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Examining the Impact of Information Technology on Healthcare Performance: A Theory of Swift and Even Flow (TSEF) Perspective

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Examining the impact of information technology and patient flow on healthcare performance: A Theory of Swift and Even Flow (TSEF) perspective

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Abstract

The impact of information technologies on manufacturing operations and performance is well established. However, scant research has been devoted to examining information technology (IT) investment among hospitals and how it influences patient care and financial performance. Using the lens of the Theory of Swift Even Flow (TSEF), we present an operations management-based perspective on the effect of IT in streamlining hospital operations. Specifically, we examined the role of IT on patient flow and its consequences for improved hospital efficiency and performance.

Analysis of data from 567 U.S. hospitals shows that IT is associated with swift and even patient flow, which in turn is associated with improved revenues. Interestingly, we find that the improvement in financial performance is not at the expense of quality because we find similar effects of IT and patient flow in improvements in the quality of patient care. Further, we observed differential effects of swift flow and even flow on various measures of hospital performance. Although swift flow affects financial performance, even flow primarily affects quality performance. Taken together, they have a mutually reinforcing overall impact on hospital performance.

The implications of these findings for hospital decision makers are that patient flow is an important mediating variable that is affected by IT and can significantly affect the quality of patient care and financial performance.

1 Introduction

Recent studies in operations management (Chou et al., 2012; Heim and Peng, 2010; Devaraj et al., 2007) have documented the important role that information technology (IT) plays in manufacturing operations. However, few studies have examined the mechanisms through which IT affects the delivery of services, specifically the delivery of healthcare. Although the role of IT is considered critical in delivering efficient and effective patient care (Stead et al., 2009), investment in IT in healthcare has been less than half of the average for private industry in general.[1] For its part the healthcare industry, including hospitals, has resisted investing heavily in IT because the benefits are perceived as uncertain (Porter and Teisberg, 2006).

An aging U.S. population, combined with the expected increase in insured patients as a result of the passage of the Patient Protection and Affordable Care Act (2010), is expected to add 32 million persons by 2019 to the pool of insured and will potentially need medical services.[2] Expanded demand from insured patients will require hospitals to become more efficient in managing patient admissions, treatment, and discharges. Healthcare managers must adopt operations management practices, such as standardization and process mapping (Boyer and Pronovost, 2010), to streamline patient flows in hospitals while improving clinical quality and financial viability. Previous attempts by hospital managers to learn from operations management have involved the application of Toyota Motor Co.'s production techniques (Wysocki, 2004) to reduce the time patients spend in treatment (Blackstone, 2009). Other efforts included deploying evidence-based procedures that improve treatment quality, cost less, and optimize patients' hospital stays (Abelson, 2008). Thus, interdisciplinary work spanning operations management, information systems, and healthcare management has the potential for synergistic results that improve efficiency and quality (Boyer and Pronovost, 2010) and unravel interesting relationships between IT investment and the effectiveness in the delivery of healthcare.

The healthcare industry, and hospitals in particular, presents an interesting as well as a challenging context for operations management researchers. Hospitals have struggled to control costs in the face of declining net margins — from 6.1% in 2007 to (–) 1.6% by 2008 (AHA, 2009). Financial pressures had prompted even the "top 100 most wired" hospitals to reprioritize their IT spending (Runy, 2009). Healthcare decision makers must find ways in which IT and operations can assist the delivery of high quality patient care and help hospitals to operate as financially viable organizations. If managers do not leverage IT to improve patient flow, it will hinder their ability to serve a growing patient population and threaten hospitals' financial viability. As operation and information systems researchers, we have an opportunity to contribute to this effort by promoting successful configuration of IT and operations principles.

We propose that paradigms and perspectives that have their roots in operations management — such as the Theory of Swift and Even Flow (TSEF) — can serve as instruments of change and bolster the realization of value from technology investments among hospitals. Given the critical challenges hospitals face and the knowledge available in operations management, we frame our key question as — *Does increased IT investment by hospitals lead to improved quality and revenue outcomes?* In seeking answers, we examined operations management principles that inform our understanding of these relationships and the intermediate operations and process variables influenced by IT investment. Specifically, using the TSEF lens, we explored the IT-hospital performance link. TSEF proposes that "…the more swift and even the flow of materials (or information) through a process, the more productive the process…" (Schmenner, 2004, p. 335) and conversely, "…[productivity] falls with increases in the variability associated with the flow…" (Schmenner, 2004, p. 335).

Understanding patient flow as the mechanism that leads to favorable outcomes in hospitals can imbue managers with a deeper understanding of how to focus IT investments. Drawing upon the tenets of TSEF, Fig. 1 presents a four-quadrant representation of hospitals along the axes of swift and even patient flow. We propose (formally hypothesized later in the paper) that hospitals in Quadrant 4, characterized by high levels of swift and even patient flow, will outperform hospitals in the other three quadrants. Thus, this research presents an interdisciplinary study to examine how hospital operations, combined with IT investments, drive organizational performance.

