The MIT Center for Digital Business — A PARTNERSHIP IN RESEARCH

Center for Digital Business

RESEARCH BRIEF

MIT Sloan

Volume XI | Number 2 | February 2009

Improving Hospital Operations Using Hospital Information Systems and System Dynamics Modeling Techniques

Dr. Masanori Akiyama, *Visiting Professor*
Koshio Atsushi, *Visiting Researcher*
Daniel Goldsmith, *Research Scientist*
Dr. Michael Siegel, *Principal Research Scientist*
MIT Sloan School of Management

Executive Summary

This research examines the challenges of implementation, management, and improvement of hospital operations during the introduction of new technologies. Specifically we examine the use of a Point-Of-Act-System (POAS) in a large Japanese hospital. After the initial set-up, system performance – measured in patient safety – remained robust, yet operational performance began to decline. Two specific staff behaviors driving performance declines were uncovered and modeled in simulation environments using the system dynamics modeling (SDM) methodology. Based upon presentation of our analytical results, financial performance of the hospital improved through modification of staff routines. The efficacy of the intervention was tested by comparing material utilization before and after the intervention. Measurement of this effect was enabled by the real-time capture system in POAS. The SDM technique employed in this study, combined with emerging rich health information system (HIS) data sets, can assist other institutions seeking to improve operations.

Introduction

The system dynamics modeling methodology has the ability to create improvements in strategic management of hospitals. Here we examine the strategies required to develop new simulation capabilities in hospital environments and to use simulation analysis to help hospital organizations address important operational problems. Prior work in this area has often addressed systematic health care challenges from a technology or public policy perspective. This work, however, focuses on how structures and decisions embedded within hospital organizations can subvert efforts to manage HIS, and how simulation models can utilize untapped data sets to improve hospital operations.

This research is motivated by the observation that many excellent HIS systems go unused or under-utilized because HIS implementation is met with resistance by staff, doctors, and managers. Further, if HIS are implemented, unanticipated behavioral decisions resulting from HIS implementation can create counterintuitive outcomes that actually subvert overall hospital efficiency. Finally, once developed, HIS data-sets are often overlooked as tools to help implement changes and improvements over time.

Case Diagnosis and Methods

We utilize system dynamics modeling techniques, which we believe effectively address the challenges of dynamic complexity in hospital environments. Developed by Jay W. Forrester at MIT in the mid-1950s, the methodology involves developing causal diagrams and building policy-oriented mathematical models for computer simulation. (Sterman, 2000)

We apply this technique to analyze a major Japanese hospital's results from the implementation of a comprehensive health information system, named POAS (Point of Act System). As described by Akiyama (2001 and 2006), the underlying concept of POAS is to enable records of "'who did what to whom, where, when, using what, and for what reason.' In short, real-time input becomes possible at the point of action." Under the system, logs of medical actions and inventories are created throughout the course of operations, recorded using bar-code scanning technology and nurses equipped with PDAS (personal digital assistants). The system operates continuously at the hospital, handling more than 360,000 transactions per hour, and has been in continuous operation for more than five years.

Soon after implementation, POAS facilitated vast improvement in multiple areas of hospital operations, with estimated savings reaching millions of dollars. In addition to POAS-enabled cost savings, the system also led to impressive improvement in patient safety. Prior to the implementation of POAS, there was a 40 percent chance that there would be a mis-administration of an injection prescription. After implementation, errors were cut dramatically.

Despite continued benefits for patient-safety, concern was raised about the sustainability of the system's financial performance. Recent data indicated that the growth in POAS–enabled savings had slowed, or even declined. System managers were concerned about how to obtain further improvements in the hospital's financial performance based on the current implementation of POAS.

Sustaining the Benefits of POAS: An Example Using Drug Injection Interactions

To appreciate the dynamics of process improvement and provide a platform for ongoing improvement, our investigation focuses on the injections administered on the various hospital wards. Injection orders are initiated with a request by a doctor for treatment, and culminates in an injection performed by a nurse.

