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ABSTRACT

This study examines data mining as an extension of system design to support continuous process improvement. This paper identifies how dynamic technological activities of synthesis, analysis, and evaluation can highlight complex relationships within integrated information systems through existing patterns of associated organizational data. The identification of data patterns and subsequent human contextual understanding are contributing factors that yield business process redesign opportunity and re-enforce continuous process improvement within the perioperative services of a hospital. Based on a 72-month longitudinal study of a large 909 registered-bed teaching hospital, this case study investigates the operationalization of data mining in business process redesign as a method to identify, qualify, understand, and capture benefits from continuous process improvement. The theoretical and practical implications and/or limitations of this study's results are also discussed with respect to practitioners and researchers alike.

Keywords

Perioperative services, hospital information systems, system design, data mining, holistic model, business process redesign

INTRODUCTION

Perioperative services provide surgical care for inpatients and outpatients during immediate pre-operative, intra-operative, and immediate post-operative periods. From a hospital's operational perspective, specialized perioperative services require multidisciplinary, cross-functional surgical teams to maneuver within a complex, fast-paced, and critical environment—the hospital environment (McClusker, Dendukuri, Cardinal, Katofsky, and Riccardi, 2005). As a result, perioperative services are tightly coupled to patient flow, patient safety, patient quality of care, and stakeholders' satisfaction (i.e. patient, physician/surgeon, nurse, and perioperative staff). Similarly from a hospital's financial perspective, perioperative services are typically the primary source of hospital admissions, averaging between 55 to 65 percent of overall hospital margins (Peters and Blasco, 2004). Given the rising cost of healthcare, the public demand for healthcare transparency and accountability, and the current economic environment—managing and optimizing the processes within perioperative services are critical success factors (CSFs), both operationally and financially, for any hospital.

Within information systems (IS), organizational data represents business processes and organizational importance. For this reason, IS and information technology (IT) have had and continue to have increasingly greater roles in the healthcare industry (Connor, Ponte, and Conway, 2002; Garg, Adhikari, McDonalid, Rosas-Arellano, Devereaux, Beyene, Sarn, and Haynes, 2005; Haux, 2006; Raghupathi and Tan, 2002). With regards to performance toward CSFs, an integrated IS offers salience because it provides both the means and metrics for measurement. With regards to mining organizational data for business process improvement, an agile IS contains organizational data that describes the desired process to synthesize. However, Wears and Berg (2005) notes that IS and/or IT only yield high-quality healthcare when the use patterns are tailored to knowledge workers and their environment. Hence, hospital IS that exhibit integration and agility would reflect present and potential business processes in its organizational data.

This paper examines the operationalization of data mining to identify, qualify, and quantify benefits derived from continuous improvement through business process redesign. The case results are facilitated by empowered individuals driven by integrated organizational data. The investigation method covers the longitudinal study of an integrated clinical scheduling information system (CSIS) within the perioperative services of a large, teaching hospital. The implementation of an agile CSIS and subsequent contextual understanding of perioperative data patterns within the CSIS prescribed the need to redesign perioperative processes. Specifically, the extension of data mining into the analysis and evaluation process of CSIS' data provides the framework for the discovery and synthesis of a new business process within perioperative services. The implementation of the newly synthesized process began the change dynamics for mining additional data patterns to discover and synthesize additional processes. The following sections review previous literature on data as a resource, system design, and data mining. By identifying a holistic model for evaluation, analysis, and synthesis between data and process design, this paper prescribes an a priori environment to support mining organizational data for business process redesign. Following the literature review, we present our methodology, case study background, as well as an analysis of the observed effects from mining perioperative data for business process redesign. The conclusion discusses implications and limitations of this study.