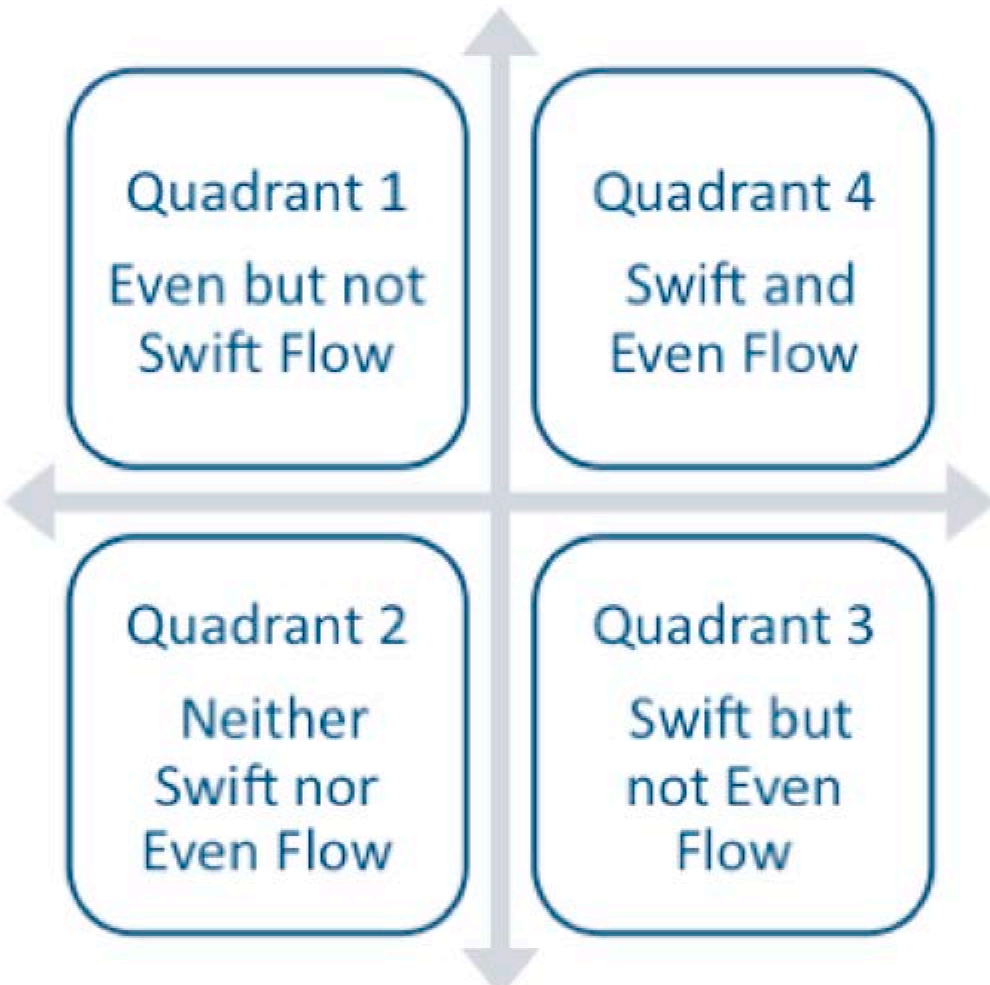

Figure 1

Swift and even patient flow hospitals.

The rest of the paper is structured as follows. In Section 2, we present a synthesis of the relevant literature from three streams — healthcare, operations management, and information systems. Section 3 presents the research model and the hypotheses tested in the study. Next, in Section **4**, we present the details of the data and analysis. Finally, in Section **5**, we discuss the results and present our conclusions.

2 Literature

In this section, we first discuss the importance of patient flow in hospital operations, followed by a discussion of IT in hospitals, with both topics leading to the application of operations management principles driven by the TSEF.

2.1 Why is patient flow important to hospitals?

Patient flow is considered similar to process throughput and is a key measure of efficiency in hospital operations. Process bottlenecks in clinical and administrative tasks can delay patient discharges and lead to lower quality and higher costs. When hospital processes deploy information systems to provide patient demographics and medical history, it is easier for clinicians to assess patient allergies and co-morbidities and avoid delays caused by unnecessary tests or drug reactions, each of which influences patient flow (**Neil, 2003**). Longer patient stays expose patients to unnecessary risks of infection and medical complications. Anecdotal evidence suggests that healthcare practices, such as clinical pathways that provide diagnosis specific automated checklists to clinicians, streamline patient care and reduce hospital stays, have lowered mortality rates (**Coskun et al., 2005**) and contribute to an operations focus that occurs, for example, when “mythic-heroic notion of surgeons as uniquely gifted artists becomes a manufacturing model consisting of choreographed steps performed by a highly skilled team” (**McCreary, 2010**, p. 97). Clinical IT systems now provide intelligent decision support to clinicians in the form of profiles customized for each patient constructed from historical data of similar patients. When combined with current research evidence, profiles help identify proactive, step-by-step, clinical pathways to prevent potential disease episodes (e.g. stroke or heart attack), while eliminating treatments known to yield sub-optimal outcomes. Thus, substantial cost savings and quality improvements accrue when clinicians utilize IT-enabled operations tools (e.g. flowcharting, statistical process control) to reduce variations in patient treatment that in turn enhance patient flow.

Managers in U.S. hospitals seek efficiency in operations because the reimbursement amounts from insurers are generally based upon predetermined length-of-stay (LOS) for a given condition (**Shi, 1996**). Therefore, delays due to inefficient patient flow are likely to consume additional hospital resources that will not be reimbursed. Timely discharges can lower hospital costs as much as $1729 per patient (**Abernathy et al., 2002**) and delays cost a hospital an estimated $2.5 million per year (**Thomas et al., 2005**). Of course, longer hospital stays under fee-for-service insurance arrangements can increase revenues but with increased scrutiny such cases are on the decline. To prevent hospitals from discharging patients too soon, there are safeguards in place. First, physicians will sign-off on patient discharges only after patients are healed. Second, if a patient is readmitted within 30 days for the same diagnosis, regulations require that the first and second stay be combined in a single LOS. Because of such factors, hospital administrators need to achieve a balance between efficient operations (patient stay, revenue, and profitability) and physicians’ approval that ensures quality of patient care (mortality, complications). We examined the role of IT in achieving this patient flow-driven balance between operational efficiency and quality of patient care. Our findings will provide researchers with the causal paths between IT and hospital performance as avenues for further exploration. Our findings will offer insights into how to deploy information technology and also will demonstrate the metrics that must be controlled to achieve operational and quality-related performance outcomes.

2.2 Information technology and hospital performance

IT investments in hospital management can lead to improved performance primarily in two areas — efficiency and effectiveness. Efficiency relates to the workings of the hospital aimed at producing higher output for a given set of inputs. Effectiveness, on the other hand, relates to doing things in a way that lead to the expected or desired outcomes. Our focus in this paper is twofold — to explore how IT leads to efficient operations, primarily through its effect on LOS, and to examine how LOS influences hospital effectiveness through quality and financial outcomes. Since our measure of IT expenditure captures expenditures in direct patient care, it represents efficiency and effectiveness achieved through integration and dissemination of information. Researchers in healthcare have proposed IT's impact on efficient patient care through process redesign (**Devaraj and Kohli, 2000**) and in cost control (**Menon and Lee, 2000**). IT creates efficient processes such as enabling patients to preregister online or via phone to avoid delays in tests or treatment. Similarly, computerized physician order entry (CPOE) systems automate physicians' orders and delivery of test results by integrating laboratory information systems and other clinical services with CPOE. This integration allows physicians to view the results at any time and from anywhere, such as using mobile devices. This ubiquitous access accelerates the treatment plan or discharge process and consequently controls LOS. Conversely, when laboratory and other diagnostic information systems are not well integrated, patients must wait until their physician can physically view the test results and make the decision to discharge. This wait can add an extra day to a hospital stay.

The effectiveness of IT in hospitals depends upon the deployment and use of IT in pursuit of quality-related performance. For instance, **Pare and Sicotte (2001)** propose that for information systems to positively affect hospital performance, IT investments should target the integration of clinical and administrative data. By examining a patient's history in electronic health records (EHR) clinicians can avoid drug interactions or order tests to detect hereditary diseases, thus improving the quality of care. Recent media reports and academic studies have highlighted the role of IT in preventing medical errors (**Piontek et al., 2010**), such as by staggering nursing shifts and reducing handoffs that are often a cause of medical errors (**McSweeney et al., 2011**). **Sobun (2002)** proposes that information systems in hospitals will be more effective when the staff is viewed as a "consulting team" rather than a "reporting shop," a change that will highlight IT's role in reporting as well as improved decision making that will influence the quality of patient care.

