx - Excel

	A	B
1	**ESRD - Dialysis - Transplant Model**	
2		
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%

	A	C	D	E	F	G	H	I	J	K	L	M
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

Figure 5. Excel worksheet for the ESRD stock and flow model

It is critical when developing the spreadsheet in figure 4 to stress to students the concepts of examining the impact of the variables over time because the systems dynamic models are designed to facilitate larger strategic decisions. These time based decisions help 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 in the process the students have moved from the conceptual level of causal loops to a specific mathematical model which provides a platform for real world decision making

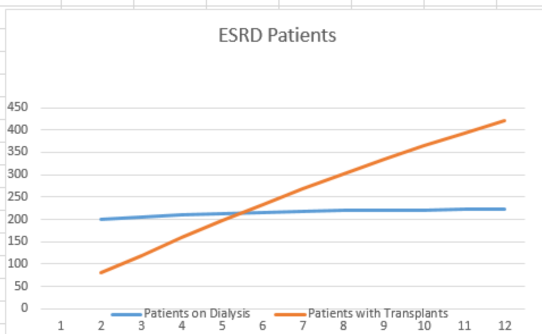
6. Scenario Analysis and Decision Making

To facilitate better decisions, students construct "what-if" scenarios using the model. 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 which increased the availability of donated organs. The model could be now run with higher rates of transplant which would consequently reduce the population of the dialysis center (figure 5.) The impact to patients in this example is positive, however, it can have significant negative financial consequences for the dialysis center. This impact may force the dialysis center to adjust its strategy from an expansion mode to a stable operation.

Two other concepts that could be used to facilitate better decision making in this case would be the concepts of conditional probability and monte carlo simulation. We use the spreadsheet to highlight the concept of conditional probability in class and discuss the use of Monte Carlo simulation. These concepts are covered in more detail in our statistics and decision making courses.

ESRD - Dialysis - Transplant Model												
System Variables (per year)												
New	70											
% of patients from new to dialysis	80%											
% of patients from new to transplant	20%											
% of patients from dialysis to transfer	10%											
% of patients from transplant to transfer	5%											
% of patients from dialysis to transplant	15%											
Activity Over time		0	1	2	3	4	5	6	7	8	9	10
New patients			70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
New Dialysis patients			56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0
New Transplant patients			14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Dialysis patients tranferred			20.0	20.6	21.1	21.4	21.6	21.8	22.0	22.1	22.2	22.2
Transplant patients transferred			4.0	6.0	8.0	9.9	11.7	13.5	15.1	16.7	18.3	19.7
Patients on Dialysis		200.0	206.0	210.5	213.9	216.4	218.3	219.7	220.8	221.6	222.2	222.6
Patients with Transplants		80.0	120.0	159.6	197.7	234.3	269.3	302.8	334.8	365.3	394.3	422.0



Behavior over time

Figure 5. ESRD model with increased organ availability (new patient to transplant = 20%, percent of patients from dialysis to transplant = 15%)

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.

