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**Improving Hospital Operations Using Bar-Code Capture
Data and System Dynamics Modeling Techniques**

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Improving Hospital Operations Using Bar-Code Capture Data and System Dynamics Modeling Techniques

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Abstract

To better understand the factors that support or inhibit process improvement in a hospital setting, we conducted a study of one hospital's attempt to implement a health information system (HIS) to reduce errors in medical treatment and manage material flows. Our analysis suggests that critical determinants of success in efforts to improve hospital efficiency include connections among key hospital staff, including doctors, nurses, and pharmacists, as well as patients. Building on these observations, we propose a dynamic model capturing the evolution of the interactions among the "physics" underlying hospital operations, information technology (IT), and staff behavior. We show that early success in one phase of process improvement can create unintended feedback in a later phase. We use a system dynamics model to examine losses in performance in these later phases. We then recommend management improvements in both materials and staff utilization and estimate the resultant cost-saving. As part of this analysis we explore opportunities to merge real-time operational data with feedback modeling to provide dynamic tools for hospital administration, risk management, and education and training. We believe that the major gains in HIS use will accompany new information gathering capabilities, as these capabilities result in collections of data that can be used to greatly improve patient safety, hospital operations, and medical decision support.

Introduction

The need for information technology (IT) implementation in hospital environments has been well documented, yet the challenges to successful implementation, and numerous high-profile failed attempts, have similarly been recorded. To date, the majority of proposed solutions to health care IT integration have focused on solving technology, integration, and operational issues. While important, these approaches fail to take advantage of the new opportunities provided by data collections systems. For example, the emerging HIS environment at a number of Japanese hospitals includes operational bar-code systems, providing increased patient safety with regard to injections. In the process of providing increased safety, the system collects information on every interaction between order, drug, nurse, and patient.

Utilizing this data, we can revisit the challenges associated with the implementation of process improvements. These efforts are often subject to failure because they do not appreciate the behavioral feedback created in dynamically complex organizations. Despite the best intentions of managers and administrators, hospital settings can be self-organizing, and the agents within them adaptive in their interaction with IT. Improved data collection systems, however, give us the means to quantify and understand system-wide behavior, and can point us in new directions for improving operations.

It is likely that previous attempted IT implementation occurred without properly considering behavioral factors, which may account for the legacy of under utilization of Healthcare IT. We believe that including the “human side” of IT integration improves chances for successful implementation. Ultimately, if barriers to learning and improvement are overcome, hospitals, despite their inherent complexity, have the potential to become dynamic organizations capable of sustained IT-enabled improvement.

Case Diagnosis and Methods

This case concerns a major Japanese hospital’s examination of the results from their implementation of a comprehensive health information system (HIS), 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 100 transactions per second, or more than 360,000 transactions per hour, and has been in continuous operation for four 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 existed nearly a 40 percent chance that there would be a misadministration of an injection prescription, due to the absence of an automated method of checking injections and the lack of real-time communication. After POAS, this percentage was cut dramatically; an alarm would sound prior to the injection if any problems existed (such as a correct patient being presented with an incorrect medication), and the staff would be able to fix the mistake prior to injection. While both financial and safety improvements coevolved from POAS, the improvement in patient safety was the most salient indicator of POAS improvements for the frontline hospital staff, who had very limited exposure to financial operations of the hospital.

In the years following the initial implementation of POAS, patient-safety benefits continued to be realized, and by all measures, improvement remained robust. Yet concern was raised about the sustainability of the system’s financial performance. Recent data

indicated that the growth in POAS-enabled savings had slowed to a peak, and may actually be on the decline. System managers were concerned about how to obtain further improvements in of the hospital’s financial performance based on the current implementation of POAS.

At the outset, we assembled a team to develop methodologies focused on operations and management improvements. This analysis was made possible by the combination of Systems Dynamics Modeling, expert input, and the analysis of data from POAS-enabled operations. We examined connections among key hospital staff, including doctors, nurses, and pharmacists, as well as patients, and developed a system dynamics model to investigate the dynamic complexity of hospital operations.

