International Journal of Production Research

ISSN: 0020-7543 (Print) 1366-588X (Online) Journal homepage: http://www.tandfonline.com/loi/tprs20

Information technology strategy for a patient-oriented, lean, and agile integration of hospital pharmacy and medical equipment supply chains

Véronique Nabelsi & Stéphane Gagnon

To cite this article: Véronique Nabelsi & Stéphane Gagnon (2016): Information technology strategy for a patient-oriented, lean, and agile integration of hospital pharmacy and medical equipment supply chains, International Journal of Production Research, DOI: 10.1080/00207543.2016.1218082

To link to this article: http://dx.doi.org/10.1080/00207543.2016.1218082

Published online: 09 Aug 2016.

International Journal of Production Research, 2016
http://dx.doi.org/10.1080/00207543.2016.1218082

Taylor & Francis
Taylor & Francis Group

Information technology strategy for a patient-oriented, lean, and agile integration of hospital pharmacy and medical equipment supply chains

Véronique Nabelsi* and Stéphane Gagnon

Department of Administrative Sciences, Université du Québec en Outaouais, Gatineau, Canada

(*Received 18 December 2015; accepted 14 July 2016*)

Both public and private hospitals are increasingly under pressure to reduce costs while improving patient care across all medical disciplines and departments. Hospitals must become patient-oriented, lean, and agile in order to properly realign and integrate health care processes, helping to reconcile efficiency imperatives with patient needs and hospital mission. One of the highest potential for improvement can be found in supply chain management (SCM) practices for medical supplies, which often represent more than 40% of a hospital's operating budget. We report on 3 case studies of business process management and reengineering projects, relying on advanced information technology, focused on the supply chains of two major urban hospitals, involving $2 million in minimum stocks for drug inventory. Case study 1 deals with an in-depth analysis of SCM practices around a key medical asset in pharmaceutical supply, i.e. infusion pumps. Case study 2 builds upon the findings of case 1, and proposes an radio-frequency identification solution to support a new hospital-wide asset location process and system, aiming for just-in-time availability of infusion pumps for critical drugs administration. Case study 3 complements cases 1 and 2 by analysing the feasibility of integrating the various components of the hospital pharmacy inventories, which in turn could be integrated to asset location systems. Our 3 case studies lead us to a number of conclusions on how hospitals can develop a patient-oriented, agile, and lean perspectives and practices, as well as ensure the proper integration of patient needs within optimised supply chains.

Keywords: Patient-oriented, lean, and agile (POLA) hospitals; supply chain management (SCM); business process management (BPM); decision support system (DSS); pharmacy inventory; infusion pumps

1. Introduction

Both public and private hospitals are increasingly under pressure to reduce costs while improving patient care across all medical disciplines and departments. Hospitals must become patient-oriented, and rely on lean and agile principles to ensure they properly realign and integrate health care processes, helping to reconcile efficiency imperatives with patient needs and hospital mission. One of the key success factor is to ensure internal logistics and external supply chain management (SCM) processes are adequately integrated, as both sides must adjust to patient needs and unexpected risk events (agile), while constantly improving quality and cost control (lean). A lack of synchronised improvement can only lead to mitigated results, and any gain in either part can be hampered by lack of focus on the other.

We report on 3 case studies of business process management (BPM) and reengineering projects, relying on advanced information technology (IT), focused on the supply chains of two major urban hospitals, involving $2 million in minimum stocks for drug inventory. Case study 1 deals with an in-depth analysis of materials management practices around a key medical asset in pharmaceutical supply, i.e. infusion pumps. Case study 2 builds upon the findings of case 1, and proposes a radio-frequency identification (RFID) solution to support a new hospital-wide asset location process and system, aiming for just-in-time availability of infusion pumps for critical drugs administration. As cases 1 and 2 are focused on internal loops (ILs) in supplies management, case 3 looks at the interface between internal and external loops (ELs). It is focused on analysing the feasibility of integrating the various components of the hospital supply chain, from pharmacy inventories, procurement functions, and supplier relations, which in turn can be integrated to asset location systems.