DATA AS A RESOURCE

Data is a prerequisite for information, where simple isolated facts are given structure through IS design to become information. Early in the IT literature, Ackoff (1967) proposed IS design should embed feedback as a control to avoid management misinformation. Zani (1970), Rockart (1979), along with Munroe and Wheeler (1980) proposed the selection and supervision of defined data as key performance indicators (KPIs) to assist management in qualifying data needs against CSFs and subsequently managing organizational action (i.e. business processes) through IS feedback. Similarly, healthcare processes within perioperative services are becoming increasingly information intensive and doubt exists as to whether perioperative process management is fully understood to meet the increasing hospital environmental demands for value and cost management (Catalano and Fickenscher, 2007). Understanding how IS design embeds processes into data input and information output is a first step toward understanding data as a resource for process redesign.

Human mind hierarchy

Given that organizational action requires people, people develop IS, people use IS, and people are a component within IS (Silver, Markus, and Beath, 1995); the content of the human mind is a requisite in understanding how organizational action via IS occur. Ackoff (1989) proposed a content hierarchy of the human mind with wisdom descending to understanding, knowledge, information, and then data. According to Ackoff, scarce to little wisdom may exist with the other four categories increasing in quantity and availability through hierarchical descent. Each category is an aggregate of the categories below it.

Achieving wisdom requires successively upward movement through the other four human mind content categories, with each level drawing content from prior levels. Data, information, knowledge, and understanding relate to past events and wisdom deals with the future as it incorporates vision and design. The IT literature accepts that data and information are IS inputs and outputs, with other authors of knowledge management literature sharing similar hierarchical views of human mind content (Earl, 1994; Davenport and Prusak, 1998; Tuomi, 2000). Ackoff (1989) concluded that wisdom might well be the characteristic that differentiates the human mind from the IS. Consequently, it is understanding and knowledge of the business process that is required by system stakeholders to develop information requirements and subsequent data requirements for IS design.

System Design

The IT literature contains volumes of studies to offer opinions on system design. For this study, the intent is to provide a basic understanding of system design activities and substantiate the need for iterative improvement. Blanchard and Fabrycky (2010) identify system design as a requisite within the systems life cycle, where technological activities of synthesis, analysis, and evaluation are integrated within iterative applications to obtain benefits from continuous improvement. Continuous improvement to system design within the systems life cycle minimizes systems' risk from entropy, obsolescence, and environmental change.

Under ideal terms, the human mind uses wisdom to recognize organizational needs, using understanding and knowledge to create IS designs based on organizational needs, and then coordinates the IS data inputs and information outputs for the desired organizational actions to meet organizational needs. The ideal situation is hypothetical, yet it does illustrate that during the design, development, implementation, and maintenance stages of an IS (i.e. the systems life cycle), the human mind identifies data only after the availability of understanding, knowledge, and information. Understanding, knowledge, and information are decontextualized into detached data and semantic data structures that are accessible by IS' processes. Tuomi (2000) called this set of human mind sequences a reversed hierarchy from the traditional model (i.e. data leads to information and then on to knowledge, understanding, and wisdom).

Data Mining

More recently, IS are used to assist in the organizational action of discovery. Jon Udell (2004) compared data to Play-doh—a tangible substance that can be squeezed, stretched, and explored directly. Witten and Frank (2005) define data mining as the process (i.e. automatic or semiautomatic) of discovering patterns (i.e. structure) within data, where the data already exists within the IS' databases in substantial quantities and the discovered patterns have organizational importance. Data mining can explore raw data to find organizational and environmental connections (bottom up), or search data to test hypothesis (top down) producing data, information, and insights that add to the organization's knowledge (Chung and Gray, 1999). Data mining uses the traditional model of the human mind to churn data, existing within the IS, into information that leads on to knowledge, understanding, and possibly wisdom. With respect to this study, data mining allowed pattern recognition of business process data, which allowed the synthesis of an improved business process. Unfortunately, the healthcare industry has not fully embraced data as a resource and utilized data mining as a knowledge discovery tool (Wickramasinghe and Schaffer, 2006; Catalano and Fickenscher, 2007; Delen, Fuller, McCann, and Ray,2009; Liu and Chen, 2009; Ranjan , 2009).

