A Model for Collaborative Workflow in the Operating Room of the Future

By

Elliot B. Sloane, Villanova University

and

William P. Wagner, Villanova University

Abstract: The $1.4 trillion healthcare industry of the early 21^{st} century is the largest single industry in the US. It accounts for 14% of the GDP, and is projected to reach nearly 20% by 2010. According to many authoritative sources, one of the biggest causes of growing costs and waste in healthcare is a compartmentalized, disaggregated business model, in which clinical specialists duplicate information and technologies that are not designed to support collaboration. In the past, there were attempts to create information coding and exchange standards within some of the larger specialized clinical fields, but until recently, no unifying collaborative framework existed. One area that has not been addressed is how the Operating Room of a hospital can use new technologies to collaborate better with other clinical specialists such as radiology. This paper presents a collaborative workflow model that can be applied to the Operating Room area of a hospital. This model is constructed using Event-Driven Process Chains (EPCs) which have become a popular process reengineering tool from the world of ERP systems engineering. The result is a model for the emerging "Operating Room of the Future," which will be a re-engineered and highly automated surgical environment that is heavily IT-enabled. As models such as these become more widely deployed throughout the healthcare enterprise, it will facilitate greatly improved inter- and intra-organizational business and workflow collaboration, clinical knowledge management and decision support.

Keywords: healthcare integration, healthcare collaboration, decision support, workflow

Corresponding author:

Elliot B. Sloane, Ph.D.
Villanova University College of Commerce and Finance
Department of Decision and Information Technology
800 Lancaster Avenue
Villanova, PA 19085
Phone 610.519.6432, Fax 610.519.5015
mailto: ebsloane@villanova.edu

I. Introduction

The $1.4 trillion healthcare industry of the early 21st century is the largest single industry in the US. It accounts for 14% of the GDP, and is projected to reach nearly 20% by 2010 [4]. For MIS researchers and practitioners the healthcare industry represents some of the greatest opportunities and challenges in the coming years. According to many authoritative sources, one of the biggest causes of growing costs and waste in healthcare is a compartmentalized, disaggregated business model, in which clinical specialists duplicate information and technologies that are not designed to support collaboration, let alone collaborative commerce. The systems and standards needed to accomplish a collaborative healthcare enterprise are only now being designed. As they begin to be applied and deployed in commercial products, they will allow implementing cross-enterprise process logic, rules and heuristics to optimize workflow, information sharing, and clinical efficiency. For example, in the healthcare enterprise (e.g., a hospital or integrated healthcare delivery network), collaborative commerce opportunities include:

1. closer resource planning and allocation,
2. more efficient scheduling and planning,
3. timely, efficient, and error-free vendor management, and
4. knowledge-sharing between stakeholders.

This paper presents a collaborative workflow model that can be applied to the Operating Room area of a hospital. This model is constructed using Event-Driven Process Chains (EPCs) which have become a popular process reengineering tool from the world of ERP systems engineering [2].

In the United States, government healthcare payments for the elderly and disadvantaged are managed by the Center for Medicare and Medicaid Services [4], such payments account for 44% of the healthcare expenditures in the US, too, making the CMS the largest single payer for medical services. According to CMS figures, total 2001 healthcare expenditures of over $1.4 trillion makes it the largest single industry in the US, accounting for over 14% of the GDP. According to their projections, this figure may approach nearly 20% of the US GDP by 2010. In 2001, CMS estimates that 9.3% of the non-farm, private sector US work force was employed in the healthcare field. The CMS US per capita medical expenses in 2000 was projected to be slightly below $5,000, a figure that is expected to nearly double by 2010. According to other published reports, US healthcare industry are costs rising at a double-digit rate, though, even in this period of exceptionally stable and low GDP growth. If this current rate of increasing expenses continues, the 2010 projections may well prove inaccurately low, especially if the elder population continues to expand and the expectations of the public continues to be increase from research, publications, Internet-accessible information, and advertising.

On the other hand, according to statistics from the Organization for Economic Co-operation and Development (www.oecd.org), the average life span in the US is lagging behind the median of other developed countries, and the infant mortality rate is substantially higher (the statistics are worse, too, for non-white minorities in the US). Furthermore, a series of severely critical reports from the Institute of Medicine [16, 17, 18], that began in 1998 states that as many as 97,000 annual patient deaths and injuries being caused by medical errors in the US. The IOM reports decry a missing "culture of safety" in healthcare, and they point to poor coordination of services and information between healthcare providers, and describe large variations in doctor's and hospital's practices, efficacy, and efficiency. In a presentation to the National Institute of

Standards and Technology, Dr. Middleton, of the Harvard Medical School points to massive overuse, under use, and waste in healthcare [26]. He also cites CMS estimates that the costs of quality failures in healthcare could approach $1 trillion, or 6% of GDP by 2001!

Many sources, including Dr. Middleton, the original IOM report, and the several IOM updates since its original 1998 publication, point out that better deployment of information technologies and the use of proven quantitative-based quality management techniques are among the key critical success factors for reversing these trends and for ensuring that the best medical practices are applied throughout the country [1, 18]. Despite the pervasive deployment of microprocessors in medical devices and the networking of many medical devices together [32], however, most computer-based hospital systems remain isolated islands unto themselves [31]. Most medical computer systems are designed to serve a unique medical specialty and/or location. Even if a system purports to support excellent care within the specialty, it is likely to depend on a doctor, nurse, or technician to integrate and interpret the information from multiple computer systems on their own, as few of the systems are designed to share information accurately and reliably with other such systems. Thus, unlike a fully-implemented Enterprise Resource Planning system, in which every participant from raw materials suppliers to the customers are effectively and automatically interconnected the healthcare enterprise must still rely on inefficient, error-prone, and unsynchronized manual information transfer and interpretation [7, 19].

II. Background for the Study

Consider this single example: in a recent report, only a small percentage of doctors were found to have access to an integrated electronic medical record for their patients. How do doctors gather information, then? They must collect copies of written reports, computer reports, and relevant images into their own personal manual files for each patient. Within a particular hospital, the manually-updated patient chart is the time-proven method of organizing much of this information, but such charts suffer from incompleteness (e.g., limited room for high-quality graphics) and difficult legibility from hand-written notes. Even if relevant diagnostic tests were recently performed at another hospital, they are not likely to be visible to the doctor, leading to missed information, expensive retesting, and incorrect or delayed clinical decisions. If the doctor had a full and current Electronic Medical Record, encompassing all current and relevant information, then the doctor would then be in a position to make the most accurate and effective diagnostic and therapeutic interventions possible.