These 3 case studies demonstrate how supply chain integration directly serves patient-oriented hospital transformation. It requires that all systems, serving internal and external processes, be integrated with such leading edge technologies as RFID and Internet of Things, helping to automate medical and pharmaceutical materials management at every step. Integration also shifts the loci of efforts in agile and lean improvements, by transforming and synchronising SCM

*Corresponding author. Email: stephane.gagnon@uqo.ca

with internal logistics, and allowing hospitals to meet patient needs and expectations in the most efficient and adaptable way.

We used a mixed research method, gathering qualitative data on pharmaceutical and drug delivery equipment supply-chain practices with interviews, observations and internal documents analysis. We then performed statistical analysis on their inventory database systems, at all steps of the supply chain (e.g. prescriptions, orders, receptions, inventories, in-process and delivery).

We first outline current research trends in hospital IT and SCM, with a focus on a patient-oriented reengineering of medical supplies management. We follow with an overview of relevant technologies for end-to-end process integration and automation. A section presents the research methods used. We then present each case study in turn along 3 separate sections present, indicating key findings and their relevance for an innovative IT strategy for hospital pharmacy and equipment logistics integration. We conclude with a discussion of the challenges in reengineering hospital SCM practices, and draw lessons for IT executives as the feasibility of patient-oriented, lean, and agile change in large health care organisations.

2. IT in Hospitals

This study offers an overview of current IT challenges in the health care sector, especially in the viewpoint of configuring Healthcare Information Systems (HIS) for greater efficiency and agility (Menon, Yaylacicegi, and Cezar 2009). System functionalities, equivalent to enterprise resource planning (ERP), such as analysis, forecasting, management decisions and performance management, must be reconciled and harmonised with patient-oriented perspective (Tai-Seale et al. 2014). While not exhaustive, this study seeks to identify the basic issues relevant to SCM within hospitals, and define the broad categories of systems required for end-to-end process integration.

Hospitals need IT to enhance the quality of care, reduce medical errors, contain expenditures and comply with governmental mandates. However, the health care sector has been relatively slow to embrace the full potential of IT initiatives (Kumar and Aldrich 2010). In general, the implementation of IT in hospitals has not been particularly successful mainly due to the complexity of health care organisations, their inappropriate organisational structure and the conflicting role of key actors. In other words, the major impediments appear to be linked more to environmental and organisational issues than to technological problems (Black et al. 2011).

IT play a vital role in process performance of the health care sector (Li and Benton 2006). They are also essential strategic assets that have the capabilities to contribute to successfully attain organisational goals and objectives (Haux 2010). Over the years, the emergence of new technology such as Internet, electronic records, wireless technology and computerised transaction systems has improved the efficiency and effectiveness of hospitals in different perspectives (Jiang et al. 2014). In recent years, many hospitals have adopted new information systems and automation technologies to improve the SCM (Kowalski 2009). These benefits are enhanced by innovative cloud and process integration architectures (Xu 2011).

Recently, managing the supply chain has been recognised as a high potential impact for hospitals. Hospital administrators are searching continuously for innovative ways to control spending, improve patient safety and optimise staff time without sacrificing quality of services. SCM has been one of the primary areas where IT has delivered tangible value and improvements (Xu, Wermus, and Bauman 2011). However, it is essential to integrate SCM IT with lean and agile principles, seeking to eliminate non-value adding to improve the SCM: over processing, transportation, motion, inventory, waiting, defects, overproduction and underutilised personnel (Park and Dickerson 2009). As such, 'Hospitals SCM automation technologies have the ability to reduce these wastes by liberating staff to focus more on patient care and safety and less on the tedious, arduous transport of materials, food and waste' (Birk 2007).