Holistic Model for System Design and System Discovery

Figure 1 depicts this study's proposed holistic model for mining perioperative data for business process analysis and redesign. The model incorporates the IT literature we have discussed over data as a resource, system design, and data mining. As stakeholders design a new IS, the system designers draw upon the reversed hierarchy (Tuomi, 2000) to embed and encapsulate organizational actions into the new application. Collected data inputs within the implemented IS represents organizational action (i.e. business processes). Data mining analyzes the data patterns for meaningful structure. Evaluation of the meaningful data pattern structures leads to synthesis (i.e. redesign) of improved or new organizational action. The model depicts the iterative nature of system design and system discovery, which derives benefits from continuous improvement.

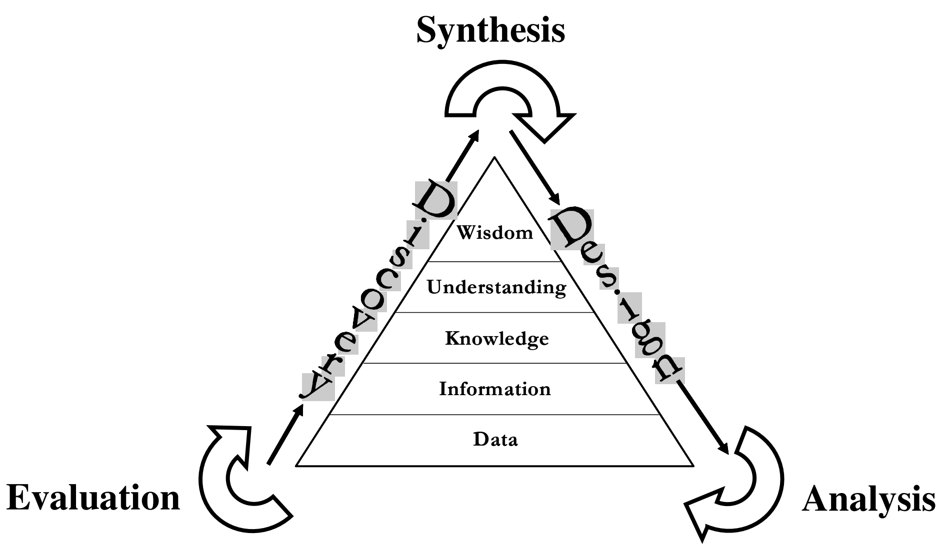

Figure 1 – Holistic Model for System Design and System Discovery
Adapted from R. L. Ackoff's (1989, page 3) hierarchy of the human mind

RESEARCH METHOD

The objective of this study is to investigate the operationalization of data mining to identify, qualify, and quantify benefits derived from continuous improvement through business process redesign. The case results are facilitated by empowered individuals driven by integrated organizational data. To this end, case research is particularly appropriate (Eisenhardt, 1989; Yin, 2003). An advantage of the positivist approach (Weber, 2004) to case research allows concentrating on a specific hospital service in a natural setting to analyze the associated qualitative problems and environmental complexity. Hence, our study took an in-depth case research approach.

Our research site is a large teaching hospital (University Hospital), licensed for 909 beds and located in the southeastern region of the United States. University Hospital is one of two magnet hospitals in the state and the U.S. News and World Report recognized University Hospital as a Best Hospital in 16 of the last 18 years. Concentrating on one research site facilitated the research question investigation and allowed the continued collection of longitudinal data. This study spans activities from 2003 through 2009. During the 72-month study, we conducted field research and gathered data from multiple sources including interviews, field surveys, site observations, field notes, archival records, and documents reviews.