Oddly, this particular problem is also being made worse currently, due to an unintended consequence of the HIPAA law that took effect in mid-October of 2003. The HIPAA law is designed to enhance Electronic Data Interchange between healthcare providers and payers, by enforcing a uniform, nationwide coding system [4]. To protect the patient's privacy, though, new security and privacy regulations took effect at the same time. In essence, each piece of information about a patient can only be released with the patient's direct consent, and/or it can only be released to an individual or organization with a bona fide need to know that information for the patient's medical care. Since automated systems do not yet exist to validate each all of a patient's current and potential doctor's identities and needs, many hospitals are restricting information access to their own house staff, and only to those staff currently assigned to the patient. The US healthcare system is heavily dependent on outside consultation for patient care, however, relying on specialized doctors' assessments and recommendations to optimize care. Because few email systems feature strong data security, many doctors and hospitals now forbid sending information that way, even to the patients themselves. Thus, medical records and reports are now being made verbally, directly over the phone or by fax, mailed, or hand-carried copies. Each doctor's records are therefore frozen at that moment in time, and will not reflect critical information that may be available from sources from that moment onward.

It should be clear that many of the problems are systemic in nature; that is, they are caused by inadequate or inappropriate system designs and grossly inadequate inter- and intra-organizational collaboration. The Institute for Medical Safe Medical Practices (www.ismp.org), the Agency for Healthcare Quality and Research (www.ahrq.gov) and the IOM all indicate that medication errors, for example, cause a substantial number of adverse patient outcomes. The use of hand written prescriptions – with separate, hand-written notes in the patient records – is a common source of errors. The doctor has to remember all of the potential drug interactions and contraindications for a specific patient, look at – and correctly interpret – all existing and prior drugs and medical complications from the mixture of hand-written notes (and only those from within his/her institution's records), and then make a decision for medication. The pharmacist must correctly dispense or compound the correct drug and dosage from the handwritten notations, avoiding closely synonymous drug and patient names, and then the nurse must administer the drug to the correct patient, at the correct time, while observing all relevant feeding and other specified restrictions. Further, there is no industry-accepted bar code identification for drugs, so the nurse must depend on memory to correctly recognize a particular pill or liquid. Lastly, since there is no uniform nationwide patient ID code or identification/tagging system, the nurse must depend on memory, a nearby family member, or the patients themselves (if lucid) to avoid giving the drug to the wrong patient.

Clinical engineers [6, 30, 32], surgeons [8, 9, 21], the Joint Commission on the Accreditation of Healthcare Organizations (www.jcaho.org), the Veterans Administration [30], and the Emergency Care Research Institute [6] have all documented similar serous communication and system problems in healthcare that have led to incorrect amputation of patient limbs, electrocution, and deaths. All of these sources identify the endemic compartmentalization of healthcare data, information, and knowledge as a primary cause of medical mistakes, waste, injuries, and death, leading to a renewed interest in designing, developing, and implementing inter- and intra-organizational collaboration systems.

II. A. The IHE Model for Healthcare Integration

The Integrating the Healthcare Enterprise (IHE) project is one of the only successfully growing international efforts in this area, focused on ending the "silo" architecture in healthcare. The IHE designs provide interoperability within and between the hospital's compartmentalized information and management systems. IHE represents a critical breakthrough towards collaborative intra- and inter-organizational business systems in healthcare, and this present paper describes a way to help enhance and accelerate the realization of those goals.

IHE is a project that was spearheaded by the Healthcare Information Management System Society and the Radiological Society of North America [14, 15]. In 2003, the IHE project also joined forces with another of the major healthcare collaborations, Health Level 7 (www.hl7.org), provides internationally-recognized inter- and intra-organizational data coding standards. Together, the IHE/HL7 initiative may well represent the largest healthcare information technology effort ever mounted, and it is growing very rapidly. Historically, the IHE project began as an effort to overcome the waste and miscommunication in one of the hospital's most high-cost, high-technology areas: the radiology department. Even though most modern radiology imaging devices were based on or had shifted to computer-based image capture, storage, and retrieval, few brands, models, or modalities (e.g., CT, MRI, or PET imaging systems) were able to exchange images or data. Thus, if an automobile accident patient needed a CT and an MRI image, the digital images and reports for each system had to be viewed, and reported, on separate Radiology Information System (RIS) terminals. Each RIS could often only store and access one type of image, and furthermore, billing details and summary diagnostic coding, had to be manually entered into the hospital's billing systems (often called a Hospital Information System – HIS – which also handles all Admission, Discharge, and Transfer – ADT transactions.)

The IHE standards for RIS and HIS are well developed today, and hospital demonstration sites are beginning to emerge [14, 15]. Several annual international collaboration demonstrations are held to allow continuous development and improvement for these standards. A hospital laboratory IHE effort is now well established in France and a Cardiology-oriented effort has been launched with the American College of Cardiology [12, 13]. Each of these projects is at an early stage, and this present work is intended to enhance their efforts.

II. B. Methodology for the Study

In the corporate world of the last decade, business processes have become a primary point of interest. Because of this, many tools have been developed to assist in process reengineering and deployment [2, 20]. This study employs the tools and techniques that have been made popular in Business Process Reengineering (BPR) for ERP systems and workflow management (WFM) to redesign the operating room. One of the most popular of these tools is the Event-Driven Process

Chain (EPC). EPCs have been used in thousands of ERP and WFM applications to date [2]. They are used to identify the core processes and model them using a simple set of icons as described in Figure 1. In the world of BPR, this relatively simple set of icons is used to create both "AS-IS" and "TO-BE" diagrams of the organization's core business processes (Curran and Ladd). This way, the implementers can perform a Gap Analysis and identify areas where system integration is needed most. This model also provides the basis for identifying the features that will be mapped to the new applications and the key system integration touch points. The result is a set of diagrams that provide guidance for the reengineering and systems integration process. Ideally this step should be complementary to the development of standardized healthcare ontologies as is occurring with the IHE as well as other industries [14]. This will lead to further systems integration efforts with specific tools such as XML, SOAP, wireless technologies, and HL7 among others [34, 35].

III. The Main Operating Room Scenario

The basic goal of the operating room is to provide a safe, effective, and efficient surgical intervention. As such there are many different stakeholders involved in a typical OR scenario. In a fundamental sense, in healthcare the primary stakeholder should always be the patient and family. On a moment-to-moment basis, however, the interaction with the hospital and departments is handled by surrogates from the medical and operational organizations. The OR represents a uniquely complex situation, too, as the patient or family can rarely speak for themselves in the midst of surgery. Instead, the patient and/or family have a team of physicians who have contractual authority and ethical responsibility to act on the patient/family's behalf during a surgical procedure. Thus, the anesthesiologist makes life-support decisions based on his/her expertise and beliefs, combined with the surgeon's input and the patient/family's written and oral guidance. Similarly, the surgeon often has to make moment-to-moment technique and technology decisions that are based on his/her own risk/benefit assessment that is, again, guided by prior patient/family input.

