USING SYSTEM DYNAMICS TO IMPROVE COORDINATION BETWEEN HOSPITAL UNITS

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ABSTRACT

Hospitals are complex systems that can be represented as networks of interacting units called "services". A model of hospital emergency room patients is used to analyze bed utilization and the backlog in emergencies using a system dynamics tool. It shows how the organizational boundary creates a lack of coordination among services. The simulation model presented uses a gaming interface to compare policies and their effects. The results show that medical service decision makers indirectly control emergency backlog problems. The study shows that solutions that do not require organizational change are often ineffective.

Keywords: hospital management, system dynamics, organizational learning, emergency room service.

INTRODUCTION

Hospitals are complex organizations made up of interdependent subsystems for receiving patients, examining, retaining, and treating them. There are numerous pathways along which patients flow through a hospital according to their specific health problem, as well as the current constraints within the subsystems that patients have to pass through (for example, a patient may mean they need an EEG, but the current backlog for EEG implies waiting for three days). This interdependency of services along the patients' pathways is what system dynamics professionals call dynamic complexity: each medical decision affects the context in which many other medical decisions are taken, and the overall implications of a decision are hardly taken into account.

Effectiveness and cost of treating a patient will depend on the availability among the different subsystems at the time of particular need. The total amount of time of treatment will increase when intense use of subsystems results in increased waiting times. Moreover, the structure of responsibilities and incentives may create situations where a physician makes decisions that are locally rational, but they generate adverse consequences in other services. These are often not fully perceived by the physician.

There are organizational frontiers that blind decision makers to the "side effects" that appear in other subsystems (Wolstenholme, 1990). At the same time, decision makers in other subsystems will make choices that are locally rational for them, in order to avoid or overcome these “side effects”. This pattern of decisions takes the form of closed loops that lock in both decision makers. Since these loop structures are extremely common, they be considered as systemic archetypes (Senge et al., 1994). An extended collection of such archetypes has been reduced to four generic archetypes (Wolstenholme, 2003). Many of these have been found in health system and hospitals (Wolstenholme, 2004).

This paper examines how one such structure operates in a hospital environment between the emergency subsystem and one inner medical service, and how system dynamics modeling has been used to improve the situation. This is a typical case where a hospital’s medical service uses beds in ways that are coherent in terms of the service’s inner logic, but create a problem in the emergency service. There are several reasons why the service wishes to use the greatest possible number of its beds at all times. However, there must be “idle” beds in order to receive patients who have been stabilized in the emergency service. If there are no “idle” beds, these patients cannot leave the emergency room to make room for new patients. In terms of decision taking, there is an organizational border (Wolstenholme, 2003) between the “emergency” and the “medical service” although the patient flow cuts across it. System dynamics can be used to negotiate a mutually satisfactory solution.

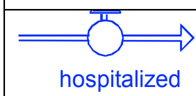
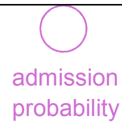
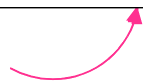
To develop this model, the essential concepts of system dynamics modeling have to be defined. These include notions of feedback loops, of time delays, and the basic characteristics of stock and flow variables. A system dynamics model to allow physicians to explore different strategies to avoid the emergency service problems without creating one for the medical service was designed. This model allows decision makers to formulate different policies concerning the admission and release of patients in the emergency and the medical service. The number of beds that the medical service keeps “idle” is adjustable to evaluate the effect on total waiting for new emergency patients. This model allows the medical service decision maker to examine the effects of their decisions on the emergency service. This presents a typical situation, thus all hospitals can adopt a similar approach to achieve optimal service performance.

INTERVENING IN COMPLEX SITUATIONS WITH SYSTEM DYNAMICS

In their simplest form all systems consist of inputs, processes, and outputs. These are fundamental to operate a productive, goal achieving organization. To comprehend an organization’s system it is necessary to examine the interactions, relationships, and transactions that comprise the substance of the organization’s day-to-day business. These dependent variables are influenced by the behavior of internal and external environmental as well as cultural factors. The structure of the relationships affects the feedback loops and direction of each variable’s interaction. This transforms the composition of other variables and ultimately influences decision-making and policy directions.

The feedback loops and their direction are capable of producing factors that determine growth, stagnation, or decline in an organization’s development. How the feedback is balanced and driven will determine the productivity of the organization. The system dynamics approach focuses on helping decision makers understand how structure drives behavior; it does so using the rigor of simulation and the power of visualization. The system dynamics model is comprised of four components represented by symbols shown in Table 1.