UNIVERSITY HOSPITAL CASE BACKGROUND

The perspective of this research focused on University Hospital's perioperative services from 2003 through 2009. Perioperative services implemented a new CSIS in 2003, after using its prior CSIS for 10 years. The old CSIS and its vendor were not flexible in adapting to new data collection needs, thus the old CSIS did not meet the needs of perioperative services. The old CSIS did not have advanced online analytical program (OLAP) tools and the perioperative data mart was a collection of Microsoft Access databases. The new CSIS from vendor C was equipped with OLAP tools, a proprietary structured query language, and both operational and managerial data stores (i.e. operational data and a separate perioperative data mart). The new CSIS had flexible routing templates that could be customized (i.e. from 4 to 36 segments to capture point of care data) over generic and specific surgical procedures. The new CSIS was fully implemented by the end of 2003. Since its implementation, University Hospital has deployed over 300+ surgical procedural modifications across the following surgical specialty services (SSS) represented in Table 1.

Cardiovascular I Thoracic	Neuro	Surgical oncology	Vascular
ENT-ear, nose, throat	Oral Maxil Facial	Transplants-including renal procedures	
GI-gastro intestinal	Orthopedic	Trauma-burns, MASH	
GYN- obstetrics, oncology, incontinence	Plastic surgery	Urology	

Table 1 – University Hospital's Surgical Specialty Services (SSS)

CSIS Data

The perioperative scheduling staff (i.e. registered nurses with extensive perioperative experience) build the routing sheets for each SSS procedure, with the option to customize the routing for surgeon specific requests or patient specific needs. In turn, the routing sheets dictate which people, devices, equipment, and materials are needed in each OR suite during each scheduled surgical case. During each surgical case, OR team members document and log activities in each OR suite. University Hospital's CSIS collects perioperative data across the entire SSS case procedure, which includes:

- Patient time out procedure data points – required by the Joint Commission on Accreditation of Healthcare Organizations and the Center on Medicare and Medicaid Services (i.e. validation to the patient as to what will occur while they are anesthetized and that the procedure actually occurred)
- Documentation of all the people, devices, materials, procedures, components, equipment, and robotic usage
- Time the patient enters the OR, the procedure starts, the procedure stops, and the patient exits the OR
- Quality issues for patient longitudinal outcomes, retained object counts, and robotic usage

After each SSS case completion, the perioperative scheduling staff reviews and reconciles the perioperative data specific to each SSS case performed and then the data is moved to the perioperative data mart for managerial access. Perioperative data is available for general reporting, CSF benchmarking/progress reporting, truth in scheduling reports, surgeon research requests, intern and nurse documentation, and OLAP (i.e. data mining). During FY2004, perioperative data was collected for over 20K SSS cases and during the time frame of this study, perioperative data is available for over 155K completed SSS cases. University Hospital's CSIS' data mart holds terabytes of perioperative data.

Figure 2 depicts University Hospital's IS architecture for Perioperative Services as of January 2004. University Hospital has six main IS: (1) a large-scale hospital materials management IS, which included pharmacy, material and medical device management (Vendor L); (2) a large scale enterprise resource planning IS (Vendor 0); (3) a patient record admit/discharge IS (Vendor Q); (4) a cost accounting IS (Vendor T); (5) a financial budgeting IS (Vendor H); and (6) a clinical scheduling IS (Vendor C) that included clinical scheduling, routing sheets, and cost data. The integrated IS have uni-directional constraints placed on sensitive information. The institutional intranet serves as portal access to extend each of the six IS. User authentication via the intranet was single entry with particular user rights and privileges negotiated upon authentication.