The basic "physics" underlying the injection process are shown in Figure 1. The first series of constructs in our model relate to the flow of orders and material. The flows, denoted by straight arrows with values, are the rate at which orders for injections are successfully moved (referred to as Rps, a bundled collection of injection materials) between stations in the hospital. Also shown in the figure are the system stocks, denoted by a rectangle, which are computed as the integration of the stock's inflows less its outflows. The stocks are the accumulation of orders waiting to be processed at three stages – the pharmacy, the nurse station, and the patient's bedside.

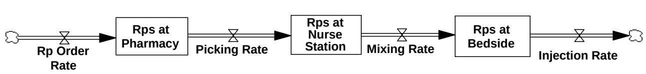

Figure 1: Flow of Drugs for Injection Process

A second series of outflows correspond to Rp orders that are canceled or amended subsequent to the initial order, but prior to the injection (see Figure 2). If the order change is processed prior to the mixing phase, the Rp components can be returned to stock by a nurse, and are generally reusable for future patient orders. However, if the Rp has been mixed, the cancellation results in the disposal of the Rp.

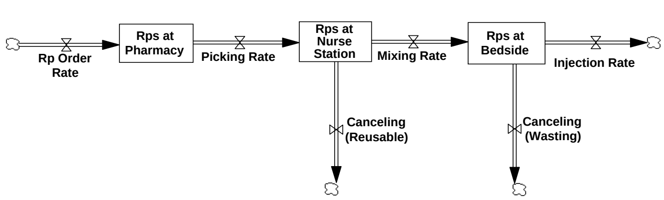

Figure 2: The Two Effects of Order Cancellation

The basic factors that result in wasted Rps are shown in Figure 3. As the number of Rps waiting at the bedside rises, so does the average injection delay (given a steady rate of injections). That is, if the stock of Rps increases while the injection rate does not similarly increase, an Rp will spend a longer time, on average, at the bedside. One consequence of the longer average delay at the bedside is that a longer window is open during which the injection is mixed and is subject to being wasted due to cancellation. The loop structure forms a balancing feedback loop (B1).

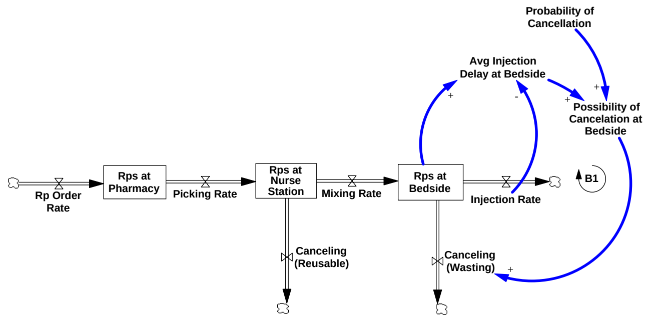

Figure 3: Modeling Causes of Drug Waste

During our investigation, we focused on dynamics that would likely increase the backlog of Rps at the bedside, in turn increasing the force, or gain, of loop B1. Through focused interviews, we uncovered a dynamic referred to as "batch mixing," depicted in Figure 4.

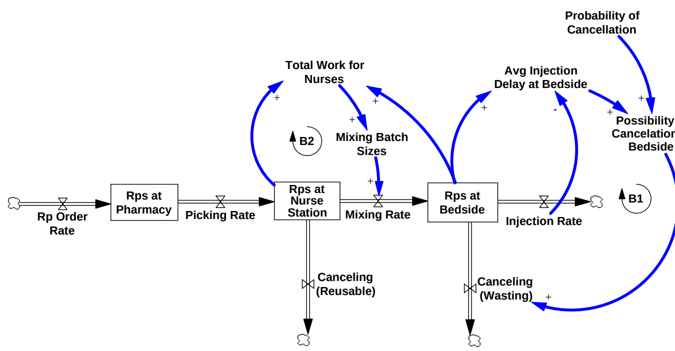

Figure 4: Batch Mixing of Drugs

As intended under POAS, each Rp is scheduled in advance to be mixed at a specific time, which corresponds to the staggered schedule of each injection. Instead of following the schedule, however, system managers became concerned during our investigation that nurses were mixing Rps in large batches throughout the day, which clusters the nurse's workload and increases the blocks of available downtime. While this might benefit the nurses, it also, in effect, increases the mixing rate, and accelerates the rate at which Rps are moved from the nurse station to the bedside (i.e., in the mixed form). As shown above in loop B1, this increases the rate at which Rps are wasted.