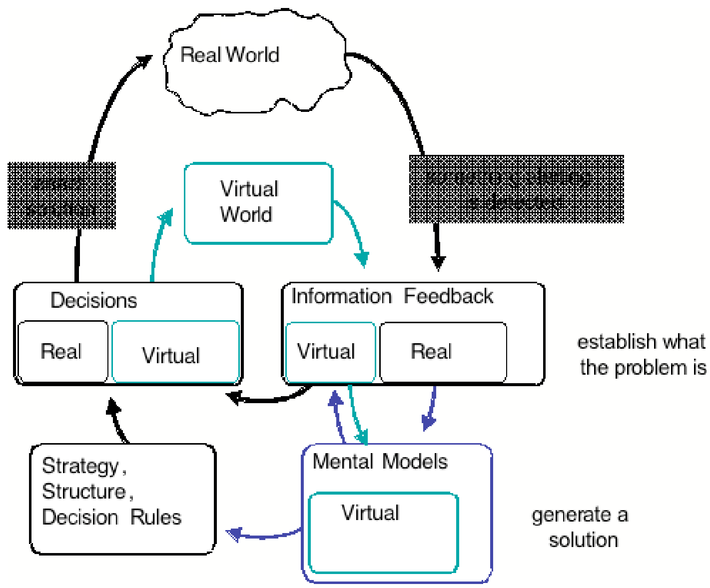
Table 1: Systems dynamics component parts

	"Stocks" are accumulators; they represent an amount of something at a given point in time, for example: available emergency room beds. The entities counted in these stocks are often called "resources".
	"Flows" are what changes stocks during a period of time. For example, hospitalized patients will diminish the number of patients in the emergency room and at the same time increase the number of hospitalized patients.
	"Converters" or "auxiliary variables" allow for indicators and ratios, for example the number of available beds divided by the total number of beds or the admission probability.
	"Information flows" enable us to describe decisions that take into account the values of certain variables.

Decisions are made and enacted to achieve organizational goals and objectives. This process is driven on one level by information feedback. Choices are made with the available information. The actions that come from these changes will modify the situation, which in turn provides new information. On a second level, there are strategies, structures, and decision rules that are applied to available information. These, in turn, are expressions of our experience and knowledge. The formation and transformation of these models is also influenced by available information. However, it is often difficult to learn from experiences in real-time because there are many singular instances of particular cases and long delays, as well as multiple influences, make it difficult to analyze experience.

The underlying cycle of action learning is depicted in Figure 1. It also illustrates the complexity of mental models and virtual models. It depicts the interactions between the components of the system. Examining the interrelationships and response loops that are developed, a decision-maker can highlight the critical areas where management intervention is needed. Understanding how each component interfaces with each other enhances the manager's ability to make more informed and appropriate decisions that fit the problem. The availability of a virtual world to interact is an opportunity to compress time and space and to perform policy experiments. This helps to transform mental models and ultimately allows for better decisions.

Figure 1: modeling and simulating to learn in complex systems
(adapted from Sterman, 2000, p. 45)

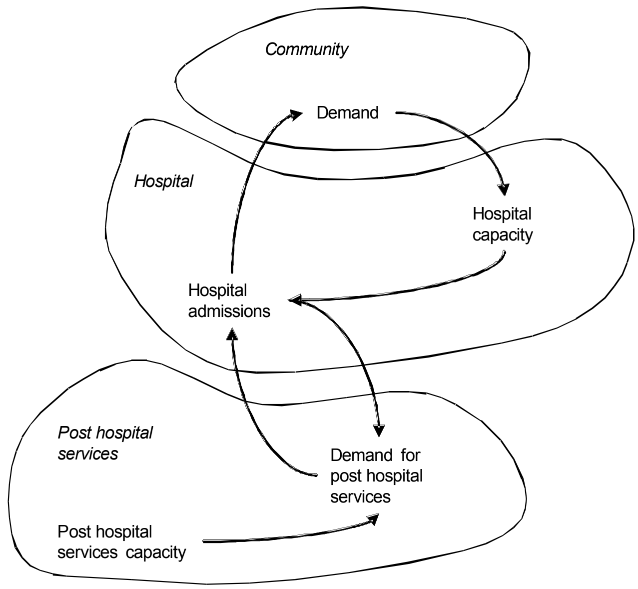


Organizations constantly interact with the internal and external environments. There is a need to identify problem areas and develop appropriate strategies to resolve problems that are detected, or strengthen the areas that are identified as weak. (iThink Manual, p. 1-10)

Managing any type of organization requires a multi-dimensional perspective. It is valuable to have a visual description of the soft variable elements and their relationships, as well as a portrayal of how these relationships affect other elements within the whole organization. This study used the iThink mapping, simulation, and modeling tool. It provides the capability of designing a model with visual images through a mapping process. Simulations can be executed on the model that will show how the elements of the system interact. The model shows not only the effect a change in one or more variables can have on each other, but also on the whole system itself. It shows how interrelationships can affect organizational learning and ultimately productivity. The essence of the system dynamics modeling approach is finding the feedback loops and relationships that are dependent on each other and have the most influence on the output of the system.