Overall, the extant literature provides substantial evidence that IT can lead to efficient and effective hospital patient care. But the route hospitals must take to deploy IT within their operations to accomplish goals of efficiency and effectiveness remains unclear. We now turn to discussing how to view hospital LOS from an operations perspective so that IT opportunities can further emerge.

2.3 Theory of Swift and Even Flow (TSEF)

Quality pioneer W. Edwards Deming argued that focusing first on getting a process right will lead to higher quality and lower costs (**Deming, 1986**). He proposed eliminating barriers between departments and anticipating problems in the production and use of goods or services. Other management theorists have expanded on Deming's ideas to construct theories of how to achieve efficiency by improving process throughput while simultaneously producing high quality products and services. We deployed TSEF as one such theory to frame our understanding of how hospitals can use operations management to reduce process throughput time.

Although early TSEF research used the factory floor as a platform, its tenets of increasing speed of flow and decreasing variation also apply to the service sector (**Schmenner, 2004**) and to financial services and hospitals (**Fredendall et al., 2009**). TSEF theorists contend that although traditional microeconomic theory is useful in understanding how labor and capital inputs translate into productivity, it contributes relatively little to many aspects of factory floor operations, e.g., bottlenecks, variability in quality, variability of demand, and workforce organization (**Schmenner and Swink, 1998**). Information systems (IS) research has also recognized TSEF as a useful framework in the context of technology adoption (**Venkatesh, 2006**).

The TSEF is governed by five basic laws — (i) The *law of variability*, based upon queuing theory, proposes that the greater the variability in a process, the less productive it will be; (ii) the *law of bottlenecks* suggests that a chain is only as strong as its weakest link. In other words, a process is only as fast as its slowest stage; (iii) the *law of scientific methods* (from Industrial Engineering) points to the efficacy of using scientific methods on the shop floor; (iv) the *law of quality* relates improvements in productivity to improvements in quality because of the reduction of waste; and (v) the *law of factory focus* is a statement favoring factories that focus on a limited set of tasks instead of a broad array of tasks.

Process *throughput time* is a critical performance measure in TSEF in accomplishing swift and even flow. **Schmenner (2004)** cites many cases in the service sector (e.g., Southwest Airlines and Walmart) in which management attention to throughput time resulted in superior performance. In the context of hospitals, throughput time corresponds to consistent, timely, and error-free patient flow. Thus, the TSEF would predict that hospitals that have mastered the rapid and steady movement of patients would perform better than hospitals that have not. As discussed in the previous section, IT plays a pivotal role in managing efficient process flow. Therefore, we hypothesize that hospital IT investments will result in swift and even flow, as measured by lower patient throughput time, and consequently influence hospital performance. We organize the TSEF tenets in **Table 1**. The five laws of TSEF are presented in italics.

Table 1. Tenets of the Theory of Swift Even Flow (TSEF) and applications in hospital settings.

TSEF concepts	**Significance in hospital settings**	**IT applications in hospitals**	**References**
Law of Variability Variability of resource utilization	Reduction in variability of DRG-resource consumption	Physician profiling systems	Chandler et al. (1991) and Kohli and Kettinger (2004)
Process standardization, streamlining	Streamlining patient flow, clinical pathway	Admission, discharge and transfer (ADT) systems	May (2004), Eastaugh (1992), Fetter and Freeman (1986).
Standardized consumption patterns, product mix, job complexity	Severity index, case mix index, service index, patient mix	Decision support and clinical reporting systems	Horn et al. (1986), Freeman et al. (1991), Vogel et al. (1993) and Roblin (1996)
Law of Bottlenecks Demand-pull strategy	Managing of patient flow, service times prediction	Clinical scheduling systems	Karmarkar (1989), Gardner (1992) and Wasin and Alavi (1991)
Law of scientific methods Materials management	Hospital purchasing, resource planning	Vendor management systems	Kannan and Tan (2005) and Souhrada (1989)
Law of quality Reduction in throughput time, work in process	Reduction in length of stay (LOS)	Enterprise resource planning (ERP) systems	Fullerton and McWatters (2001), Shi (1996), Bray et al. (1994) and Nackel and Kues (1986)
Waste elimination	Establishing standardized resource requirements within DRG's	DRG grouper system	Giffi et al. (1990)
Total quality management, reducing defects	Reduced resource consumption, fewer adverse drug events (ADEs)	Pharmacy ADE systems	Kannan and Tan (2005), Gaucher and Coffey (1993), Jaeger et al. (1993) and McLaughlin and Kaluzny (1994)

Law of factory focus Operations planning, scheduling	Job shop, batch flow, line production, patient-physician scheduling	Operation room scheduling systems	Schemenner (1986), Showalter (1987), Nackel et al. (1984) and Heskett et al. (1990)

3 Research model and hypotheses development

We describe below our conceptual model and then construct the relevant hypotheses. Hospital managers have long sought to accomplish efficient operations, particularly in relation to IT investments (**Devaraj and Kohli, 2000, 2003**), the drivers of patient LOS (e.g. **Shi, 1996; Lave and Frank, 1990**) and the causes of variation in providing patient care (**Anderson and Pulcins, 1992**). Our research model seeks to examine the impact of IT investment on the swiftness and evenness of patient flow and subsequently on hospital performance. **Fig. 2** shows the operationalized research model and the direction of association for each hypothesis.

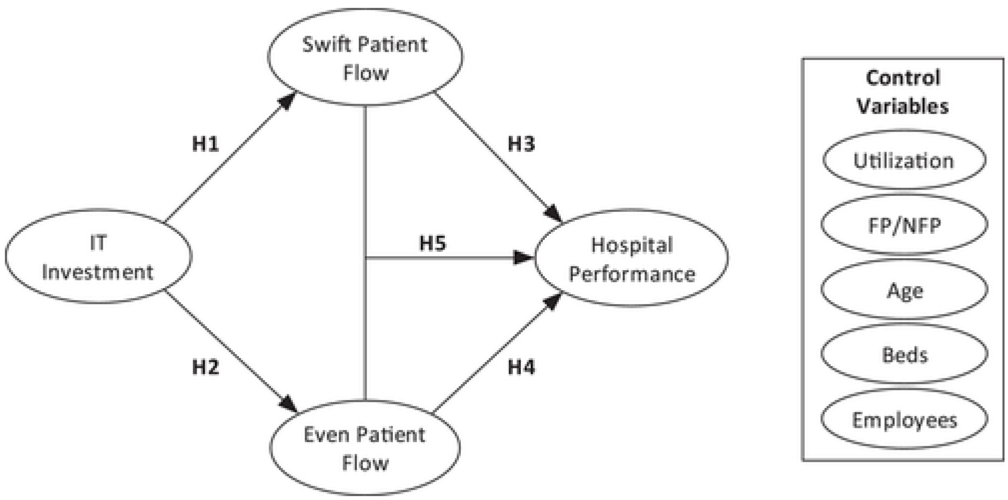

Figure 2

Operationalized research model.