Increasing the cancellation rate also has a second-order effect that diminishes hospital efficiency. Because canceled orders often involve "rework" to correct and remix the new replacement order, they increase the total workload for the nurses, as show in loop R1 of Figure 5.

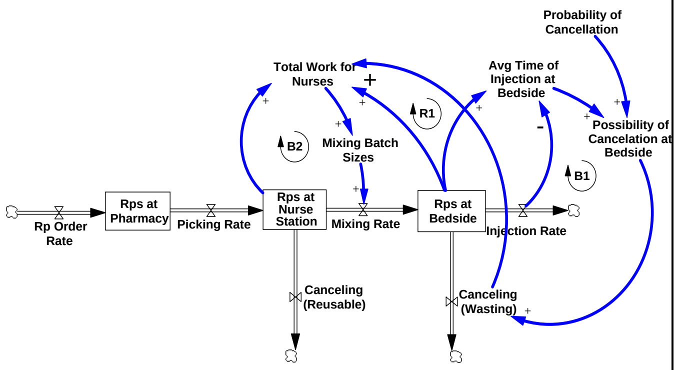

Figure 5: Rework Created By Cancellation after Mixing

When taken together, loops B1, B2, and R1 depict the dynamics leading to increased costs, both in wasted Rps and in staff time. This loss of material and staff time accounts for the decreased financial performance experienced during the later stages of POAS implementation. It is important to note that none of the loops directly affect patient safety. Because POAS was billed as a patient-safety system to the staff, nurses believed the system was operating as intended.

Analysis and Recommendations

As a first step to address the dynamics inhibiting the ongoing financial success, we simulated the effects of removing specific costly medicines from the batch mixing dynamic. We were aided by the use of POAS-enable data, which allowed us to find high-leverage (i.e. cost) drug candidates by analyzing the stream of operational output. We chose five medicines—Novact M, Funguard, Kenketsu Venoglobulin-IH, Rituximab, and Gran Injection—that we determined accounted for nearly 25 percent of the overall waste.

We used the coded data as an input to the system dynamics simulation model. Simulating the effects of subjecting these five medicines to different mixing procedures, which would ensure an improved mixing schedule, lead us to estimate potential savings of approximately 70 million yen, or 600 thousand US dollars, on an annual basis (Figure 7). In addition, with the new approach to batching we saw an improvement of nurse utilization. The total time spent on injection operations decreased by approximately 7 percent (Figure 8).