The OR does not function in a vacuum within the hospital. It is a sort of "surgical factory" that has a large number of suppliers and customers that must be integrated effectively in order to ensure efficient and safe outcomes. There are two types of OR patients: those with elective surgeries and those with emergencies, In an elective surgery, the patient and physician can usually choose when and where the surgery will take place, and appropriate supplies, staff, and other resources can be scheduled in advance. Emergency situations may allow limited prior planning by the patient/family, and the available resources may be constrained by circumstance or inadequate prior planning and/or experience. This discussion will focus on the elective surgeries, which include any type of surgery that can be scheduled in advance (e.g., replacement of a hip, abdominal cancer, cosmetic surgery, etc.).

There are multiple stakeholders in any elective surgery. They might be broadly grouped in to suppliers and customers, but the role of any one stakeholder may actually vary over the duration of the surgical event. As a simple example, in the midst of a surgical procedure, the pathology laboratory may supply the surgeon with several very rapid ("stat") tissue evaluations to help determine if a tumor has been completely removed from the patient's organs (i.e., a service supplier role for the surgeon). In order to properly invoice the patient's insurance, though, the pathology department may need to receive the surgeon's final diagnostic interpretation (i.e., an information customer of the surgeon).

One way of organizing the stakeholders may be by common clinical, administrative, and operational departments. In most clinical departments, there are often two or three components of the process, too

1. Clinical services (e.g., pathologist's evaluation of a tissue sample, including business office support such as bills, reports, and office consultations.)
2. Operational activities and resources (e.g., the laboratory equipment and facility, technical operators, quality assurance and maintenance services, and related reporting and billing support)
3. Necessary specialized supplies and services unique to the particular situation (e.g., special tissue staining chemicals or an outside consultant's independent diagnostic service.)

Here is a list of the common surgical stakeholders and the roles they often play:

Administration: Billing, staffing, facility management, records management. All of the building, facility, and staff must be coordinated to provide appropriate services for the surgical procedures. Each surgical procedure has a unique profile of necessary resources that must be properly allocated for a safe and efficient outcome. For example, an open-heart surgery may require a scheduling of an outsourced team of specialized "perfusionists" and related equipment to manage the heart-lung-bypass process, a specific operating room may have to be reserved for a long block of time to accommodate for the lengthy set-up, operating, and clean-up processes, appropriate nurses and surgeons must be available throughout the procedure, and a suitable recovery room and intensive care resources to ensure a safe outcome for the patient. Of course, there is also quite a bit of back-office work that needs to be facilitated, too, such as meticulous record keeping, electronic and manual billing, and general building and staff dietary services.

Anesthesiology department: The anesthesiologist (physician) and/or nurse anesthetist who plans and administers the drugs necessary to reduce or eliminate a patient's experience of discomfort or pain. This task also includes the critical moment-to-moment assessment of the patient's safety and monitoring the patient's vital signs before, during, and after the surgery. This role provides management of complex technology (e.g., the anesthesia machine that delivers anesthetic gases and also breathes for the patient), as well as an information management system that creates and stores an electronic journal of all vital signs during the surgery. (Pre-tasks: discuss anesthesia options and risks with patient; get signed consent form. Mid-tasks: Manage anesthesia, medications, fluids, and general patient safety. Post-tasks: Assist patient's recovery from anesthesia; manage complications.) The anesthesiologist is also responsible for managing the patient's blood pressure temperature, blood oxygen level, and heartbeat with the appropriate drugs, devices, and fluids.

Laboratory department: Pathology (cellular level evaluation of tissue samples as well as relevant viral and bacteriological consultation) and blood chemistry analysis. This department must often provide pre- and post-surgical analytical services in addition to "stat" examination and diagnosis during the surgical procedure in order to confirm adequate excision of diseased tissue and/or blood chemistry results during critical, life-threatening procedures.

Radiology and Imaging: X-ray, CT, MRI, Nuclear Medicine, Ultrasound. Many surgical procedures require prior diagnostic images and interpretation in order to accurately identify the disease/injury location, status, or gross pathology. Regardless of the imaging modality (e.g., X-ray, CT, MRI, etc), an accurate interpretation of the images is necessary. In addition, many cardiology, gynecology, neurology, orthopedic, and other surgeries require using imaging modalities during the procedure itself, and a specially-trained imaging technologist may be needed to operate the device(s).

Operating Room (OR)/Surgery: Any given hospital has a finite number of ORs, nursing staff, and surgeons. There are also a limited number of feasible combinations that are possible with these resources, and there may be a wide variability in the time that each surgery will require because of each patient's unique complications. Furthermore, some surgeries require special implants, donor organs, unique surgical supplies, and even specialized rental devices like laser scalpels or high-cost imaging systems (with specialists, of course), in order to properly perform the procedure. Those personnel within the sterile field near the patient must avoid contact with non-sterile objects or surfaces nearby, and depend on nearby mobile support staff to transfer information and objects to/from the sterile area properly. Many critical pre-operative tasks must be correctly performed, too, from general room, surgical area, and instrument cleaning and sterilization to careful patient-specific tasks, such as surgical site confirmation, drug allergy and interaction reviews, and organ blood-type matching. Since few of the items in the OR are bar-coded, all processes require a combination of manual and automated tasks.

Pharmacy: Special drugs may be needed for specific patients, due to allergies or unforeseen clinical circumstances. If the patient has an unusually difficult infection, or infection risk, special antibiotic "cocktails" will need to be mixed for intravenous (IV) infusion. Also, if a patient cannot eat, a special IV feeding fluid will need to be prepared. All IV fluids go directly into the patient's bloodstream, so sterility is very critical. Unfortunately, IV fluids mixed in the pharmacy often have a limited sterility lifetime. They cannot be readily mixed and stored in advance, so they are prepared only as needed.

Emergency Rooms (ER): Emergency surgeries have similar issues too. They require more abstract forecasting, though, because all contingencies cannot be known in advance. For example, there may be no way to control, or even predict, the timing of events like an earthquake. Most hospitals are required by law to have emergency plans in place, but few such plans are integrated into an automated command and control system. Adding the ER into the above list of stakeholders can make a lot of sense, especially for high-frequency trauma facilities in urban areas. Such a system could even include planning tools to help factor in the probably surgical needs of patients arriving in ambulances. Even if such a system were designed for a hospital, today it would only be a local solution that others could not easily adopt, as there are few industry standards in the field.