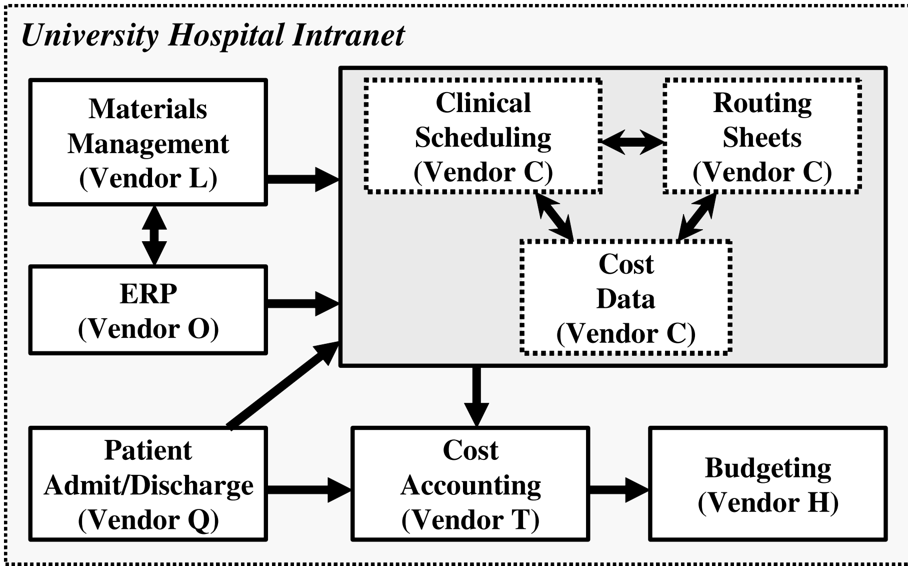

Figure 3 - IS architecture (October 2004)

Perioperative Critical Success Factors

KPIs in managing and optimizing perioperative services are monitoring the percentage of surgical cases that start on-time (OTS) and the number of first-of-the-day surgical cases (FCOD_OTS) that start on-time (Barnes, 2010). OR schedules are tightly coupled to the individual OR suites and surgeon. When the prior case runs over or a surgeon is not available to start the next case, the subsequent scheduled cases in the particular OR suite or particular surgeon fall behind. Poor KPIs on either metric (OTS or FCOD_OTS) impacts critical success factors of patient safety, patient quality of care, surgeon/staff/patient satisfaction, and hospital margin (Barnes, 2010; Peters and Blasco, 2004; and Thomson Group, 2010). The Thomson Group (2010) also noted that physician/surgeon satisfaction, a critical success factor for hospital margin, is also impacted by OR suite turnover time between cases and a flexible, efficient perioperative work environment.

November 2004

University Hospital opened a new diagnostic and surgical facility in November 2004, which covers three-fourths of a city block rising 12 stories. Perioperative services were relocated into three floors, with operating rooms (ORs) located over two floors and Central Sterile Supply (CSS) located separately on the third. The move expanded perioperative services to cover an additional floor and nine additional ORs. The new facility housed 40 state-of-the-art OR suites, each equipped with new standardized equipment. Groups of SSS OR suites categorized a surgical specialty (i.e. Cardiovascular having six unique ORs), with each particular room among the group containing specialty equipment. Within six weeks of occupying the new perioperative facility, scheduling metrics reflected chaos. On-time surgical case starts plunged to 18% during December 2004. Within a highly competitive hospital industry, having only 18% OTS was unacceptable. Within perioperative services, having 82% of scheduled surgeries backlogged risks patient care and safety.

Perioperative concerns were laid out before a quickly convened executive committee that included the chief executive officer, the chief financial officer, the chief information officer, the chief nursing officer, and top representatives of surgeons, anesthesia, CSS, and perioperative management. The meeting resulted in a changed management structure and the formation of a cross-functional, multidisciplinary executive team who was empowered to evoke change. The executive team and numerous task forces formed to address specific problems and/or opportunities were chartered to focus on patient care and safety, attack difficult questions, and no issue was “off-limits.” The executive team was commissioned by executive officers to investigate the challenges and determine what were the underlying issues and the overall strengths of each issue. The team consisted of surgeons, nurse leaders, anesthesiologists, and perioperative management. The executive team and task groups were challenged to systematically identify issues and enlist working managers for solutions that would facilitate change and minimize departmental chaos.