Figure 2 shows the relationship between the hospital's capacities to meet the increasing demand of the community. This archetype illustrates the major policy connection between health care management systems and their communities. The essence of this idea is to facilitate more hospital admissions and meet the demands of the community. In this example the unintended result of the hospital policies is to increase more need for post-hospital services. In both cases, there is limited capacity and thus the consequence is the underachievement of the objective which the community's demand.

Figure 2: Example of a systemic archetype.
Adapted from Eric Wolstenholme, Using Generic Archetypes to support thinking and modeling. Systems Dynamics Review, 20(4), 2004, pp. 346-347.



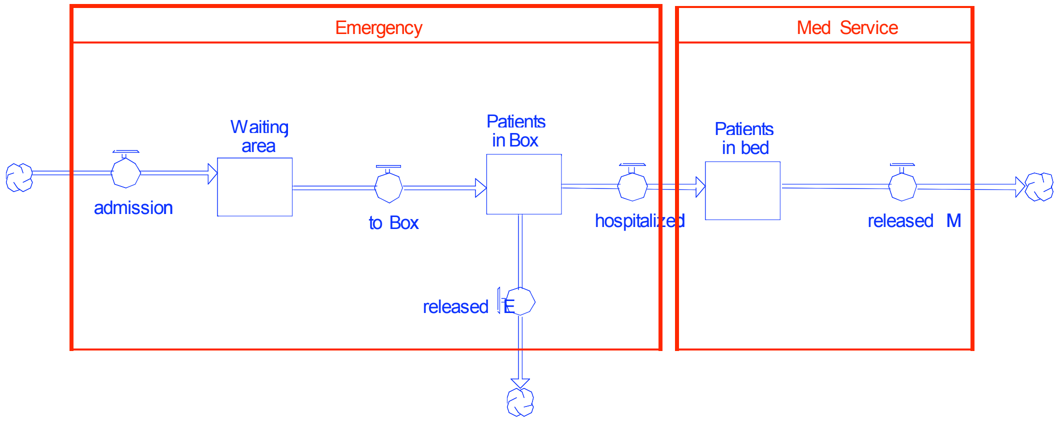
Hospitals struggle to provide the services that are essential for each patient, yet resource constraints and inflexible service pathways cause congestion and frustration among the service consumers and the service providers. In the following sections we present an alternative perspective and solution that considers the interrelationship of the hospital systems components that can create the constraints and cause the frustrations.

ANALYTICAL MODEL

To evaluate this simple yet complex delivery system, a simulation model can be used with a gaming interface that has been designed to represent a particular organization. The purpose of designing such an interface is to allow for experiments or the iteration of "what If" scenarios. The in a hypothetical hospital modeled contains one medical service and one emergency service. Its focus is on the flow of patients through the emergency service and – sometimes- towards the medical hospital bed stay. The analytical model helps promote alternative thinking and different perspectives regarding problems managers encounter in day-to-day operations.

The use of modeling and simulating is a means to reflect upon problems and to get a feel for changes that may prove helpful. This does not present a specific solution; thus, the parameters used and the scenarios simulated are generic. Rather than deriving specific recommendations for a hospital, conclusions can be drawn concerning the decision-making approach. To demonstrate the value and power of this systems dynamic modeling schema, a simulated five days (by hours) configuration of a hospital with six emergency beds and 100 medical beds that encounters a hypothetical daily flow of new emergency patients. A portion of the model is shown in Figure 3.