Additional stakeholder issues: The above list is representative, but is by no means exhaustive. There are many other departments and processes that play an important role and/or are directly affected by the specifics of each surgical case. Some patient's situations may require that specialized implants, organs, or other specialized supplies be available in advance. Morbidly obese patients – a more and more frequent issue today – may even require special surgical tables, transfer stretchers, bariatric recuperation beds, and rehabilitation devices that can safely support 400+ pounds. Most hospitals do not own such specialized devices, but instead rent them as needed. Careful coordination with the rental agency is needed, however, to ensure that these large devices come in and out of the hospital swiftly, so that they do not take up precious space – or waste money – unnecessarily. Many similar examples exist, including the rental of very specialized laser surgical devices, special video systems for surgery, and even certain portable imaging devices.

In short, it should be evident that effective surgery truly depends on coordination of efforts and data between many individuals, departments, and their information systems. Relying on word of mouth and memory has proven to be a recipe for disaster and waste in the OR. In the ideal surgical environment, there should be inter- and intra-organizational systems in place to help ensure a good outcome. The tools for this are beginning to emerge, however, and the IHE program will be one critical component of the solution.

IV. Reengineering the Operating Room Core Processes

The starting point for reengineering the OR is to examine the core processes and information sharing required to support them on in the OR. This discussion is based, in part, on an "Operating Room of the Future" concept that is currently being designed, developed, and tested by US government and hospital teams [23, 24, 25, 27,]. The OR of the Future, as described by these researchers, is an attempt to overcome many of the sources of waste and mistakes in the OR. As will be shown, there are many internal and external businesses that must collaborate in order for surgeries to proceed efficiently and effectively. For example, Figure 2 shows some of the key information and workflow that is must be coordinated by various departments and information systems in a hospital. (Legend: PIS – Pharmacy Information system; AIS – Anesthesia Information System; HIS – Hospital Information System; ORIS – Operating Room Information System; LIS – Laboratory Information System; RIS – Radiology Information system.) One design requirement of the Operating Room of the Future design is to enable integration of such information and workflows, and the tools and methodology in this paper is intended to help realize that goal.

The information-related tasks shown in Figure 2 represent an approximate time sequencing, which is elaborated in much more detail in the following section. The darker blocks in Figure 2 represent core, or required activities. The lighter blocks represent activities that may or may not be necessary.

The following figures show EPC process flow diagrams to illustrate a representative surgical event for one patient. They begin with the decision to schedule an "elective" surgical procedure (i.e., it is an "elective" event because it is not an emergency) and run through a series of process steps until the patient is released to home care. For clarity, it can be noted that there are many other steps involved before and after the surgery, but they are not included because they are not directly relevant to this discussion.

At the top of Figure 3, the patient has just made a decision to schedule an elective surgery. This typically would occur after a specialist and/or a surgeon has made a preliminary diagnostic evaluation and recommendation that surgery appears to be the recommended therapy. Two events must take place: the surgery must be scheduled at a time when all of the necessary resources (staff and facility) are available. Although many preliminary diagnostic procedures are likely to have been already completed, some pre-surgical blood work or X-rays may need to be scheduled. Also, if the patient's situation is unique, special medicines, implants, or other supplies may need to be ordered in advance. At the end of Figure 2, all of the necessary requirements prior to surgery are complete, and no additional actions may be needed until the patient arrives for the surgery itself, as shown in Figure 4.

The Admission process may require multiple events, including final insurance verification, updating of medical records with recent records, and evaluation and possible repeat of any last-minute diagnostic tests that raise flags (e.g., an unexpectedly low red blood cell count may indicate a new surgical risk.) Presuming that everything is in order, the patient will be assigned a Pre-Op Bed to await the next steps. Often, as shown in Figure 5, this will involve a brief consultation with the anesthesiologist to make a final decision about the appropriate method and to obtain written consent from the patient.

As shown in Figure 5, once the patient has signed the anesthesia permission paperwork, pre-anesthetic doses of muscle relaxants and sedatives may be administered for the patient's comfort. The patient is then transported to the OR to surgery.

Once the patient arrives in the OR, several events take place. As seen in Figure 6, these events can include the actual initiation of anesthesia, which may include inserting a needle in the spine and/or a breathing tube in the larynx. In addition, a member of the surgery team must ensure that the correct surgical site is identified, draped, and appropriately prepared for surgery. The actual surgery cannot proceed until the patient is satisfactorily anesthetized and a sterile surgical field has been fully established in order to minimize the possibility of unnecessary infections.

Figure 7 shows the flow that would occur in a simple, uncomplicated surgical event, but, according to published research unexpected complications extend the procedure 50% or more of the times. When this happens, not only is the surgeon, anesthesiologist, and OR availability delayed, but the patient's post-surgical support needs may need to be changed significantly. In these situations, many other stakeholders (and their information systems) must be notified in order to accommodate the changes, as illustrated in Figure 8.

Examples of the changes that can happen when major complications arise in Figure 8 include the following:

1. Subsequent patient's surgeries may need to be delayed or cancelled.

2. A different surgeon and/or anesthesiologist may need to get permission to manage the surgery for one or more delayed patients.
3. Additional surgical and medical specialists may need to be consulted to devise a safe action plan.
4. Support services, such as the Laboratory, Radiology, and Pharmacy may need to arrange overtime coverage to accommodate the extended surgical day.
5. The administrative team may need to suddenly arrange find a high-acuity bed, which can be a serious problem if the hospital is full.

Figure 9 illustrates that in a collaborative enterprise like an OR, any significant complication has multiple cross-enterprise process implications. The surgical complication in this scenario not only affects the surgeon, nurses, and OR availability, but also the laboratory and radiology technicians, anesthesiologist, pathologist, radiologist, and pharmacist. It is documented that this happens in 50% or more of surgical cases, but in most current hospitals, this coordination depends on individual communication and manual paperwork.

Each of the activities in Figure 8 represents critical opportunities for improved collaborative commerce. For example, in the center of the figure is the task of rescheduling ICU and other hospital bed resources. Although a casual observer may not realize it, many US hospitals are having chronic bed shortages [4, 10]. Decision support systems (DSS) using neural net and other techniques are emerging in the research literature to aid optimal decisions and allocation of scarce hospital beds and other resources [22, 28, 29, 33, and 36]. In order for DSS and KM tools – including critically needed healthcare collaboration tools from other industries [3, 5, 11, to be successfully deployed in healthcare, they must be integrated into a collaborative workflow system.