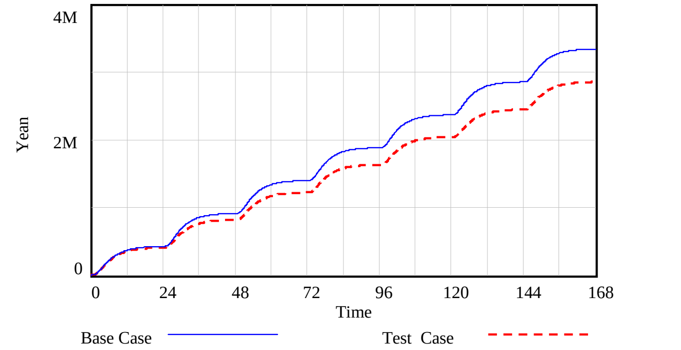

Figure 7: Cost Savings Due to Delayed Mixing of Five Drugs

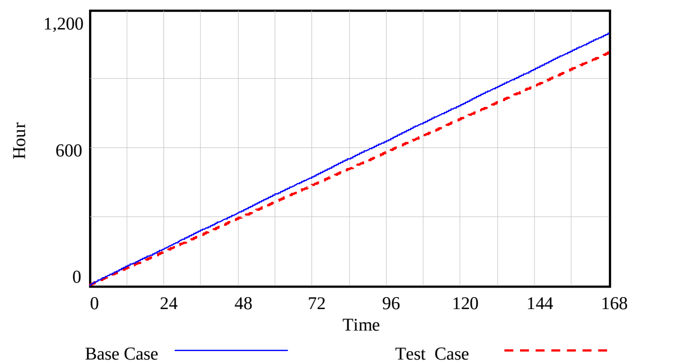

Figure 8: Weekly Savings in Nurse Time Due to Delayed Mixing

Thus our analysis used system dynamics modeling techniques combined with hospital system data to identify a considerable savings in both materials and staff utilization.

Implementation

Based upon these results, we presented our findings to the nursing staff at the Japanese hospital in May 2007. During this meeting, we discussed the model structure, our results, and ways in which the nursing staff might be able to implement the results. We initially intended to run trials that initiated with the pharmacy marking the top five wasted drugs, instructing the nurses to delay mixing of those orders until bedside delivery to the patient. However, based upon our meetings, the nurses decided to address the problem on their own, and began to reduce the

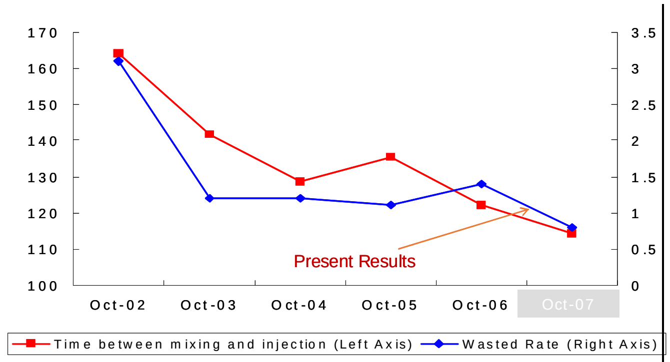

Figure 9: Weekly Savings in Nurse Time Due to Delayed Mixing

mixing time (the time between mixing and injection), which in turn, drove reductions in the wasted drug rate. Mixing time (the left axis, measured in minutes) declined from 130 minutes to 115 minutes, and wasting rate (the right axis, measured in percentage) fell from 1.5 to 0.75.

The use of SDM combined with systems data provided and an excellent medium to communicate with front line workers. In the future, we see the ability to run SDM-enabled experiments and analyze the results with real-time data capture systems as a crucial tool to improve health care operations.

Pharmacy Operations

We were able to extend our research beyond the nursing ward into other areas of hospital operations. Specifically, we were able to model and examine the relationship between the drug supply chain, the pharmacy, the doctors, and ward operations. For example, we found a stove-pipe effect, in which the pharmacists were *intending* to maximize efficiency within the pharmacy, but because they were missing a system-wide view, were doing so at the expense of the nurses (and ultimately themselves).

As a result of efficiency improvements accompanying POAS implementation and higher patient turnover, total work for pharmacists had increased. In an effort to accomplish their workload while also retaining occasional downtime, the pharmacists also had adopted the "batch processing" practice. Pharmacists increasingly relied on processing injection orders in large batches throughout the day to cluster their workload and, on average, decrease the amount of time each order resided in the pharmacy.

To understand the consequences of batching, we return to the possible outcomes of an injection order; it can be (a) successfully injected, (b) changed before mixing while at the pharmacy, (c) changed before mixing while at the nurse station, or (d) changed after mixing at the bedside. There are important differences between outcomes: most importantly, once the order is mixed, it must be discarded, as it cannot be used for other patients. Additionally, an order returned from the nurse station has accumulated more work time "invested" than one changed at the pharmacy.

The initial consequences of pharmacy batching are captured in Figure 10. The large arrows indicate the direction of change in variables as a result of batching. To start, as batching increases, the work completion rate in the pharmacy increases (up arrow above 'pharmacy processing rate'), causing the stock of remaining orders in the pharmacy to decrease (down arrow above 'injections in pharmacy') and the number of order changes occurring at the pharmacy to also decrease. The first downstream consequence of this dynamic is that the stock of orders at the nurse station rises (up arrow above 'rps at nurse station.') The dashed rectangle indicates the limits of the pharmacy's perspective of this process.