3.1 IT and Swift and Even patient flow

The deployment of IT facilitates movement of information and patients through hospital processes. For example, clinical scheduling systems can track preregistered patients to schedule appropriate staff in order to avoid delays in clinical procedures. The TSEF factory focus also promotes better scheduling of facilities and equipment. Clinical staff can log into the scheduling system, identify open slots, and self-schedule working hours. This avoids bottlenecks in the patient care processes. Furthermore, clinicians can track patient histories as well as "best practices," thereby reducing the need for unnecessary tests that can prolong a patient's hospital stay. Given the incidence of clinical errors in hospitals, management of appropriate staffing levels ensures that patients move through the system without incident (**Kovner and Gergen, 1999**). Estimates indicate that preventable adverse drug events can add up to 4.6 days to a LOS (**Bates et al., 1997**). Consistent with the TSEF laws of bottlenecks and quality, IT can enable the swift flow of patients.

Although most previous studies support the positive impact of IT on swift patient flow, some have found evidence that IT has contributed to the hindrance of patient flow. The Joint Commission, the hospital accreditation body, found that IT investments in electronic health records actually affected patient flow negatively through incorrect dosages and misdiagnoses (**Mostrous, 2009**) that ultimately resulted in congressional hearings. Nevertheless, based on the reasons we presented above, our first hypothesis (**H1**) is as follows:

Hypothesis 1 1. Higher IT investments in hospitals will be associated with swift patient flow.

Variability in a process is not conducive to predictable performance outcomes. The TSEF law of variability proposes that those facilities that are good at reducing variability will achieve improved quality and efficiency. Given that the needs of patient care vary due to patient mix or severity levels, some variation is expected. Nevertheless, variation places greater demands on physicians and nurses and manifests as uneven flow among patient care processes. However, because such variability is an uncontrollable input, an IT system can build flexibility into processes to better cope with this random variability (**Devaraj and Kohli, 2002**) and deliver access to integrated patient records (e.g., electronic medical records) through decision support and clinical reporting systems to facilitate an even flow of patients. To manage variability in demand, hospitals use clinical scheduling systems and operation room scheduling systems to group similar patients and elective procedures close together. This permits better scheduling of resources and facilitates communication among the clinical and technical staffs, operating and recovery room facilities, and ensures availability of supplies. On the other hand, contrary to the prevailing evidence, some studies have found that new technology hinders patient flow because it interferes with established norms of patient care (**Bates, 2005**). Further, pressure from senior leaders for the adoption of IT generates resistance by clinicians (**Currie, 2012**) and continued use of manual scheduling that results in uneven patient flow. Despite these contrary research findings, we believe that the more compelling result will be a positive effect, and thus, our second hypothesis (**H2**) is:

Hypothesis 2 1. Higher IT investments in hospitals will be associated with even patient flow.

3.2 Patient flow and hospital performance

Efficient patient flow streamlines hospital processes and results in desirable financial and quality-related outcomes. When hospitals achieve internal process efficiencies through the tracking and recording of inventory used in patient treatment, the resources consumed are accurately recorded and billed, thus fully capturing the revenue. Further, when patients flow swiftly through their processes the demand on hospital personnel can be better managed such that it optimizes the use of physical and human resources. Of course, these gains in revenue may be lost if clinical professionals do not view the process technologies as useful (**Ketikidis et al., 2012**) and do not assimilate them into their clinical and operational processes (**Setia et al., 2011**).

Improved coordination among hospital functions because of enterprise resource planning (ERP) systems is known to result in efficiency gains (**Shang and Seddon, 2002**). Efficient hospitals schedule and perform a greater number of procedures and efficiently move patients through the system. In the face of increasing demand as a result of the Patient Protection and Affordable Care Act (2010), swift patient flow is critical to hospitals. The alternative is to expand bed capacity. Because each additional bed requires nearly $1 million in capital and $25,000 in operating costs (**Litvak and Bisognano, 2011**; p. 77), failure to improve patient flow within existing capacity is likely to have severe effects on capital expenditures and financial performance. Consistent with the TSEF, inefficient processes increase the time required to render appropriate patient care. In turn, this delay can lead to medical complications and increase the incidence of patient mortality. Therefore, we propose the following hypotheses:

Hypothesis 3a 1. Swift patient flow will be positively associated with a hospital's revenue outcome.

Hypothesis 3b 1. Swift patient flow will be positively associated with a hospital's quality outcome.

Previous studies have found that managing the schedules for elective surgical or diagnostic procedures can lead to consistent patient flow, thus avoiding the need to hire more clinical and support professionals (**Litvak and Bisognano, 2011**). Through decision support and clinical reporting systems, administrators can access utilization information and schedule clinical procedures that lower the risk of patient infections (**Wisniewski et al., 2003**). The even flow of patients promotes better scheduling and reduces delays, such as in developing X-rays and in transporting patients to clinical specialists, resulting in timely diagnosis and treatment (Bui et al., 2004). Even and predictable patient flow allows physicians to plan treatment protocols that lead to efficient and effective treatment. A smooth flow of patients also leads to higher quality through elimination of process inefficiencies that generally lead to confusion and errors. In a competing perspective, recent studies in medicine have identified 'meaningful variation' as a precursor to improving quality (Selby et al., 2010) because innovative ways to treat patients are likely to emerge when clinicians diverge from established treatment regimes. Such variations may disrupt the evenness of patient flow and lead to higher rates of patient complications and mortality. Thus, there is competing evidence to argue whether higher revenue and quality are the result of even patient flow due to properly documented treatment procedures or clinical innovation resulting from meaningful variation. Therefore, we hypothesize the following:

Hypothesis 4a 1. Even patient flow will be positively associated with a hospital's revenue outcome.

Hypothesis 4b 1. Even patient flow will be positively associated with a hospital's revenue quality outcome.

The above-cited hypotheses (H3 and H4) test for swift patient flow and even patient flow separately. However, hospitals are likely to deploy processes that address both swift and even flow (Quadrant 4 in Fig. 1) in pursuit of improved financial as well as quality-related hospital performance.

The concurrent deployment of swift and even flow can achieve supra-normal benefits because the swiftness directly influences efficiency by increasing throughput of patients in a hospital. For example, when patients from emergency room (ER) are admitted to the hospital, swift processes to stabilize patients must be matched with the even patient flow into the hospital's acute care units (e.g. ICU or Surgery). From an operations management perspective, having only swift flow without even flow might lead to bottlenecks in the process and lead to suboptimal process performance. Evenness of patient flow ensures that patient care activities are appropriately staffed. Due to the predictability of tasks, hospital managers can schedule trained staff in each specialty to ensure that appropriate quality of patient care is available. However, the presence of only even flow without swift flow might be indicative of slack in the system which might lead to lower process performance. When the swiftness of patient discharges is well coordinated between clinical and administrative departments, hospital beds are promptly allocated to other incoming patients, thus increasing hospital revenue. A counter argument is that swift flow makes it difficult to achieve evenness if delays occur in any one of many interdependent activities (e.g. between the ER and Surgery units or between Surgery and Discharge), thus negatively affecting hospital revenue. Further, unnecessarily long hospital stays expose patients to infections and communicable diseases that can weaken quality of patient care. Therefore, to test the joint impact of swift and even flow, we propose our fifth and final hypotheses as follows:

Hypothesis 5a 1. The interaction between Swift and Even patient flow will be positively associated with a hospital's revenue outcome. That is, hospitals with Swift and Even flow will be associated with higher hospital revenue.