V. Conclusions

Healthcare is a critically important industry, and an increasing amount of resources are devoted to it. Despite this, it is well documented that there are many inefficiencies in the healthcare enterprise. Attempts have been made in the past to integrate and standardize the electronic sharing of information, but comprehensive cross-enterprise models are only now beginning to emerge. In this paper we have adapted a proven design and documentation tool, the Event-Driven Process Chain (EPC), from the Business Process Re-engineering (BPR) world of Enterprise Resource Planning (ERP). We have used EPC diagrams to organize and represent the collaborative workflow needed for surgery. This modeling approach can also serve as a tool for designing and implementing the Operating Room of the Future.

In addition, this model can be extended to facilitate the planned expansion of the IHE framework to, and across, multiple clinical information systems. This model captures both the front- and back-office processes, instead of only emphasizing clinical (front-office) aspects. Back-office processes like bed management, vendor/supplies procurement, facility maintenance services, scheduling, and billing are all essential to efficient hospital enterprise operation.

Lastly, and perhaps most importantly, this methodology provides a formal representation that development and programming teams can use to guide their system design and implementation. Prior IHE development has proceeded slowly, in part because it has relied on strong manufacturer support and investment to figure out how to actually implement the broad tasks and goals into each medical specialty. This has delayed the development and deployment of commercial IHE-compatible systems. Going forward, each new clinical area that IHE embraces will increase the complexity, and cost, of implementation, because the newcomers not only need to master their own areas but they must also figure out how to integrate with prior system design from the other specialties. If EPC or some similar tool is adopted now, it can save wasted effort and money. It can help to improve the overall outcome by enhancing the visibility of the inter- and intra-organizational collaboration processes that must be supported.

Despite the enormous complexity of collaborative commerce in the healthcare enterprise, we believe that the success of EPC, BPR, and ERP in the corporate world bodes well for this endeavor in the healthcare field. Once the fundamental integration and collaboration issues are addressed in healthcare, new opportunities will emerge. Comprehensive, consistent databases and information systems may be finally joined together to facilitate desperately needed DSS and KM tools, opening the way to a new era of collaborative healthcare business management. It would be hubristic to suggest that this present model captures all of the details necessary to understand the highly complex OR work and information flow. Each of these individual diagrams in and of themselves could be the subject of extensive future research. Each group of processes will likely require lengthy efforts by a dedicated IHE committee to carefully define and resolve all of the critical design details that will be needed to develop an acceptable, generalizable, industry-standard model. This paper is a first attempt at applying general cross-enterprise MIS process re-engineering tools and techniques to healthcare's IHE project. Further research is required in order to validate, extend, and apply these tools to the multiple complex business centers within the healthcare industry.

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FIGURES

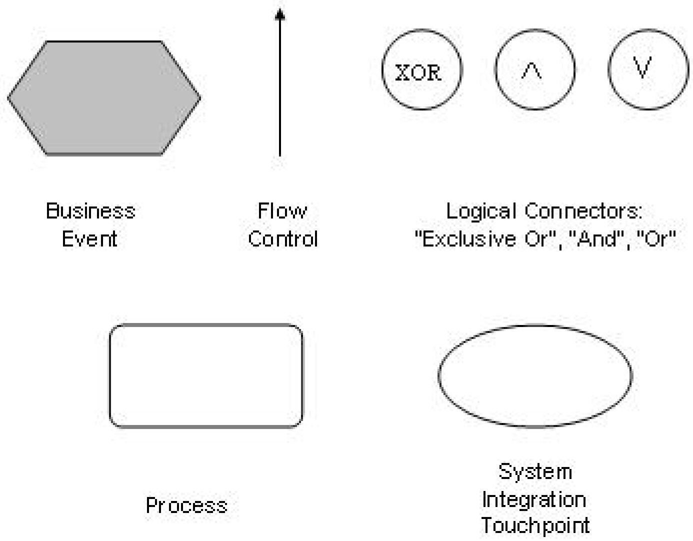

Figure 1 Examples of Event-drive Process Chain (EPC) methodology icons

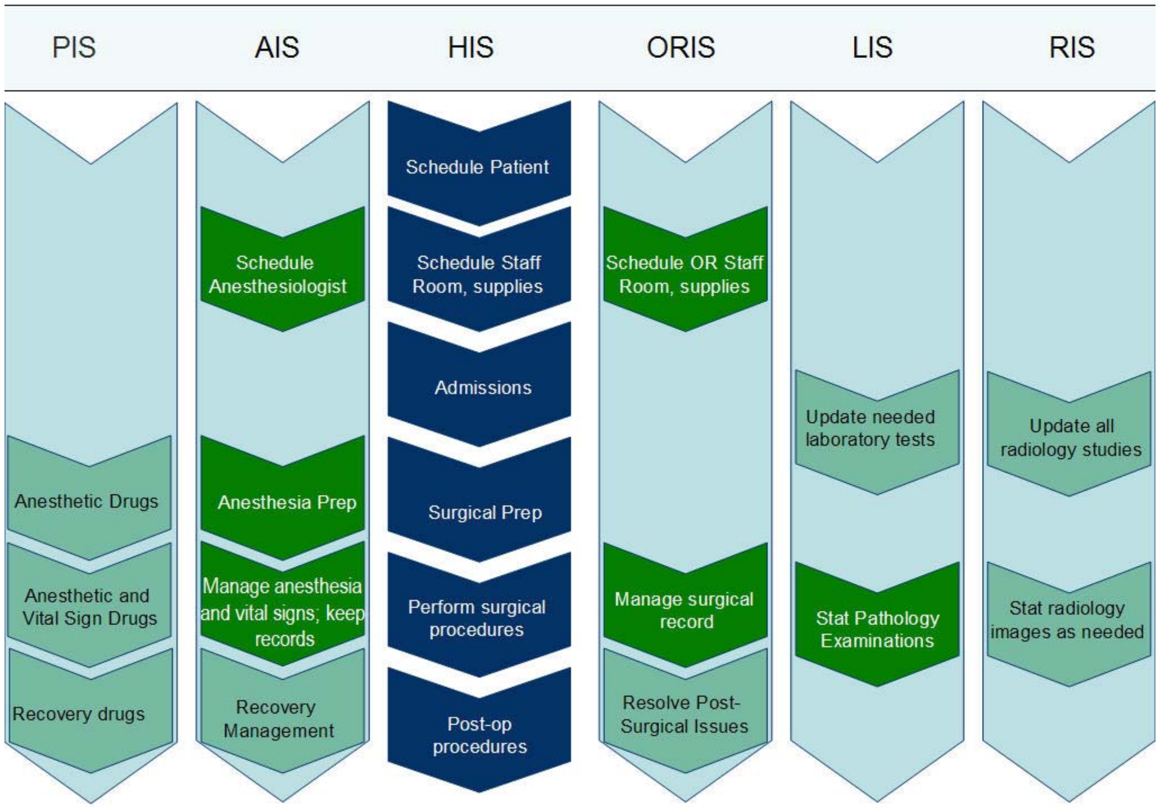

Figure 2: Sample of the surgery-related information used by hospital information systems