Perioperative SSS Block Scheduling

In November 2004, University Hospital allocated OR suites by SSS—scheduling blocks of time for an OR suite from 7 a.m. to 4:30 p.m., regardless of the SSS caseload. Scheduling OR suites by SSS assigned blocks did not reflect actual SSS cases within the scheduling blocks (i.e. the scheduling method did not reflect the OR data collected by the CSIS). The inefficient practice of block scheduling OR suites was directly attributable to University Hospital reaching 100 percent of capacity for its new perioperative facilities within six weeks of relocating, even though the new facility had increased existing OR room capacity by 33 percent. However, block scheduling a single OR suite was required. As a Level I trauma center, University Hospital must accommodate trauma patients 24/7, so the practice of block scheduling one of the general OR rooms was retained, specifically for trauma patients.

The hours logged within the data mart from SSS cases were analyzed. The data patterns showed the need to re-design the OR scheduling process. As a result of the perioperative data analysis, a straight SSS block assignment was discontinued. Given that physician satisfaction is linked to OR block scheduling by SSS (Peters and Blasco, 2004), block assignments were kept for outside-of-a-week planning purposes. However, the block assignments of OR suites were modified to reflect the actual SSS case loads. This particular data analysis has been instituted as part of the perioperative review process. SSS specific block release rules were established with consideration to the individual service's patient population. Similar to marketing segmentation among demographic groups, SSS specific needs were analyzed to establish predictable surgical specialties having patients with prearranged surgery conditions. SSS with wide variability in scheduling were given consideration and a reduction in the number of early release blocks of OR suites.

Given the slow learning curve associated with the OR relocation disruption, a new KPI was established to track surgical case OTS within 10 minutes. Figure 4 represents the surgical case OTS for December 2004 through May 07 and the OTS within 10 minutes for October 2005 through May 07.

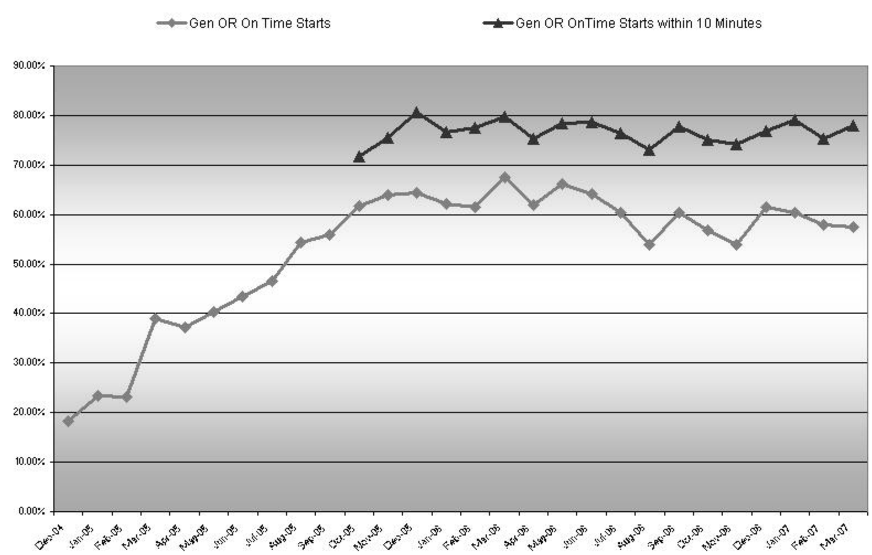

Figure 4 – OTS and OTS within 10 minutes key performance indicators | December 2004 to May 2007

With the discontinuance of SSS block scheduling, the true OR suite utilization was obtainable through the perioperative data from the CSIS. Another KPI was developed from CSIS data to reflect the utilization of existing OR Suites. The OR suite utilization metric is a function of OR suite use during available scheduling blocks between 7:00 a.m. to 4:30 p. m. daily. Figure 5 depicts a graph of OR suite utilization between October 2006 and April 2008, where the OR suite utilization ranged between 74 and 90 percent, without SSS block scheduling and excluding the one OR suite blocked for trauma patients.