Hypothesis 5b 1. The interaction between Swift and Even patient flow will be positively associated with a hospital's quality outcome. That is, hospitals with Swift and Even flow will be associated with better quality outcomes.

4 Research design

We gathered data from Solucient, Inc. a commercial, subscription-based, industry-standard database provider. The Solucient, Inc., database (now Thompson Medstat, Inc.) consists of several hundred data fields for each hospital licensed by the Centers for Medicare and Medicaid Services (CMS)[3] of the U.S. Department of Health and Human Services (HHS). The U.S. federal government requires each hospital to submit a standard report with predefined fields for financial, productivity, and expense data. Solucient, Inc., among other vendors, acquires this publicly available data from CMS, combines it with a variety of industry sources and applies a series of proprietary processes to consolidate the data into a searchable database. It then markets subscription-based access to this value-added database.

Our second data source for hospital benchmarking data is Comparion Medical Analytics (formerly known as The Delta Group). Comparion Medical Analytics is a healthcare information services and consulting company that provides analytical products and services to measure, manage, and monitor the clinical, financial, and market performance of healthcare organizations. It develops and markets benchmarking data so that hospitals can measure their quality against national benchmarks. As a part of our analysis, we merged the benchmarking data from Comparion Medical Analytics with the Solucient, Inc. data. Our sample consists of 567 hospitals across the United States that reported data on their IT expenses and other variables of interest to our study. The average size of the hospitals included in our sample, measured in number of beds, is 303 and the average number of full-time employees is 1253.

4.1 Dependent variables

We utilized net patient revenue (NPR) as a dependent variable of hospital performance. Performance measures must consider hospital-wide criteria as opposed to unit level functional criteria because it can result in suboptimization (**Roth and van Dierdonck, 1995**). Although costs and profitability metrics are commonly used as performance measures, NPR is more meaningful for hospitals because costs and profitability are affected by the terms of contracts (e.g., discounts or preferred rates) with insurance companies. NPR is a consistent measure of the extent of services a hospital provides and is unaffected by discounted reimbursement or by the local competitive environment. We adjusted for the size of the hospital by dividing NPR by the number of beds in service. **Table 2** lists the descriptions of the variables employed in the study along with their definitions.

Table 2. Description and definitions of key variables.

Variable	Description	Definition	Source
Patient revenue	Net patient revenue	Net patient revenue = (gross patient revenue less (−) deductions for contractual allowances and discounts, charity care, and similar “uncollectibles”). Net patient revenue is a measure of the revenue actually received from the provision of patient care services.	Solucient database
Mortality	Mortality rate	The number of inpatient deaths (patient status of 20) divided by the patient population at risk for mortality.	Comparion Medical Analytics
Complications	Complications index	The number of patients who had one or more complications, divided by the patient population at risk for a postsurgical or postobstetrical complication.	Comparion Medical Analytics
Hospital size	Number of beds in service at hospital	The total number of beds in service in the inpatient acute-care units of a hospital at the end of a fiscal year (excluding bassinets and nursery beds). A measure of the capacity or size of a hospital. Calculation: Adults & pediatrics beds + ICU beds + CCU beds + other (nonintensive) care unit beds	Solucient database
IT investment	Direct expenses towards information processing	Information processing: direct expense (as reported in the general ledger)	Solucient database
FP/NFP	(Not) For profit status	Legal status of hospital (for profit or not-for-profit)	Solucient database

LOS	Length of stay (Average LOS when aggregated at hospital level)	The total number of inpatient days in the hospital divided by the total number of admissions to the hospital. A hospital's average length of stay is a key indicator of utilization and is predictive of average resources used by a hospital per patient discharge. Calculation: (Σ acute care inpatient days/total acute care patient admissions)	Solucient database
Utilization	Percentage utilization of hospital beds	Calculation: Utilization = average daily census/beds in service	Solucient database

In addition to NPR, measures of the quality of patient care are highly relevant and commonly tracked by insurers and accreditation agencies. Two commonly used metrics of hospital quality are risk-adjusted mortality and complications (**DesHarnais et al., 2000; Iezzoni et al., 1995**).

Risk-adjusted measures account for differences among patients that arise because of demographics, severity of medical problems, and co-morbidities. In essence, the complications measure captures the occurrence of expected complications during a patient's stay, and the mortality rate is defined as the number of mortalities within 30 days of an operative procedure divided by the total number of operative procedures conducted in the relevant time period. Comparion Medical Analytics computes these measures based upon national clinical and financial data comprised of Medicare cases discharged from all general, acute, non-federal U.S. hospitals.

4.2 Mediating, independent, and control variables

Swift and even patient flow: A standard hospital variable, LOS, sometimes referred to at the aggregate level as Average LOS (ALOS), is our operationalization of swift-even flow. Prior literature has viewed LOS as an outcome and as an indicator of performance alongside patient care quality and financial outcomes (**Shukla and Pestian, 1997**). Directing IT toward managing LOS can lead to better financial performance for hospitals (e.g., through higher revenue) because it reflects better utilization of resources.

Conversely, higher LOS raises hospital operational costs and is likely to adversely influence the quality outcomes of patient care (discussed in detail below). LOS is measured as the average of the number of days in the hospital for all patients; it is reported for all the hospitals in our sample drawn from the Solucient, Inc., database. A hospital's LOS depends on the mix of patients admitted. Therefore, we adjusted the LOS by computing the mean and standard deviation of case-mix-adjusted LOS over a three-year period. The case-mix adjusted LOS is used to identify hospitals that have swift and even patient flow. The mean value of LOS (which is the equivalent of process throughput time) captures whether swift flow is present at a specific hospital. Lower values represent swift patient flow because, all else being equal (captured by the case-mix index), patients are treated, healed, and discharged sooner at these hospitals.

The standard deviation of LOS (Std Dev LOS) of a hospital captures the evenness of patient flow. Lower values represent more even patient flow. These hospitals can also be considered to have even patient flow because the variation in patient throughput time is less than for other hospitals in the sample. The interaction (or product) of the terms for swift and even flow (mean and standard deviations of LOS) characterizes the swift/even patient flow at hospitals.