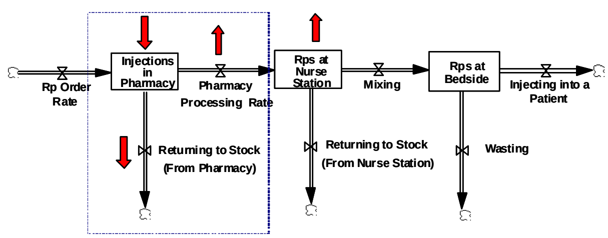

Figure 10. Batching Reduces Changes at Pharmacy

This strategy appeals to the pharmacists because it reduces the number of order changes that occur in the pharmacy, and thus decreases the amount of work (perceived) they must do.

Next, we capture the perspective of the nurses in Figure 11. As previously described, batching in the pharmacy causes the stock of orders at the nurse station to rise (up arrow above 'Rps at nurse station.') Nurses respond to this increase with their own batching strategy, which increases the mixing rate. This both decreases the amount of changes occurring while the order is at the nurse station, and increases the stock of orders now at the bedside. Ultimately, as orders reside longer at the bedside the number of injections that must be wasted increases (up arrow besides 'wasting').

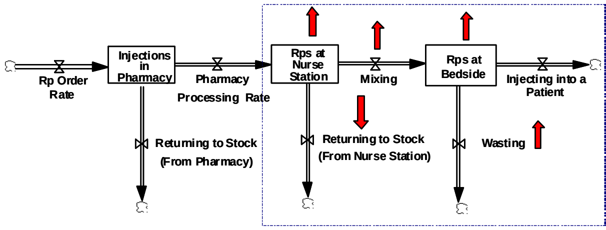

Figure 11. Batching Reduces Changes at Pharmacy

Pushing orders faster out of the pharmacy does reduce “redos” while they are in the pharmacy, but only by delaying the same redos until the nurses are working on them (incurring more staff time and increasing the risk of wasting). In other words, the redos from the nurses are the very same redos the pharmacy would have processed if the order had stayed in the pharmacy longer.

Pharmacists, however, did not make this connection. Instead, when redo orders were returned from the nursing ward, they appear via the *exact same process as new orders*. Pharmacists were treating new and redo orders as if they were all new orders. Because of how the redo orders were processed, pharmacists lost the traceability of ordering that would have let them match up the subsequent order change with the original order.

This line of investigation suggests that critical determinants of success in efficient hospital operations include the perceptions stakeholders have about the effects of the actions on upstream and downstream processes. By building simulation models we can holistically and quantitatively connect cause and effect throughout the hospital.

Supply Chain

The batching dynamic in nursing and pharmacy operations has important downstream effects for the injection supply chain. The increase waste from the batching dynamic ‘artificially’ increases the amount of medication used per patient, and thus, the amount of pharmaceutical stock that the hospital must keep on hand. The increased inventory costs are amplified back across the supply chain in a “bull whip effect”, in which each preceding vendor in the supply chain now must also carry greater inventory on hand. The total costs to the supply chain from batching are therefore much greater than simply the cost of the wasted injections in the pharmacy.

Our investigation also uncovered another dynamic of concern that increased supply chain instability—inventory buffers in the wards. Under normal conditions, nurses would keep a small amount of highly used medications in the ward for either emergency use or to be able to quickly deal with order changes. However, as more order changes started occurring in the ward, nurses started to stockpile larger amounts of more drugs. The existence of new supply chain buffers at every ward in the hospital, rather than relying on a single centralized stock at the pharmacy, also artificially increased inventory costs.

We looked at the role new technologies, such as radio frequency identification (RFID) tags could play in improving supply chain performance. RFID tags would allow for better demand forecasting and greater traceability of inventory throughout the hospital. Addressing both hospital inefficiencies and utilizing new technologies would allow for a ‘multiplier effect’ to decrease costs across the supply chain.