3. Research methodology

We outline the configuration of our research project that involved two years of fieldwork. A brief overview of our research site, case study design, data collection and data quality control methods are presented.

3.1 *Research sites*

The research was conducted over one year in two Canadian public hospitals in the same county, which offer a wide range of medical, surgical, diagnostic and preventive programmes. These hospitals maintain a total of 508 beds and employ more than 3000 staff, including physicians, interns, nurses, pharmacists, medical technologists and others health care professionals. The employees operate three shifts 24 h a day.

Their primary mission is to provide specialised services to a regional and inter-regional clientele, along with their more traditional mission of general and specialised services to urban residents. The two public hospitals rely on various enterprise applications such as maintenance management system (MMS) to manage asset maintenance both preventive and services. They rely on material resource management system, which requires manual intervention and a line of sight, to identify assets and update inventories. Moreover, one of the hospitals has implemented a Wi-Fi network. Nearly 100% of the hospital is Wi-Fi.

The hospitals are geographically within 20 min of each other. The supply chain expenses represent approximately 40% of medical devices costs and nearly 25% of pharma costs. Total drugs spending for both hospitals rose 7% from $12 million in 2006 to $17 million in 2011. In 2011, the two pharmacy departments employ nearly 100 staffs, processed more than 382,000 prescription orders, made more than 26,000 preparations of sterile drugs, and produced more than 1225,000 bagged doses. According to a 2012 report by the Canadian Institute for Health Information, several factors influenced spending on prescriptions drugs over the past decade such as population growth and ageing, general inflation, price effects and volume effects.

3.2 *Case study design*

We performed an exploratory study, and we used an inductive research design seeking evidence towards better practices for SCM and the various layers of the enterprise architecture (EA).

The aim of this research was to develop a reengineering strategy and roadmap for optimising the overall pharmacy and equipment supply chain processes. Specific objectives for this study include:

(1) Analyse the complexity of the entire SCM processes and systems;
(2) Identify key strengths and weaknesses (constraints) across the supply chain;
(3) Perform data quality and systems integration tests;
(4) Propose pilot studies for implementing end-to-end process integration.

Our approach offered rich data for a case study methodology, a method suitable for the study of complex processes (Eisenhardt 1989). As argued by (Yin 2014) in his seminal work, ‘the case study method allows investigators to retain the holistic and meaningful characteristics of real-life events – such as individual life cycles, small group behaviour, organisational and managerial processes, neighbourhood change, school performance, international relations, and the maturation of industries’ (Yin 2014, 4).

A series of 3 case studies were performed to gain in-depth knowledge and understanding of the overall pharmaceutical supply chain processes and systems. This approach enables to study one or more situations within one or more organisations, in depth and intensively. The method allows researchers to discover new problem sets and shed light on a phenomenon, and then generate a new theory thereafter (Strauss and Corbin 1990).

3.3 *Data collection and quality control*

Our long-term case study methodology allowed us to employ multiple data collection methods to gather information. Data collection for the case study approach was based on several sources:

(1) Executive focus groups with directors of product management, materials management service, biomedical engineering and pharmacy;
(2) Semi-structured interviews, between 30 and 90 min each in 2 rounds:
    (a) First Round with 13 informants in and around hospital pharmacies, involving intra- and inter-professional collaboration, and interfacing between clinical, administrative, and supply chain stakeholders;
    (b) Second round with personnel directly involved in the supply chain at the two hospitals, including Director of Pharmacy, Pharmacy Technicians, Assistant Pharmacists, Pharmacists, and Nurses;
(3) Multiple on-site observations;
(4) Internal documents.

The quality of our data collection process required six months of regular work on and off site. We relied on several methods to match empirical evidence during this period. Both qualitative and quantitative data were corroborated using several techniques:

(1) Process mapping;
(2) Process map reviews with 12 informants;
(3) Database analysis for data integrity and systems integration tests on inventory and pharmacy databases covering 11 million medical prescriptions (Rx) over seven years for nearly 3000 drugs.