The Structure of Drug Injection Interactions

The modeling structure we developed provides a useful way of thinking about the challenges associated with process improvement in hospital settings, in particular with regards to hospital ward management. We first present the lessons that have emerged from our research in causal diagrams. The theory reported here draws on extant literature in process improvement, system dynamics modeling, as well as our study of one hospital setting. To appreciate the dynamics of process improvement and provide a platform for ongoing improvement, our investigation focuses on the injection process—the sequence of operations that starts with a request by a doctor for treatment and culminates in an injection performed by a nurse.

Figure 1 begins with the basic “physics” underlying the injection process. 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. Figure 1 also shows three of 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 and waiting to be processed at three stages, the pharmacy, the nurse station, and the patient’s bedside.

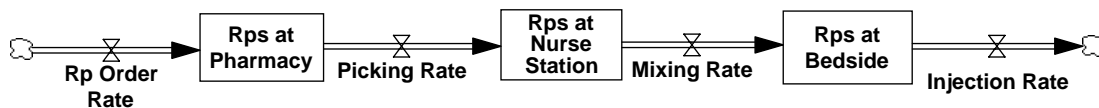


Figure 1. Flow of Drugs for Injection Process

In Figure 2, a second series of outflows correspond to Rp orders that are canceled or amended subsequent to the initial order but prior to the injection. 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.

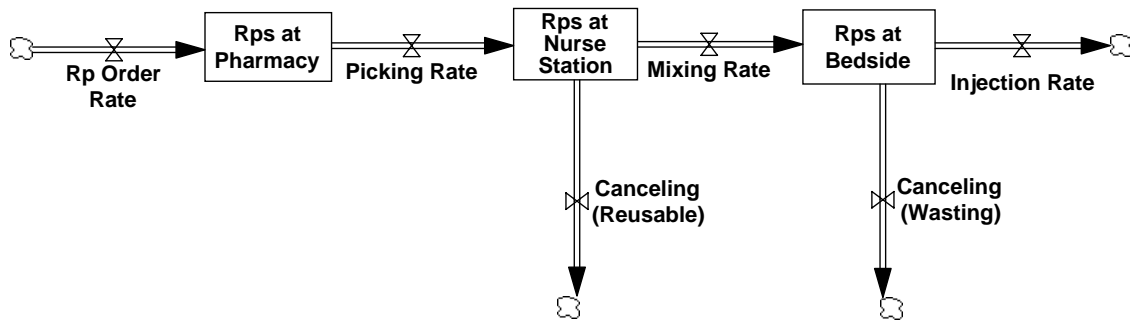


Figure 2. The Two Effects of Order Cancellation

While cancellations, either before or after mixing, may be process problems, they can also result from normal hospital operations. Tools to help reduce the number of order changes would prove valuable for hospital management, but the complexity of patient diagnosis makes this a challenging task. Furthermore, evidence showed (i.e., examination of POAS data) that the cancellation rate was nearly constant throughout POAS implementation, and therefore was assumed to be exogenous to important system behavior. Instead, we modeled the split between canceling reusable Rps and canceling wasted Rps as the manifestation of systemic process problems.

Figure 3 depicts the basic factors that result in wasted Rps. 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 subject to being wasted due to cancellation. The loop structure forms a balancing feedback loop (B1). While the causality of the loop “balances” the Rps waiting at the bedside, bringing the number of Rps waiting to a lower level, it does so a non-beneficial way, as the outflow results in wasted Rps.