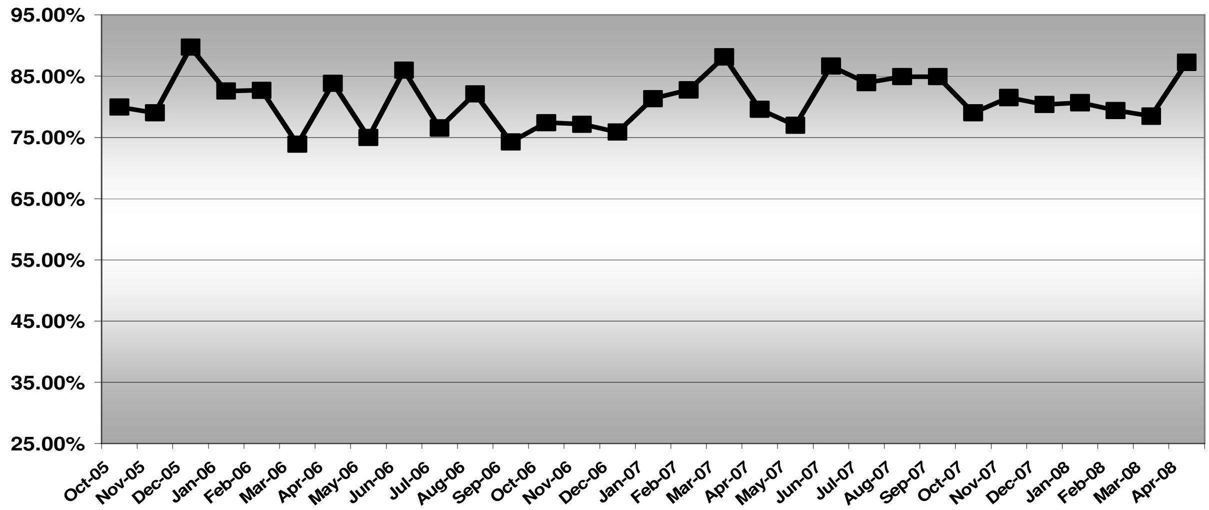

Figure 6 – OR Utilization KPI | October 2005 through April 2008

An analysis of the perioperative data from the CSIS also showed a clear mismatch between OR staff assignments and the time required by surgeons to complete cases, which yielded unscheduled staff overtime and unpredictable work hours. Hence, mandated five day-a-week eight-hour staffing processes were redesigned to more flexible three 12-hour or four 10-hour shifts. Furthermore, the perioperative data analysis also justified pay incentives to address the registered nurse staff shortage.

October 2005 to Present

Since the discontinuance of SSS block scheduling and the implementation of SSS block release rules, the CSIS data mining has produced a good estimate of SSS blocks assignments for the outside-a-week planning horizon. The SSS blocks assignments were accurate enough to institute an across SSS block release rule of 72-hours to the division and 48-hours to any other SSS. In effect, the CSIS data mining of projected case loads by SSS was accurate in estimating how many blocks of OR suite time is needed for each SSS. Unscheduled SSS block time is released to other surgeons in the specialty division 72 hours out and 48 hours out to any surgeon. This block release rule shows a tight coupling between CSIS projected block assignments and actual surgical cases. Across all SSS, University Hospital's block release rule offers a looser coupling (i.e. more flexibility) than suggested SSS block release rules from Peters and Blasco (2004).—releasing the SSS block 2 days out rather than 5 days out. The looser coupling gives University Hospital's perioperative scheduling more surgeon flexibility, which is critical success factor in surgeon/physician satisfaction.