Figure 3: patients' flow through the two units

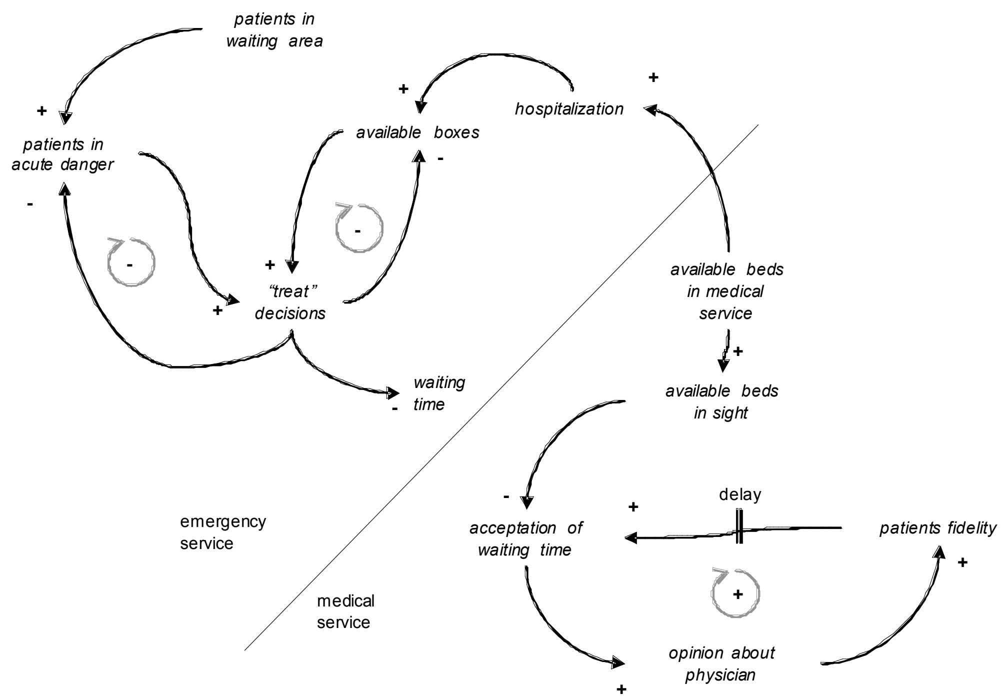


The emergency service receives patients that have to be stabilized in order to stay alive. The basic unit of treatment shown is the "box", where each patient receives treatment by a physician. From there on, the patient may be released or hospitalized. If the patient has to be hospitalized, they will be transferred to the medical service, which has to have a bed available at that precise moment. If there is no bed available, the patient has to remain inside the box and wait in order to receive a bed in the medical service they will be transferred to. During the "waiting period" in the box, the following patient cannot enter into treatment, and a backlog of critical patients builds up in the emergency service.

The model of the hospital has a medical service that receives patients from other areas, gives them treatment, and then releases them home or transfers them to other service areas. The physician manages several resources in order to attend to their patients. One of the critical factors in this services delivery situation is the bed availability. Without free beds, a physician cannot hospitalize patients. Physicians also consider the patient's opinion concerning service. If the patient feels badly served, they may switch to another physician or hospital. On the other hand, the hospital's interaction leads to a policy that aims at keeping free beds at a minimum.

When the physician receives a patient that needs to be in hospital, there may be reasons why an immediate hospitalization is not possible. After all, there are many patients demanding attention, and some are in a more pressing situation that others. Also, there may be resource constraints that preclude immediate attention. However, a particular patient may not understand that they have to wait if at the same time they see beds available (resources). So in the physician's logic, if it is important to make the patient feel well attended, then it makes sense not to have too many free beds.

Figure 4: Two local systems and one organizational frontier



Physicians and hospital administrators reviewed the complete model and simulations. They quickly grasped the structure of the model and accepted is as valid representation of their situation. After inspection of the model's behavior, they concluded that this approach could help them and shape their ideas. They have many ideas about how to improve their hospital, but they felt that without a rigorous way to articulate them, their proposals remained only speculations. The model also illustrated that effective solutions require organizational change to be effective.

The scenario chain of events, together with the involved variables and results of the model, are available from the authors. This model is currently being expanded to cover other specific hospital conditions and issues. One scenario under development will attempt to resolve the question of how many beds have to be available for emergencies that may be encountered by a hospital over a period of one year.

DISCUSSION

The hospital situation is similar to that frequently encountered in *logistics (supply chain management)*, and helpful contributions may come from this field. It is also essential to recognize that some of the variables implied in this situation behave as *accumulators*, while others behave as *flows*. An accumulator is passive: unless new material arrives or some is evacuated, the quantity inside the accumulator remains constant. A flow is what changes the quantity of an accumulator, adding to it or taking from it. For example, waiting areas, the emergency beds, and hospital beds are accumulators with their characteristic inertia. New admissions and other movements of patients or changes of state (beds and boxes) are flows, and only they can change the accumulators. In turn, the situation of accumulators determines the flows. The differences and relationship between accumulators and flows have been theorized and systematically used in *system dynamics* to design effective interventions in complex systems, and helpful analysis may come from this discipline.