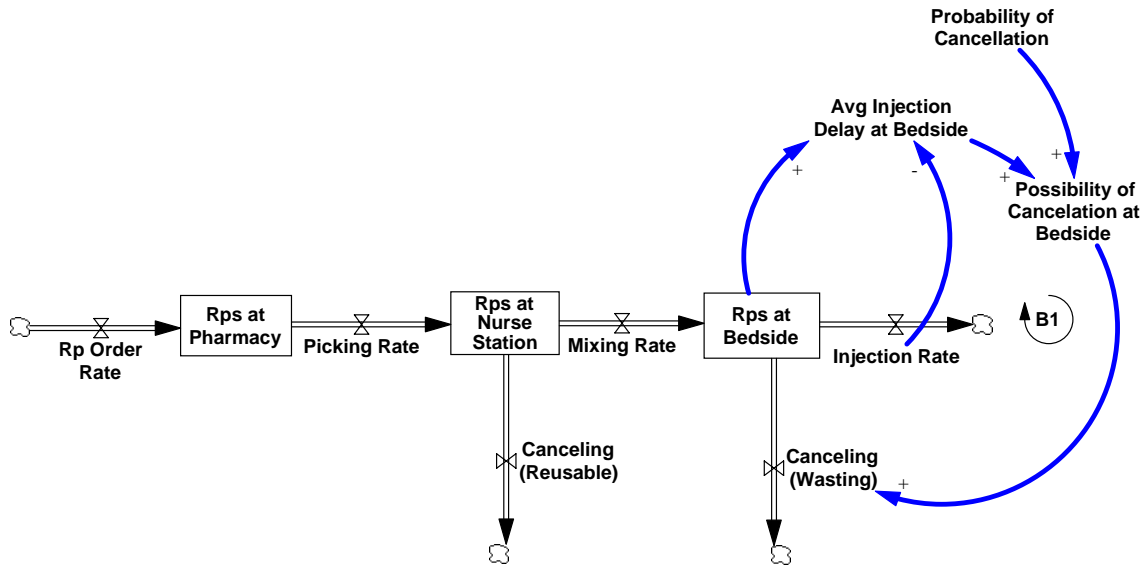


Figure 3. Modeling Causes of Drug Waste

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.

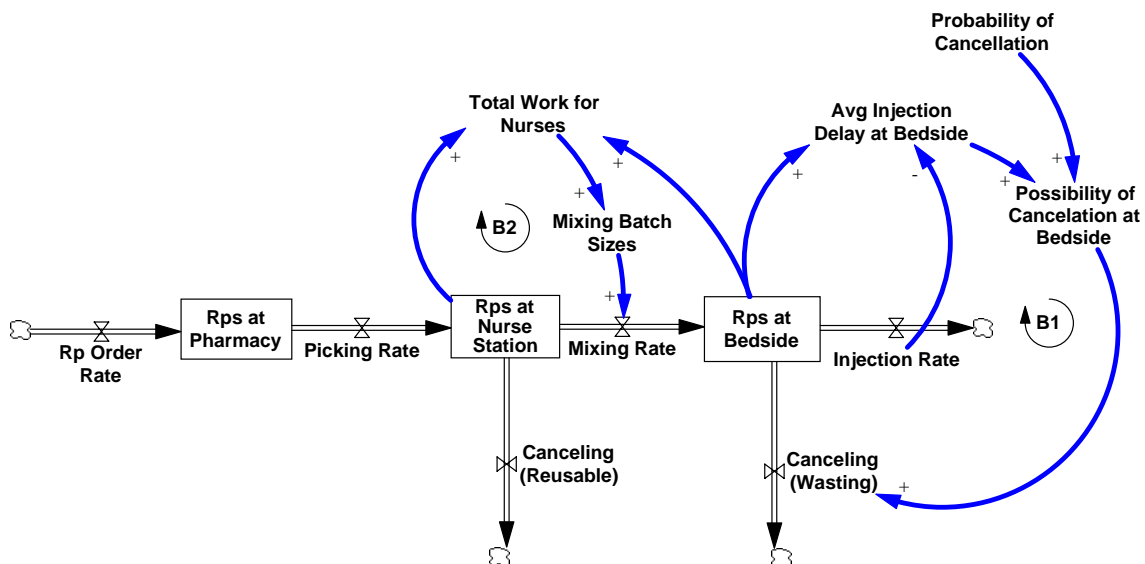


Figure 4. Batch Mixing of Drugs

As a result of efficiency improvements accompanying POAS implementation and higher patient turnover, total work for nurses had increased, resulting in more injections to process at both the nurse station and the bedside. In an effort to accomplish their workload while also retaining occasional downtime, the nurses adopted the “batch

mixing” practice. 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. The additional causal link forms a reinforcing feedback loop, by which cancellations increase the total workload, increasing the imperative for batch mixing, and ultimately causing even more cancellations. While the time lost to each canceled order may be small in magnitude, taken in aggregate the cancellations create a cycle of rework and ratcheting time constraints that damages efforts at process improvement.