Since October 2005, University Hospital's perioperative services scheduling has broadened it scope to include two other perioperative services within the University Hospital System. The two off-site surgical clinics have 17 and 13 OR suites, for an additional 30 rooms. Altogether, University Hospital's perioperative services schedule 70 OR suites using the same CSIS. Both off-site clinics implemented CSIS within the past 18-months and have adopted the University Hospital-wide perioperative scheduling processes. KPIs are available for each of the OR suite sites and in aggregate.

ANALYSIS AND DISCUSSION

Caccia-Bava, Guimaraes, and Guimaraes (2005) identified determinants of BPR success in hospital environments, which included: (1.) the cross-functionality of the project team; (2.) the process used by the project team to implement the BPR project; (3.) the expertise available to the project team regarding the processes being redesigned/reengineered; (4.) the quality of the IT support extended to the project; and (5.) the project leadership and motivation for the project. University Hospital's perioperative services BPR efforts were successful and this study's research did identify underlying themes similar to the determinants of successful BPR, which include:

- The executive team was cross-disciplinary and represented all the perioperative stakeholders. In most of the process redesign outcomes, all stakeholders benefited.
- The process used by the project team to implement each process redesign was very open to all stakeholders. No issue was above questioning and perioperative data patterns suggested the process redesign.
- The expertise available to the executive team regarding the processes being redesigned was within perioperative services. The data for benchmarking the new KPIs were derived from the CSIS and national benchmarks.
- The quality of the IT support extended during each new process synthesis was instrumental to each redesign success. The whole redesign effort could not have been accomplished with the old CSIS, as it did not have the tools, agility, or space to collect the perioperative data as needed. The new, agile CSIS was a critical success factor in adapting to routing changes and collecting varied perioperative data across multiple SSS. The ability of the new CSIS to add perioperative scheduling to two off-site clinics with an additional 30 OR suites is an example of its agility and flexibility.
- Perioperative management and all other surgical team's management were the executive team and process improvement was the motivation, which spawned many perioperative data mining efforts that synthesized process redesign

Overall, the data mining efforts from the CSIS' OLAP tools did direct the redesign efforts of many of the perioperative scheduling processes as well as serve to identify KPIs for the performance measurement process. More importantly, the data mining and process synthesis efforts focused perioperative staff and surgical teams on using perioperative data as a resource—for continuous system design improvement and perioperative process improvement.

CONCLUSIONS

Empowered individuals, integrated IS, and a holistic model for data mining redesigned perioperative processes within University Hospital, while providing continuous improvement to system design and perioperative processes. Moreover, the BPR experienced within perioperative services improved the environment for all stakeholders. Patients were exposed to less risk associated with surgical procedures, without sacrificing the quality of their perioperative care. Anesthesiologists and surgeons, as scientists, gained better efficiencies and flexibility with the scheduling process redesign, which yielded more operating time, better research data, and less scheduling problems. Nurses and perioperative staff gained increased communication, more flexible work schedules, enhanced work-life, and increased professional awareness.

Adopting the holistic model for system design and system discovery, educates hospital and perioperative management on the benefits of agile, integrated IS along with OLAP tools for discovery and redesign. The discovery of potential process synthesis reinforces communication and learning, which stimulate continuous improvement.

Our case study contributes to the healthcare IT literature by investigating how mining perioperative data can synthesize process redesign, using a prescribed a priori model to foster its occurrence. This paper also fills a gap in the literature by describing how hospital process data is a resource. This study was limited to a single case, where future research should broaden the focus to address this issue along with others that the authors may have inadvertently overlooked. The case examples presented in this study can serve as momentum for healthcare data as a resource methodology comprehension and extension, while the results should be viewed as exploratory and in need of further confirmation. Researchers may choose to further or expand the investigation; while practitioners may apply the findings to create their own version of using healthcare data as a resource to improve systems design within the hospital environment.

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