IT expenditure: IT expenditure is a cost item reported in the Solucient, Inc., database. This item includes expenses incurred for information systems related to direct patient care; it covers IT hardware, software, and services for patient care activities. Our measure for IT expenditure is adjusted for the size of the hospital by dividing it by the number of employees. Hospitals get credit for expenses incurred that in turn affect their reimbursement rates. Therefore, they strive to report accurate IT expenses so that the cost report does not appear to inflate their profitability.

Utilization; for profit/not-for-profit status: In accordance with the literature in healthcare management, we include two additional variables — (i) utilization and (ii) for-profit (FP) or not-for-profit (NFP) status — that might influence hospital performance. The capacity utilization of a hospital is measured as its occupancy rate and can significantly affect its revenue if there is organizational slack. The NFP status of hospitals confers benefits such as lower taxes, although these hospitals incur greater burden of community services and charity care than the FP hospitals. Given that the status of hospitals continues to be a subject of debate, we included a dummy variable in the model to indicate if a hospital is FP or NFP because it is possible that revenues at FPs are higher than at NFPs.

Other control variables: We used the “age of the hospital” as a control variable because newer facilities might be technologically more advanced or have more up-to-date infrastructure than older ones that might affect hospital performance. Finally, we used two measures of hospital size — number of full-time employees and number of beds — as proxies for organizational size. These are commonly used control variables in examinations of organizational performance.

4.3 Results

The relationships proposed in Fig. 2 were estimated through ordinary least squares (OLS) regression analysis. A summary of the descriptive statistics and the corresponding correlations are displayed in Table 3.

Table 3. Descriptive statistics and correlations.

	Mean	**Std. Dev.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. Patient revenue	111,973,842	117,371,272	1								
2. Mortality	4.33	3.19	0.09	1							
3. Complications	24.53	10.98	−0.01	0.63	1						
4. IT investment	2945733	5665257	0.68	0.02	−0.02	1					
5. Average LOS	5.14	8.82	−0.16	0.15	0.11	0.1	1				
6. Std Dev LOS	0.58	2.64	−0.13	0.02	0.08	0.08	0.37	1			
7. Beds	302.63	221.28	0.76	0.1	−0.03	0.53	−0.21	−0.09	1		
8. Age	11.01	36.9	−0.03	0.02	0.03	−0.09	−0.04	0.01	0.02	1	
9. FTE's	1252.9	1351.55	0.85	0.1	−0.01	0.7	−0.15	−0.12	0.76	−0.01	1
10. Utilization	56.28	16.34	0.46	−0.01	−0.01	0.32	0.05	0.1	0.43	0.02	0.44

We examined assumptions of normality, independence, and constant variance of the residuals and conducted standard checks using residual plots and Kolmogorov–Smirnov and White's tests. The results did not indicate deviations from these assumptions. We present results to examine whether the effects of investment in IT lead to swift-even patient flow, which in turn, was hypothesized to lead to both higher patient revenues and improved quality of care.

The results of the impact of IT investment on swift patient flow and even patient flow are presented in Table 4. The results indicate that IT investment is significantly related to both swift flow and even flow at the 0.05 level of significance, which lends support to Hypotheses H1 and H2. The negative sign for the IT investment variable indicates that the greater the investment in IT the more swift and even the patient flow. The control variables of Beds and FTEs are also statistically significant (at the 0.05 level) in both regression models. The age of the hospital as well as the NFP/FP stature of the hospital was not significantly related to either swift flow or even flow.

Table 4. Regression results with Average LOS and Std Dev LOS as dependent variables.

Variables	**Average LOS**		**Std Dev LOS**	
	Coefficient	**Sig.**	**Coefficient**	**Sig.**
IT investment	−.11	.03	−.09	.04
Beds	−.21	.00	−.10	.02
FTEs	.19	.00	−.12	.00
NFP/FP	−.04	.56	.01	.91
Age	.05	.24	.01	.75
Utilization	.04	.33	.11	.02
R-Square: .17			*R*-Square: .12	

Next, we conducted hierarchical regression analysis to estimate the impact of Average LOS and Std Dev LOS (measures of swift and even flow) on measures of hospital performance. We introduced the interaction effect of Average LOS and Std Dev LOS as a product term in these estimation models. The dependent variables of hospital performance in this analysis are NPR as a financial measure (Panel A), mortality (Panel B) and complications (Panel C) as measurements of quality. Results presented in Panel A of Table 5A, indicate that Average LOS and the product of Average LOS and Std Dev LOS are significantly related (at the 0.05 level) to patient revenue.

Table 5A. (Panel A) Hierarchical regression results with patient revenue as dependent variable.

Dependent variable: net patient revenue (NPR)	**Model 1**	**Model 2**	**Model 3**	**Model 4**
NFP/FP	.017 (.841)	.017 (.838)	.016 (.829)	.016 (.812)
Beds	.211*** (5.432)	.210*** (5.314)	.204*** (5.215)	.194*** (4.862)
FTE's	.682*** (16.864)	.680*** (16.543)	.641*** (15.365)	.637*** (15.131)
Age	.010 (.496)	.009 (.473)	.009 (.471)	.009 (.470)
Utilization	.083*** (3.431)	.081*** (3.373)	.080*** (3.291)	.080*** (3.274)
IT investment		.153*** (3.361)	.1477*** (3.140)	.121*** (2.962)
Std Dev LOS			.010 (.501)	.010 (.481)
Average LOS			−.095*** (−3.612)	−.105*** (−3.834)
Std Dev LOS × Average LOS				.102*** (3.461)
R-Square	65.3%	72.4%	82.3%	89.8%

- ***significant at the 0.01 level, ** significant at the 0.05, * significant at the 0.10 level.

Thus, swift flow, as well as the interaction of swift-even flow, has a statistically significant impact on patient revenue. These results support Hypotheses H3 and H5. The lack of a statistical main effect of even flow on NPR did not support Hypothesis H4. As before, the control variables of Beds and FTEs are statistically significant (at the 0.05 level). Another control variable, Utilization, was also statistically significant. We present interaction plots in Appendix A. The interaction plot for Patient Revenue as a dependent variable shows that the highest patient revenue is realized for low values of both Average LOS and Std Dev LOS confirming the nature of the interactive (combined) effect of these variables. The plot also shows that when Average LOS is low the patient revenue is high, and that on average there is no impact of Std Dev LOS on patient revenue.

From Panel B of **Table 5B**, we observe that the Std Dev LOS and the product term of Std Dev LOS and Average LOS have a statistically significant impact (at the 0.05 level) on complications. That is, even flow and the combination of swift-even flow have a significant impact on complications lending support to **Hypotheses H4 and H5**. The impact of Average LOS (swift flow) on complications was marginal with a *p*-value of 0.064. Among the control variables, only Beds and Utilization were statistically significantly related to Complications.

Table 5B. (Panel B) Hierarchical regression results with complications as dependent variable.