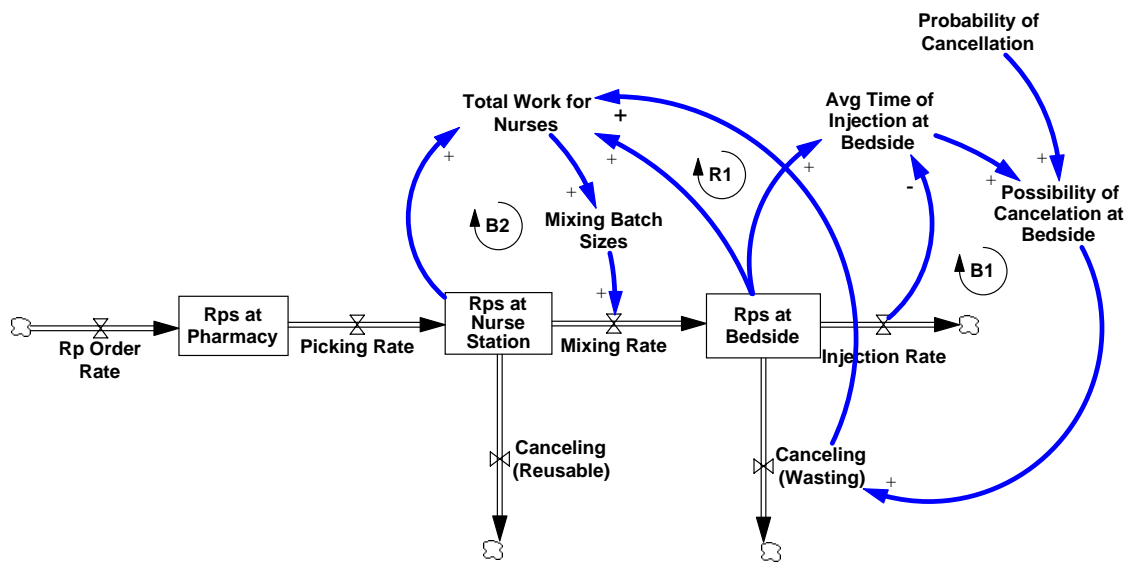


Figure 5. Rework Created By Cancellation After Mixing

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. Operating in an environment with little information about the financial consequences of their actions, and with a strong focus on patients, nurses sought an outlet for the increased work pressures in which their actions were not as salient, resulting in the “unintended side-effect” of batch mixing.

Analysis and Recommendations

As a first step to address the dynamics inhibiting the ongoing financial success, we simulated the effects on removing specific costly medicines from the batch mixing dynamic. We were aided by the use of POAS-enabled data, which allowed us to find high-leverage 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.

Shown in Figure 6 is a limited sample of the data used in analyzing the cost benefit from not batching a set of drugs. This sample data comes directly from the POAS system and is available over a four-year period. The sample below includes: macro coding information, including an order ID, a unique number for each discrete hospital action, an act key, referring to the specific action undertaken, and a patient-specific code; information for hospital billing, such as the medical department code, the ward code, the medicine code, and the medicine cost; and data on the timing of the patient’s treatment, including the scheduled injection time, the time of delivery of the injection, and the actual injection time.

Order ID	Act Key	Patient Code	Medical Dept Code	Hospital Ward Code	Scheduled Inject Date	Delivery of Goods Date	Injection Execution Date	Medicine Code	Cost
3000008248156	3000008248156040610100	03865806	N04	19	06-Apr-04	05-Apr-04		YT0272	3240
3000008249113	3000008249113040210100	03874817	N05	19	02-Apr-04	01-Apr-04	02-Apr-04	YT0272	3240
3000008249113	3000008249113040910100	03874817	N05	19	09-Apr-04	08-Apr-04	09-Apr-04	YT0272	3240
3000008305063	3000008305063040210100	03880500	N07	19	02-Apr-04	01-Apr-04	02-Apr-04	YT0272	3240
3000008305074	3000008305074040610100	03880500	N07	19	06-Apr-04	05-Apr-04	06-Apr-04	YT0272	3240
3000008348984	3000008348984040210200	02330525	S12	04	02-Apr-04	01-Apr-04	02-Apr-04	YT0272	3240

Figure 6. Sample POAS-enabled Data Set

We used the coded data as an input to the system dynamics model. Simulating the effects of subjecting these five medicines to different mixing procedures, which would ensure a desirably scheduled mixing, leads 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 nursing utilization. The total time spent on operations decreased by approximately 80 hours of nurse time, per week (Figure 8).