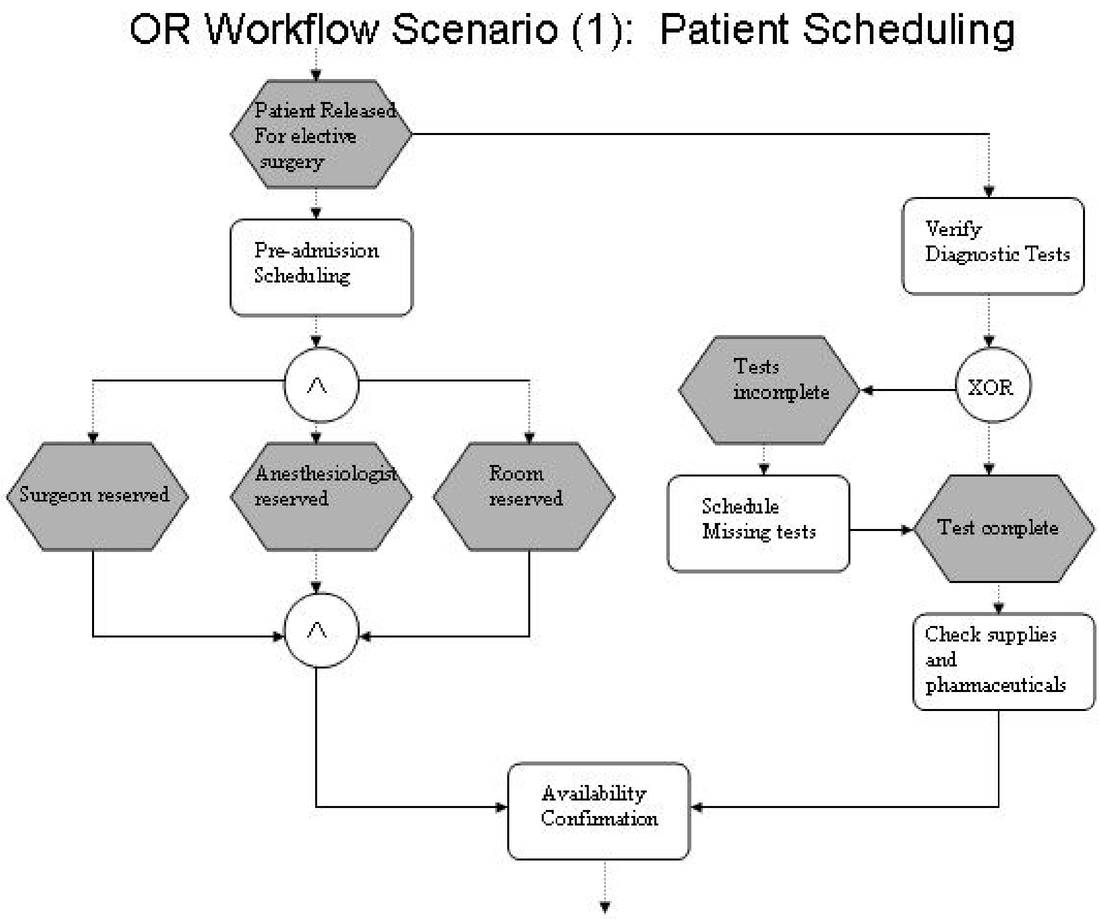

Figure 3 Initial entry of patient into the surgery process; pre-surgical scheduling and diagnosis