There are several lessons that can be derived from this model and multiple simulations. First, the emergency service cannot solve the congestion problem coming towards it from the medical service, since all possible decisions are made in the medical service. In fact, the decision variables that can be affected by the simulation user are part of the "medical service" sector. Next, changing patient release times to coincide with daily emergency peaks will only bring a one-shot relief and not affect the performance significantly. A constant checkout of patients is able to repeat this impulse every day and thus allows improving performance (patient throughput). Third, developing a simulation model allows a comparison of alternatives and to understand important differences between them.

CONCLUSIONS

A hospital can be analyzed as a net of interacting "services" and focused on what happens between two of these services: "emergency" and a prototypical "medical service". It became clear that the medical service uses bed assignment policies according to its inner logic, and that the side effects this causes in emergency are not taken into account. For example, if the emergency unit perceives a bottleneck because they cannot transfer stabilized patients to the medical service; being unable to treat new emergency patients, they can send home patients who may not be at vital risk, but there is no substantial policy available to solve the problem.

The simulation has shown that unless the underlying "physical" relations are balanced, "firefighting" decision policies will only have superficial effects. The simulation model in this representation shows managers that the policy levers are not in the emergency unit, but are actually found within the medical service. This approach allows decision makers to test and compare decisions as well as policies to determine the proper mix of hospital resources combining sensible effects with affordable efforts.

The model presented in this paper is a generic, as are the findings. Because this model is flexible, it offers adaptation and applicability to most hospitals. The model's mapping feature also provides a compelling visual representation of the various interrelations between and among the variables in any organization. While the mapping feature gives decision makers a visual perspective, the dynamic modeling that is embedded in the software provides a better understanding of the impact of decisions that are made or not made in an organization. This facilitates a novel simulation method for decision makers to learn and test ideas that were previously not available. A hospital can also use this tool as a means to maintain a learning organization. However, this model is just one approach to help managers in an organization sustain its competitive edge in a rapidly changing environment.

REFERENCES

Caceres, P.A. and Rodriques-Ulloa, R., (2007), An application of soft systems dynamics methodology (SSDM), 58(6), pp. 701-713.

Coyle, G., Road, C., and Shivenham, S., (2007). Qualitative and Quantitative Modelling in Stystems dynamics: Some Research questions, System Dynamics Review, 16(3), pp. 225-244.

Forrester, Y. (1961), *Industrial dynamics*. (MIT Press, Cambridge).

Grobler, A. (2007), Systems dynamics project that failed to make an impact, System Dynamic Review, 23(4), pp. 437-452.

iThink Systems Thinking Manual (1992), iThink: The Visual Thinking Tool For the 90s, High Performance Systems Incorporated, (Hanover, New Hampshire).

Lane, D. (2007). The power of the bond between cause and effect. Jay Wright Forrester and the field of systems dynamics, System Dynamics Review, 23(2/3), pp. 95-118.

Lane, D.C. and Husemann, E. (2008). Systems Dynamics mapping of acute patient flow, Journal of Operations Research Society, 59, pp. 213-224.

Roberts, E.B. (2007) Making System Dynamics useful: a personal memoir, System Dynamics Review, 23(2/3/), pp. 119-136.

Senge, P., Ross, R., Smith, B., Roberts, Ch. and Kleiner, Ar. (1994): *The fifth discipline fieldbook*, (New York: Doubleday).

Sterman, J. (2000). *Busyness dynamics: systems thinking and modeling for a complex world*, (Wiley-New York).

Sterman, J. (2007). Exploring the next great frontier: System dynamics at fifty, 23(2/3), pp. 89-93.

Visser, M. (2007). System Dynamics and group facilitation: Contributions from communication theory, System Dynamics Review, 23(4), pp. 453-463.

Weil, H.B. (2007). Application of System dynamics to corporate strategy: An evolution of issues and frameworks, System Dynamics Review, 23(2/3), pp. 137-156.

Wolstenholme, E. (1990), *Systems enquiry*, (Wiley, Chicester).

Wolstenholme, E. (2003), Towards the definition and use of a core set of archetypal structures in system dynamics, *System Dynamics Review* 19(1), pp. 7-26.

Wolstenholme, E. (2004), Using generic system archetypes to support thinking and modeling, *System Dynamics Review,* 20(4), pp. 341-356.