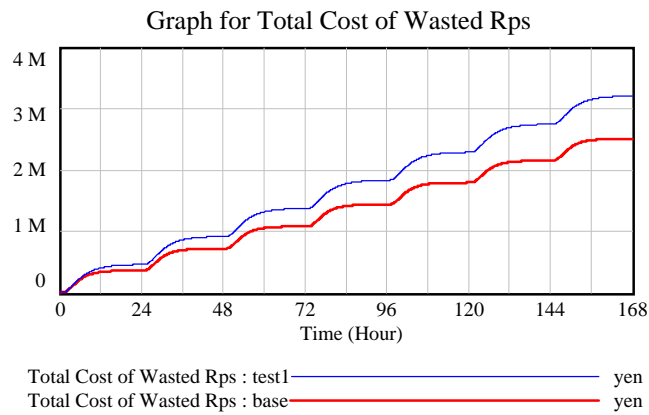


Figure 7. Cost Savings Due to Delayed Mixing of Five Drugs

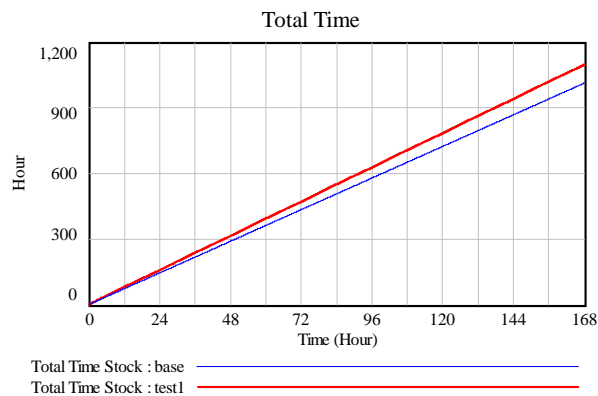


Figure 8. Weekly Savings in Nurse Time Due to Delayed Mixing

Our analysis used system dynamics modeling techniques combined with hospital system data to identify a considerable savings in both materials and staff utilization. The complete simulation model used in this analysis is shown in Appendix 1.

Cognitive and Perceptual Biases

While the value of addressing the causes of wasted Rps has been demonstrated, it is important to note that nurse’s role in injection operations, including their adoption of the “batch mixing” phenomenon, exists in a wider hospital context. Narrowly focusing on nurses can lead to attribution errors about root causes of efficiency declines, and could ultimately subvert improvement effort. Because process improvement is characterized by time delays, defensive routines, barriers to learning, limited information and ambiguity, and misconceptions of feedback (Repenning and Sterman, 2002); prescriptive recommendations drawn from a narrow analysis are often incorrect. After our initial investigation, we widened our analysis, and examined the role doctors play in the injection process.

From a process design perspective, batch mixing by nurses does not conform to the designer’s intentions because the nurses create their own schedule for mixing. Looking at the intended schedule, however, reveals the impossibility for nurses to actually conform

to the system as designed. Figure 9 shows a simplified injection ordering for three doctors and one nurse. As depicted, doctors work on the patient level, with each doctor taking responsibility for the scheduling of one patient. Nurses, however, work on the ward level, and are thus responsible for a cross section of patients. Because of the different viewpoints, it is often the case that three doctors (Drs. X, Y, and Z) will simultaneously order injections for three different patients (Patients A, B, and C) to be performed by the same nurse (Nurse A) at the same time. Accepted practice by doctors is to schedule all injections in the same timing patterns, despite the different injection needs of patients A-C: that is, while patient A needs one injection, patient B needs two injections, and patient C needs three injections, all receives their first, or only, injection at 6 am. This presents a challenge for the nurse, who must devise a work-around to the intended schedule.

	Dr. X	Dr. Y	Dr. Z
Time	Patient A	Patient B	Patient C
Nurse A	Injection 1/1	Injection 1/2	Injection 1/3
6:00			
12:00			
18:00		Injection 2/2	Injection 2/3
22:00			
24:00			Injection 2/3

Figure 9. Injection Scheduling Conflicts

It is likely that the origins of the “batch mixing” phenomenon were seeded by the conflicting schedules set by doctors for nurses. Because hospital operations are tightly coupled, the apparent policy resistance by nurses may in fact be rooted in a separate process entirely: doctor scheduling. The multiple actors in the hospital are dynamically linked, and successful process improvement needs to follow the connections, avoid miss-attributions of cause and effect, and consider the differing perspectives of each stakeholder.