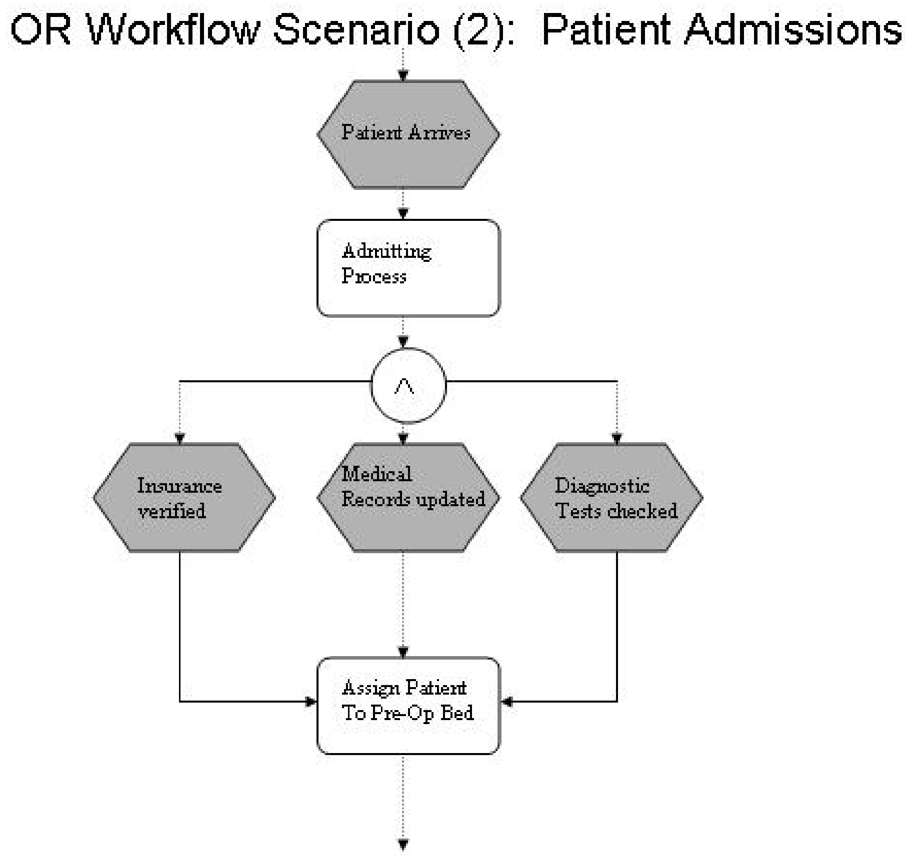

Figure 4 Patient admission process, immediately prior to surgery

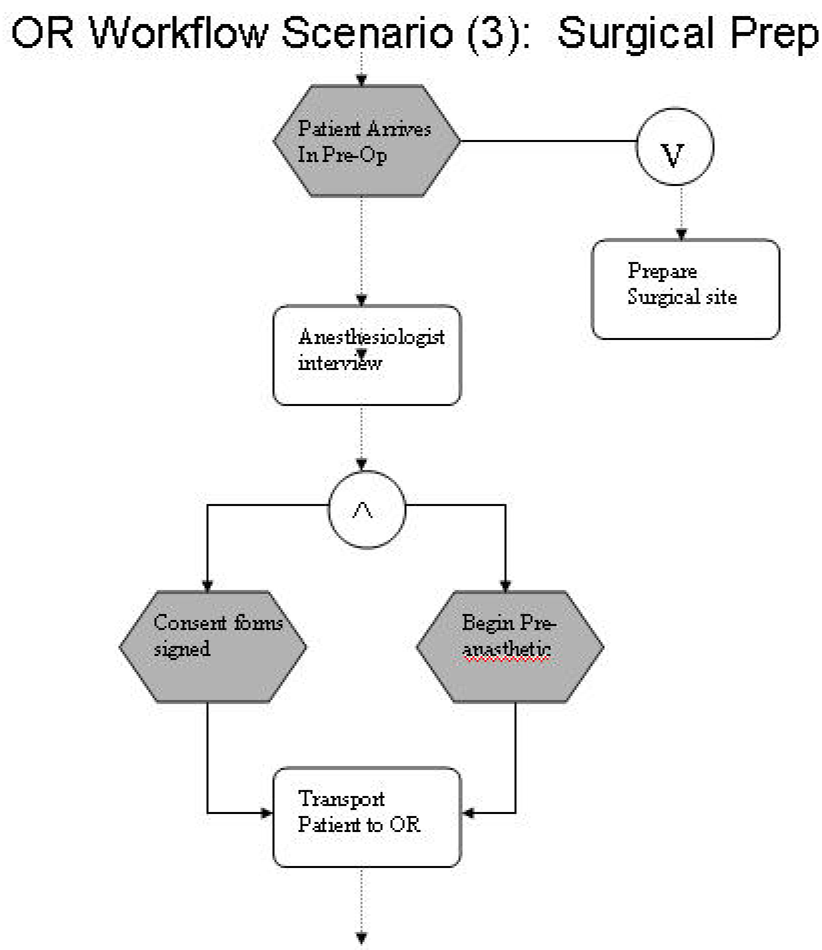

Figure 5 Initial Pre-Surgical process: Anesthesiology-related tasks

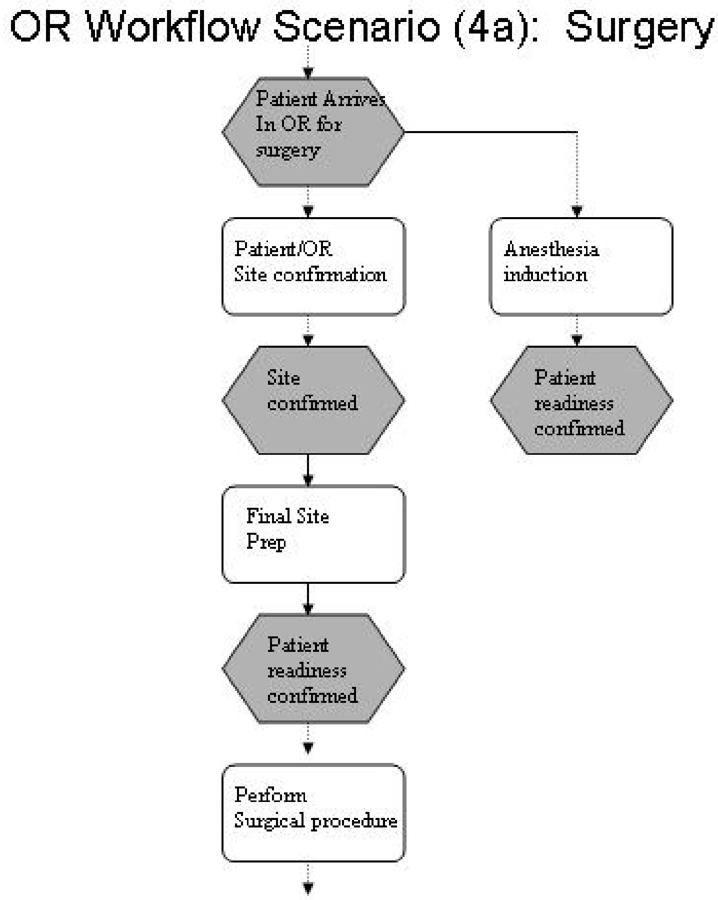

Figure 6 Early activities with the patient inside the OR

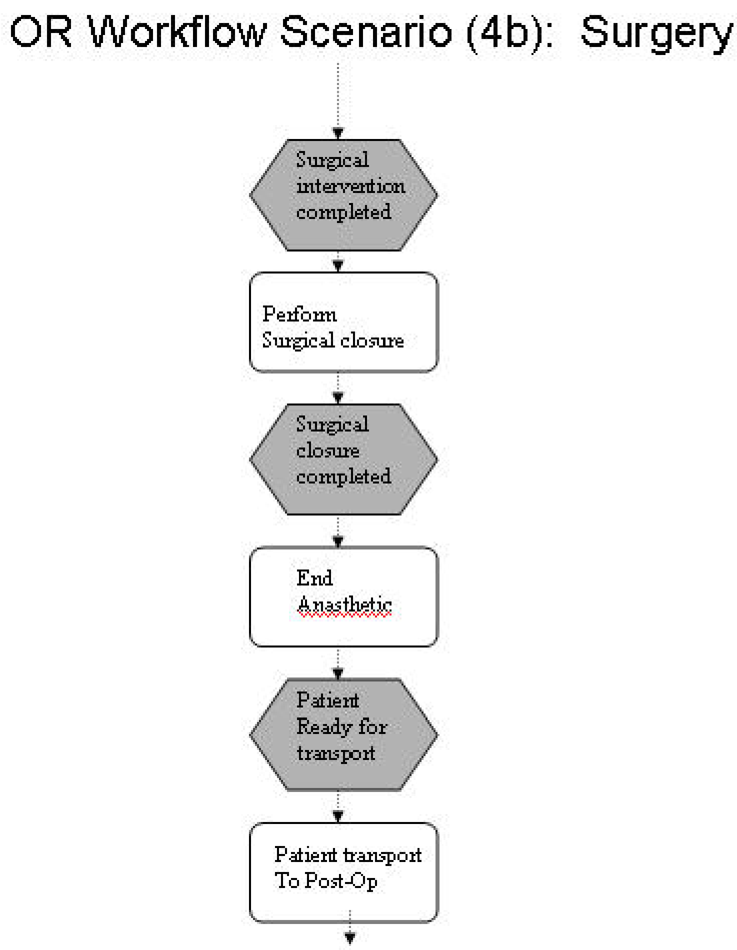

Figure 7 The activities in the surgery itself (no significant complications)