Dependent variable: complications	**Model 1**	**Model 2**	**Model 3**	**Model 4**
NFP/FP	.005 (.094)	.005 (.094)	.004 (.083)	.004 (.081)
Beds	−.190** (−2.262)	−.190** (−2.241)	−.171** (−2.031)	−.178** (−2.147)
FTE's	−.015 (−.168)	−.015 (−.164)	−.013 (−.143)	−.013 (−.138)
Age	−.011 (−.232)	−.010 (−.202)	−.010 (−.194)	−.09 (−.183)
Utilization	.115* (1.976)	.117* (2.013)	.114* (1.962)	.115* (1.954)
IT investment		.010 (.183)	.009 (.173)	.010 (.185)
Std Dev LOS			.101** (2.122)	.112** (2.147)
Average LOS			.093* (1.87)	.098* (1.92)
Std Dev LOS × Average LOS				.166** (3.318)
	7.1%	7.9%	12.1%	14.8%

- ***significant at the 0.01 level, **significant at the 0.05, *significant at the 0.10 level.

Finally, results in Panel C of **Table 5C**, indicate that Std Dev LOS and the product term of Average LOS and Std Dev LOS have a statistically significant impact (at the 0.05 level) on mortality of patients in hospitals. This finding supports **Hypotheses H4 and H5**. **Hypothesis H3** that relates swift flow to mortality was not supported. Consistent with the earlier models, the control variables of Beds, FTEs, and Utilization are statistically significantly related to Mortality (at the 0.05 level).

Table 5C. (Panel C) Hierarchical regression results with mortality as dependent variable.

Dependent variable: mortality	**Model 1**	**Model 2**	**Model 3**	**Model 4**
NFP/FP	.035 (.784)	.033 (.677)	.033 (.677)	.031 (.673)
Beds	.292*** (3.210)	.284*** (3.139)	.297*** (3.251)	.286*** (3.126)
FTE's	−.372*** (−3.765)	−.382*** (−3.841)	−.373*** (−3.814)	−.352*** (−3.741)
Age	−.010 (−.213)	−.010 (−.216)	−.010 (−.215)	−.011 (−.231)
Utilization	.274*** 4.813)	.287*** 4.936)	.274*** 4.821)	.272*** 4.791)
IT investment		−.013 (−.167)	−.010 (−.130)	−.010 (−.131)
Std Dev LOS			.144** (2.912)	.146** (2.982)
Average LOS			−.024 (.752)	−.025 (.761)
Std Dev LOS × Average LOS				.129** (2.418)
	7.9%	8.4%	10.4%	13.1%

- ***significant at the 0.01 level, **significant at the 0.05, *significant at the 0.10 level.

Interaction plots for Mortality as well as Complications (**Appendix A**) highlight the nature of the interactive effect of Average LOS and Std Dev LOS on these dependent variables. In situations where the Average LOS and Std Dev LOS are low, we observe low values for Mortality and Complications. Further, on average, lower Std Dev LOS is associated with lower Mortality and Complications.

Thus, based upon the above analysis that shows the positive impacts of swift-even patient flow on NPR and quality outcomes, we find that swift-even patient flow was not achieved at the expense of quality. In fact, we observed that swift-even patient flow was associated with a decrease in complications and mortality. Therefore, swift-even patient flow has the dual benefit of an increase in patient revenue and a reduction in patient complications.

Another noteworthy result lies in the main effects of swift and even flow on the revenues and quality performance of hospitals. We noticed that the main effect of swift flow is significant only for NPR and not for quality. In contrast, the main effect of even flow is significant only for quality performance (complications and mortality) and not for financial performance. More important, though, is the fact that the combination of swift and even flow has a beneficial impact on both financial and quality performance. In other words, although swift and even flow might have differential impacts on financial and quality performance, they have a mutually reinforcing overall impact on hospital performance.

The control variable Utilization had a positive significant effect on hospital revenue and mortality (0.01 level), but was not significantly related to complications. We did not observe any significant difference between FP and NFP hospitals. This finding is consistent with the previous literature on healthcare in which no significant difference has been found in the efficiency and productivity of FP and NFP hospitals (**Shukla and Pestian, 1997**).

We examined whether IT investment had a *direct effect* on hospital performance in addition to its mediated effect through swift-even patient flow. This involved examining the significance of the IT Investment variable in the hierarchical regressions. Interestingly, we observed that IT investment had a significant impact on financial performance (NPR), but not on the quality measures of complications and mortality. This indicates the dual role of IT in our model — a direct impact on hospital NPR as well as an indirect impact through patient flow. These results indicate statistical support for the relationship between IT investment and hospital revenue *partially mediated* by swift/even patient flow. Given the lack of significance for the IT Investment variable in the models for hospital quality, we find evidence for the relationship between IT investment and hospital quality (mortality and complications) to be *fully mediated* by swift/even patient flow.

5 Discussion, contribution, and areas for future research

Our findings support the notion that hospitals can improve their efficiency and consequently their financial performance by focusing on optimizing current assets and improving the flow of patients. Further, we found evidence that IT investment is associated with hospitals that have swift-even patient flow. We did not find evidence to support media reports that IT can lead to bottlenecks or hinder swift patient flow in hospitals. Our findings support the theoretical mechanisms of how IT contributes to improving hospital operations. Examples of such mechanisms are better diagnoses, scheduling, and coordination of patient care, as proposed by the five laws of TSEF.

We find evidence that swift and even patient flow together positively influence hospitals' NPR. This suggests that hospitals benefit when they use their resources optimally to ensure that patients and information flow quickly, yet in a controlled manner, through the hospital's processes. However, we did not find that even-flow by itself influenced NPR. One explanation is that hospitals are unable to fully capitalize on the efficiency that results from swift patient and information flow, especially when demand for services fluctuates. Another explanation for this finding is that when there is uneven demand across two accounting periods, the revenue from some patients in one accounting period may appear in the next period because of delays in revenue capture and adjustments.

We also found that swift and even-flow combined have a significant influence on reduction of complications, a quality outcome in hospital operations. Further, swift-flow by itself also was found to influence a reduction in complications. To rule out the possibility that the swift-even patient flow, represented by reduced LOS, could adversely affect quality of patient care (e.g., in case patients are discharged too soon), we estimated the impact of case-mix-adjusted LOS on patient complications and mortality. We found that LOS was positively related to complications, i.e., an increase in the LOS is associated with an increase in complications. This is consistent with evidence in clinical studies that indicate that lower LOS results in fewer patient infections and consequently fewer complications (**Coskun et al., 2005**). From an operations perspective, our findings indicate that decreasing LOS has the dual benefit of increasing NPR and decreasing complications. Our findings provide evidence that IT investment, when viewed through the TSEF lens, enables hospital managers to indirectly influence quality (e.g., by redesigning patient care processes) and financial performance through shorter LOS. Overall, our findings are consistent with the extant literature that IT influences hospital operations that in turn influence financial and quality-related performance.