Conclusion

We envision a system that merges newly available operational data sources (i.e., real-time POAS data), electronic medical records, and operational data into feedback models that create dynamic hospital management tools. We propose a system that would provide information to hospital stakeholders about efficiency metrics, and would provide managers a means to change policies – such as which drugs to exempt from mixing – at any point during ongoing hospital operations. This platform would be open for additional learning, promoting the development of a broader set of tools that improve operations and manage patient risk. With the reported initial results and continued research, we predict that this work will have a significant impact on reducing hospital costs, increasing patient safety, and accommodating improvements in hospital staff operations.

References

1. Linda T. Kohn, Janet M. Corrigan, and Molla S. Donaldson, Editors. To Err Is Human: Building a Safer Health System Committee on Quality of Health Care in America, Institute of Medicine. 2000.
2. Akiyama, Masanori. Migration of the Japanese Healthcare Enterprise from a Financial to Integrated Management: Strategy and Architecture. Department of Medical Informatics, International Medical Center of Japan, Tokyo, Japan. 2001.
3. Akiyama, Masanori. Risk Management and Measuring Productivity with POAS – Point of Act System. Center for Digital Business, Massachusetts Institute of Technology Sloan School of Management. 2006.
4. Forrester, J. W. 1958. Industrial Dynamics: A Major Breakthrough for Decision Makers. Harvard Business Review, 36(4): 37-66.
5. Repenning NP, Sterman JD. Capability Traps and Self-Confirming Attribution Errors in the Dynamics of Process Improvement. Administrative Science Quarterly 2002; 47(2):265-295.
6. Sterman, J., N. Business Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: McGraw-Hill/Irwin. 2000

Volume XI *Number 3* *December 2008*

ABOUT THE MIT CENTER FOR DIGITAL BUSINESS

Founded in 1999, the Center for Digital Business is the largest research center in the history of the Sloan School. We are supported entirely by corporate sponsors whom we work with closely in directed research projects. The Center has funded more than 45 Faculty and performed more than 60 research projects. Our mission is to join leading companies, visionary educators, and some of the best students in the world together in inventing and understanding the business value made possible by digital technologies. Our interactions are a dynamic interchange of ideas, analysis, and reflection intended to solve real problems.

Examples of Current Focused Research Projects:

- Implications of e-Commerce for New Services and Structure of Logistics Systems
- How Do Intangible Assets Affect the Productivity of Computerization Efforts?
- Wireless and Mobile Commerce Opportunities for Payments Services
- Benchmarking Digital Organizations
- Security and the Extended Enterprise
- Pricing Products and Services in the High-Tech Industry

The Center for Digital Business is completing its Phase II, focusing more explicitly on business value, while at the same time including technologies beyond the Internet in its purview. Our goal, in part, is to reduce that timeline through basic and applied research, engagement with industry sponsors, and the sharing of best practice, and the MIT's credo of combining rigor with relevance is well served.

We are co-located with MIT Sloan's Center for Information Systems Research and the Center for Collective Intelligence to facilitate collaboration. Our cross-campus collaborations include work with the Media Lab, AutoID Center, Computer Science and AI Lab, and Communications Futures Program.

Please visit our website for more information.

http://digital.mit.edu/

We are organized into four areas of expertise – or Special Interest Groups:

1. **Digital Productivity**
2. **Digital Marketing**
3. **Digital Services**
4. **Digital Health**

Founding Sponsors

Cisco Systems
CSK Corporation
General Motors
McKinsey
SAP
Suruga Bank

Research Sponsors

BT
France Telecom/Orange
Google
Hewlett-Packard
Liberty Mutual
Oracle

Member Sponsors

SAS
Solution Services, Inc.

CONTACT INFORMATION

MIT Center for Digital Business
MIT Sloan School of Management
5 Cambridge Center, NE25-700
Cambridge, MA 02142
Telephone: (617) 253-7054
Facsimile: (617) 452-3231
http://digital.mit.edu/

David Verrill, Executive Director
Erik Brynjolfsson, Director
Glen Urban, Chairman
Carlene Doucette, Executive Assistant
Tammy Buzzell, Financial Assistant