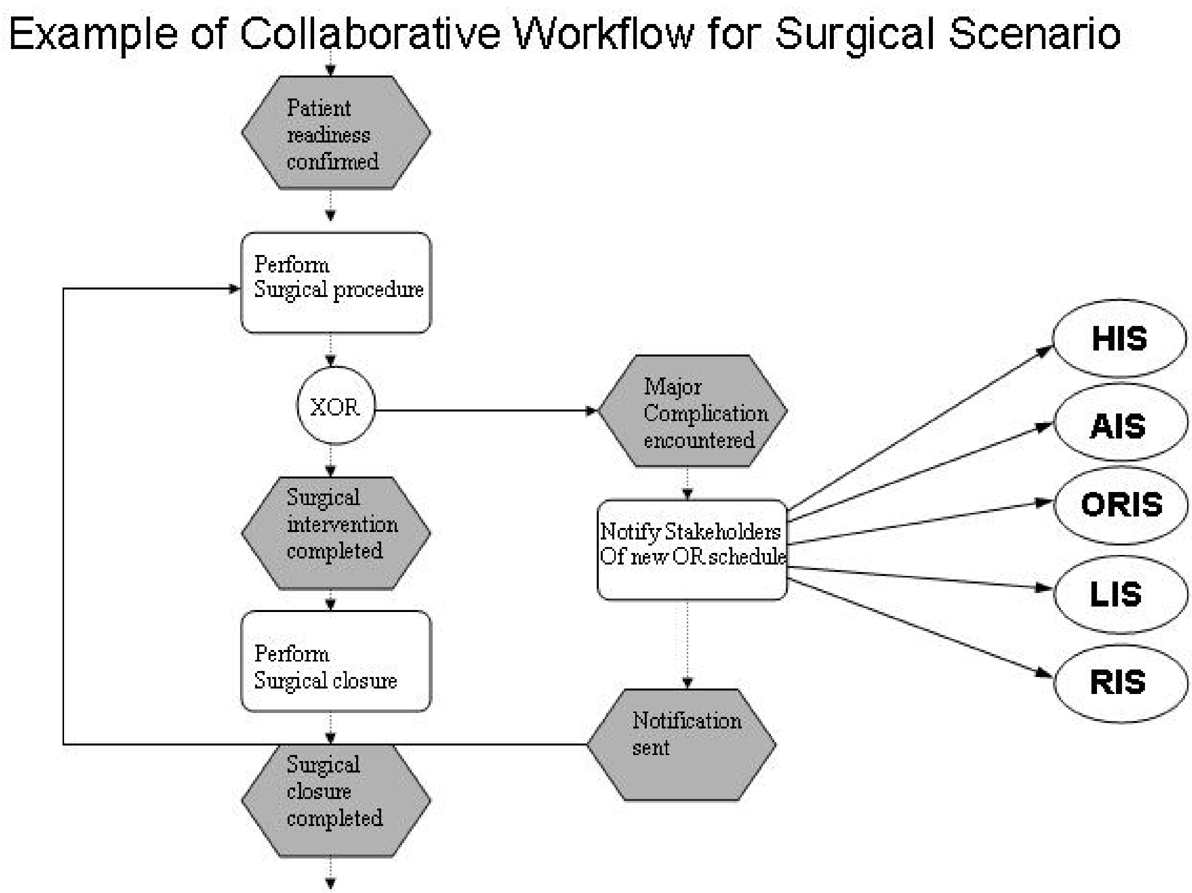

Figure 8 Inter- and intra-organizational collaborative workflow to accommodate surgical complications that frequently occur. (Touchpoints to stakeholder information systems are

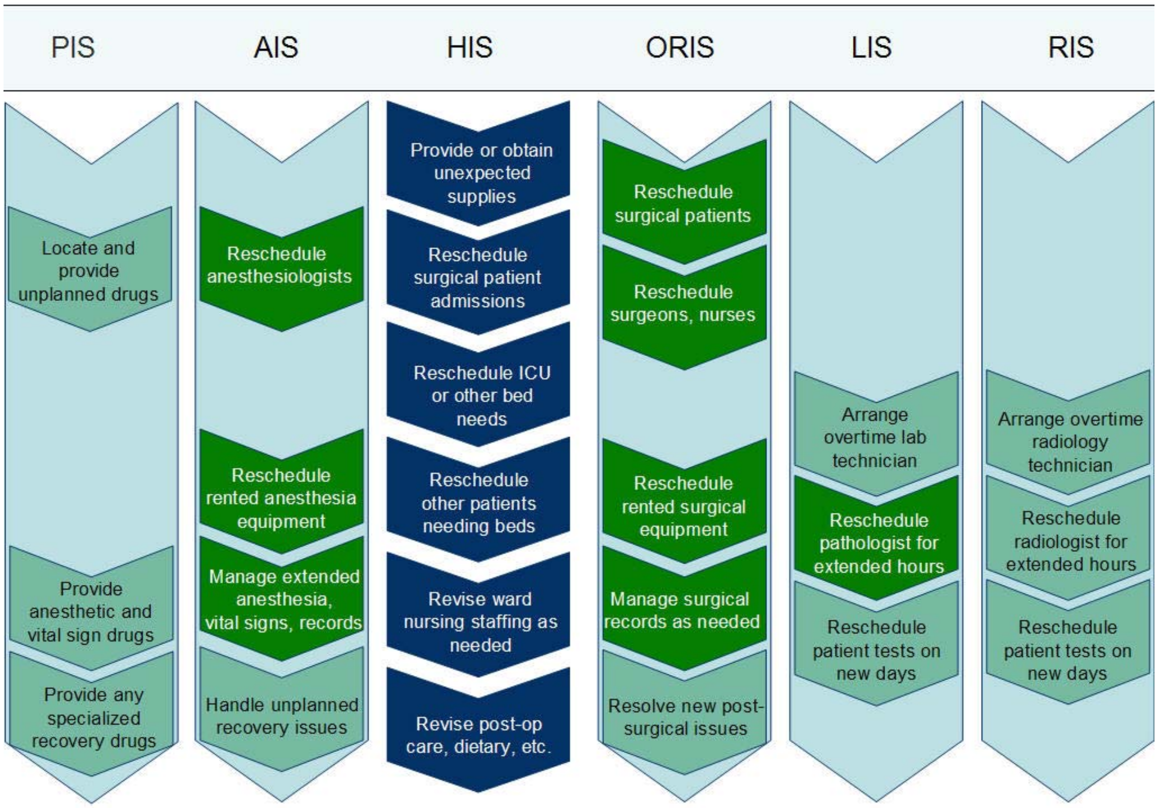

Figure 9 Representative workflow impacts of surgical complications (occur >50% of the time)