Conclusion

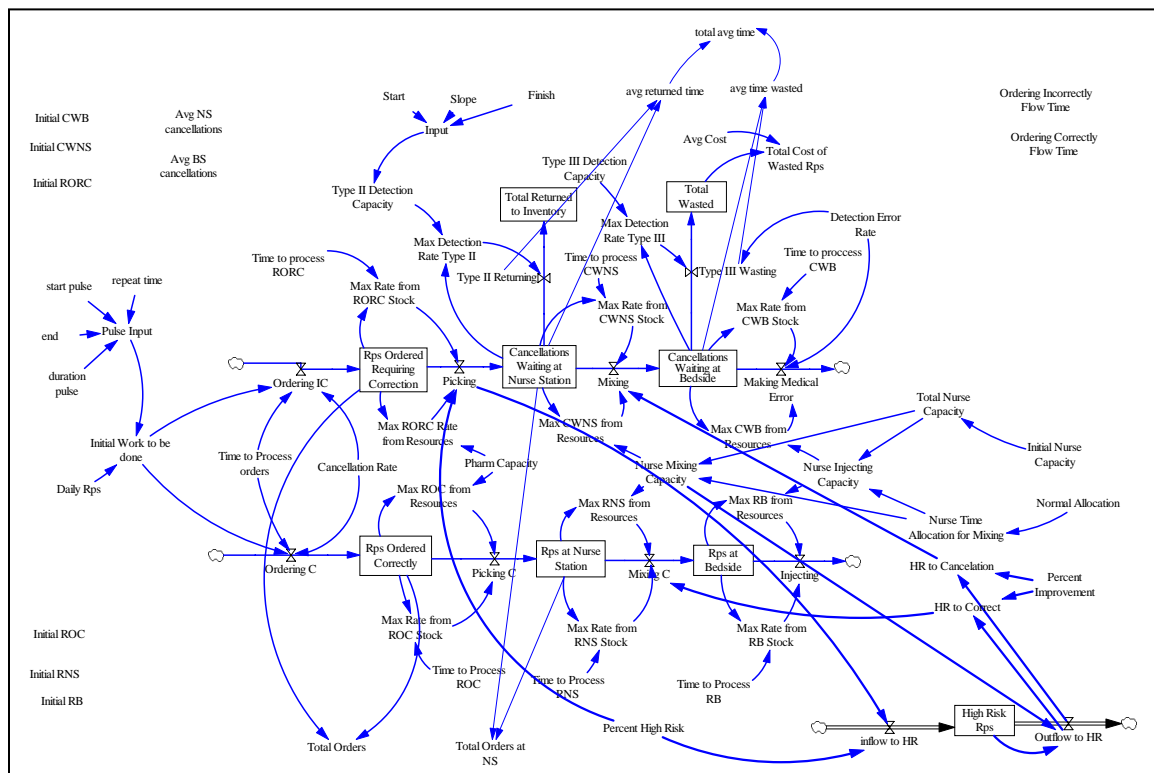
The goal of research in this area is to develop management improvements by means of systems modeling and analysis combined with the use of newly available operational data sources, such as POAS. We expect that this style of research will help sustain and advance system-wide improvements in operational efficiency in a hospital setting. Ongoing investigations will focus on designing robust experiments and simulations to increase understanding of the causes and effects for sustained improvement. While implementation challenges to this process improvement exist, we have proposed a high-leverage yet non-

disruptive improvement to quickly demonstrate financial benefits. Continued studies, including additional staff interviews, will focus on better understanding the culture involved in ward management to develop a workable solution for more comprehensive improvements in ward management.

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 ward management tools. We propose a system that would provide information to hospital about efficiency metrics, and would provide managers a means to change policies, such as which drugs to exempt from mixing, at any point during on-going hospital operations. This platform would be open for improvements, promoting the development of additional tools that improve operations and manage patient risk.

The data produced by the POAS system combined with computational social science methodologies, particularly system dynamics modeling, is an exciting step forward in understanding the dynamics of managerial improvement in hospitals. With the reported initial results and continued research, we predict that this work will have a significant impact on reducing hospital costs, improving patient safety, and accommodating improvements in hospital staff operations.

Appendix 1. Diagram of simulation model



Bibliography

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.

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.

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.

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.

Sterman, J., N. Business Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: McGraw-Hill/Irwin. 2000.