5.1 Contribution

The findings of our study contribute to research and practice in a number of ways. First, we expand our understanding of the relationship of IT and hospital performance through the impact of IT on hospital LOS. Second, by applying TSEF, we are able to gain insights into the IT "conversion effectiveness" process that sheds light on how IT investments successfully improve performance of U.S. hospitals. Third, by simultaneously examining the antecedents and consequences of LOS, our findings inform healthcare managers by offering insights into how technology affects hospital performance. These findings illustrate the impact of patient flow on hospital revenue, while also demonstrating that this improved financial performance does not come at the expense of quality patient care. Our findings suggest that healthcare managers must assess, evaluate, and monitor patient LOS and that IT plays a direct as well as indirect role in improving hospital performance. Given the significance of healthcare in our economy, and the importance of patient outcomes, even a slender association between IT and lower rates of mortality and complications is a significant achievement for patients and hospitals. Thus, healthcare managers can view IT investments as one of the levers they can control in the pursuit of improved quality and financial outcomes.

From information systems perspective, processes and outcomes are complementary investments alongside IT investment. Simply automating existing processes is not likely to provide optimal benefits of new IT. IT investments offer an opportunity to redesign processes in a way that take advantage of the automation and ubiquity of information access leading to transformation of existing processes. For instance, a hospital can take advantage of mobile IT and cloud computing by redesigning the patient discharge process such that digitized reports from consulting physicians are automatically appended to a patient's record in the private and secure 'cloud.' When the patient record is complete, the discharge IT system prompts the attending physician to access the patient record from the cloud. After reviewing the record, the attending physician can digitally sign the record and issue orders to discharge the patient. Because the entire patient record resides in the cloud, the attending physician can complete the entire process through a mobile device and discharge the patient from anywhere. If a hospital automated the current process that requires attending physicians to physically come to the hospital, often the next day, in order to review and sign discharge orders, the LOS may not be significantly reduced. Therefore, it is important for hospital managers to understand such complementarities (e.g., TSEF) to ensure that IT is appropriately placed in the patient care "system." Although healthcare managers intuitively understand the importance of LOS, the TSEF offers a novel mechanism to gain efficiency and improve the quality of patient care by ensuring that patients traverse the hospital processes swiftly and evenly. Conventional wisdom in healthcare administration focuses more on swiftness, but not on evenness. Swift flow, in the absence of evenness, can create bottlenecks. An example of such a disparity occurs when patients are set up for swift testing but end up waiting in hallways because the flow through the diagnostic equipment is uneven. When viewed through the TSEF lens, our findings provide managers with empirical evidence that investing in IT to improve operations can influence both financial and quality outcomes.

5.2 Limitations and areas of future research

Our findings are subject to several limitations that future research may seek to address. Although our findings hold true at the hospital level, it is conceivable that there are services or departments within a hospital where the impact of IT is more pronounced. Future research may examine whether our findings of the reduction of throughput time and lower LOS will, in general, hold true across the different levels and functional specialties within a hospital. Finally, because our data are drawn from U.S. acute care hospitals, the generalizability of these findings is limited to similar settings. Future studies may examine tertiary care hospitals and non-acute care facilities in U.S. and international settings.

Future studies can identify more creative ways to deploy technology and reduce LOS. Future researchers may identify the features of IT and match them with the steps in the clinical process. Researchers can identify the critical process steps that are of high cost, time consuming, or error-prone and seek ways through which IT can automate, mitigate or by-pass such steps. For example, through networking and communication capabilities, IT can help redesign hospital structures in which specialized facilities offer alternatives to community hospitals and treat patients for a given disease type (e.g. cardiac care). Physicians' offices, outpatient clinics and emergency rooms can then schedule patients to the appropriate facility. This will save time and match patients with the highest quality care for their condition. Can specialization reduce hospital costs as well as LOS? Will treating similar patients validate the "practice makes perfect" adage and improve patient outcomes? We anticipate that practitioners will benefit from our empirical analysis in responding to the question of how IT's efficiency furthers policies to design and deliver high quality patient care.

6 Conclusion

In responding to recent calls to apply operations management to healthcare (**Boyer and Pronovost, 2010**), we have examined the role of swift-even patient flow, an operations management principle in the TSEF, to study how IT investment affects hospital performance. We used a unique dataset comprising public and proprietary hospital performance data and explored the role of IT in improving operations through its improvement of resource utilization. Specifically, we examined the effect of IT in reducing LOS, an operations management construct of critical clinical importance that has far-reaching financial and patient care implications for hospitals. Our findings are consistent with the outcomes predicted by the TSEF that a streamlined operational flow will lead to improved efficiency and effectiveness.

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- 1 IT investment per worker in healthcare is $3000 compared with an average of $7000 in private industry and $15,000 per worker in banking (Porter and Teisberg, 2006; p. 213).
- 2 Kaiser Family Foundation, http://healthreform.kff.org/the-basics/access-to-coverage-flowchart.aspx.
- 3 Also called MedPAR data. CMS makes this data available for a fee. See http://www.cms.hhs.gov/LimitedDataSets/.

Appendix A

See **Fig. A.1**.

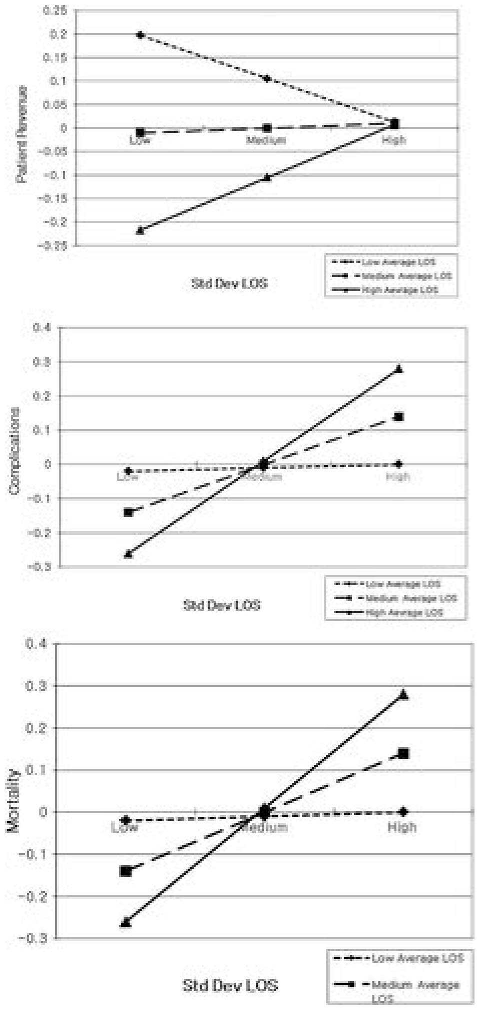

Figure A.1

Interaction plots.

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