The team developed a stock and flow model of this new system – Figure 6

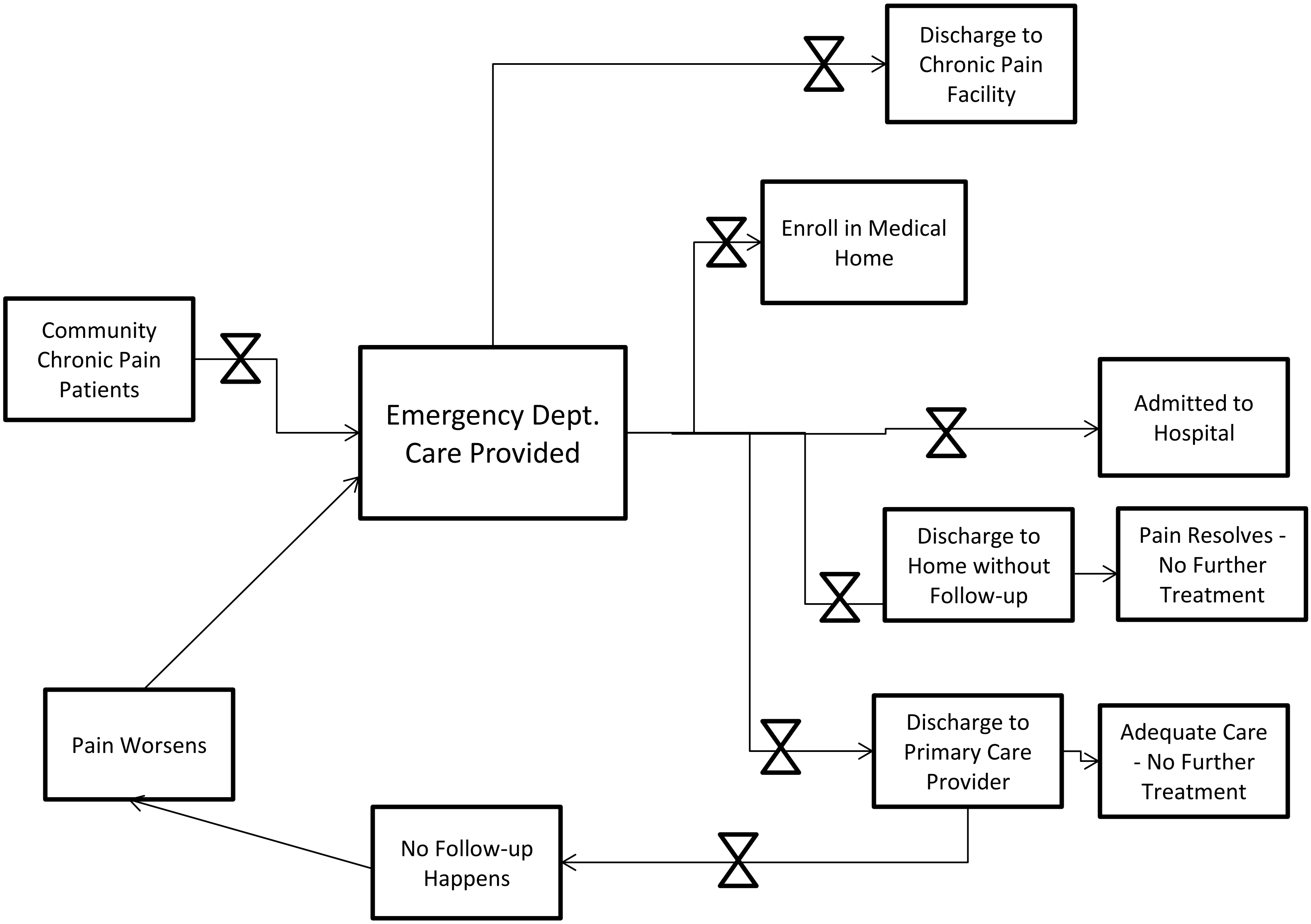


Figure 6. Student Project - Stock and Flow model of Chronic Pain Management

The system parameters were calibrated with data from the healthcare system's electronic health records and two journal articles (Gore, Sadosky, Stacey, Tai, and Leslie 2012; Mashari R Minty, L. Minty, Hopman, and Kelly 2012)

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

Dr. Matthias, who is the Vice President of Medical Affairs of the St. Cloud Hospital (a part of CentraCare) was a part of the team of Healthcare MBA students who created this systems dynamics model. 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"

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 skill with Excel and it is difficult to remedy this shortcoming during the class

- Because students are creating real projects with data from their workplaces, data acquisition and data quality is difficult for some students
- Once a model is built and calibrated the manipulation of the 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.

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 the system. We believe it could be used more widely in the curriculum of programs in health administration as large operational databases are now becoming available, We encourage other instructors to refine this well tested approach. The combination of big data and systems dynamics provides students with a much broader viewpoint from which to identify and solve problems and to develop new strategies to improve the healthcare system.

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