4. Case study 1: internal logistics of infusion pumps

The first case study deals with an analysis of internal logistics surrounding infusion pumps. This case leads to a second one dealing with a pilot project aiming at RFID implementation, among others for infusion pumps but also as an innovative way for supply chain integration. The third case study deals with an upward integration of the supply chain with supplier-to-patient end-to-end integration of the whole pharmacy.

4.1 *Reengineering the infusion pumps supply chain*

On a daily basis in intensive care units (ICU), nurses need a timely supply of medical devices, among others infusion Pumps, to administer critical drugs. Because of equipment shortage and mismanagement, it is often the case that a nurse must waste valuable time locating the necessary pumps, as they may not be in their original location, and if an another nurse in the ICU needed the same asset in an emergency case, the problem can dramatically impact patient care. The larger the hospital, the bigger is the problem. Nurses have reported that in many occasions they have to search for equipment outside their unit and across several floors, often without much success. The challenge is that infusion pumps move constantly both inside and outside the hospital, as patients are reassigned to other facilities.

Clearly, real-time tracking and information sharing of medical assets is vital. Lack of proper tracking of these assets will result in poor service quality, low patient satisfaction, frustrations of hospital staff, increases of operation costs and loss of life for certain patients (Oztekin et al. 2010).

4.2 *Role of infusion pumps in bedside care*

Infusions pumps (see Figure 1) are sophisticated devices used in a health care facility that intravenously delivers nutrients or medications into patient's body in a controlled manner. They normally use software to automatically control both the rate and volume of a medication's flow. To set a pump for an individual patient's needs, a doctor, a nurse or other health care professional enters information by using the buttons on a pump's keypad. This medical device whose design and manufacture is regulated by the Food and Drug Administration. This means that their design and construction must satisfy the requirements of the applicable statutes and the Code of Federal Regulations.

In 2010, the MRM system reported 324 infusion pumps. Table 1 shows the total pumps by model for each hospital that circulated between wards. As can be seen, there is a difference of 6 devices between them. From this table a variation on the total pumps by model can be noticed, there is higher number of Abbott PLUM 5000 model (273 pumps) than Abbott PLUM A+ model (51 pumps). However, some pumps are not included in inventory because some are lost or hidden.

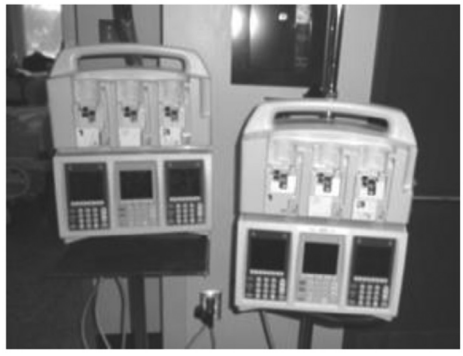

Figure 1. Infusion pumps.

Table 1. Total of infusion pumps by model for each hospital.

	Abbott PLUM 5000	Abbott PLUM A+	Total
Hospital A	144	21	165
Hospital B	129	30	159

Generally, an infusion pump has a useful life of 10 to 12 years. It was found that more than 200 infusion pumps have over 10 years. The MMS knows that the hospitals have an ongoing need for some additional units to replace existing infusion pumps, as they reach the end of their useful life. Past five years, the MMS has purchased only 60 pumps. For this year, with the end of the device purchase contract period nearing, a multidisciplinary committee evaluated potential of infusion pumps for the two hospitals use. The MMS has to negotiate a new contract with the same manufacturer for this asset in order to renew the park of pumps.

4.3 *Infusion pumps logistics processes*

Three processes related to infusion pump turned out to be quite important for all participants, namely transfer of pump to a medical unit (warehousing), request of pump (usage) and request for maintenance (maintenance). Figure 2 displays the 'as is' business processes from the general to the more detailed.

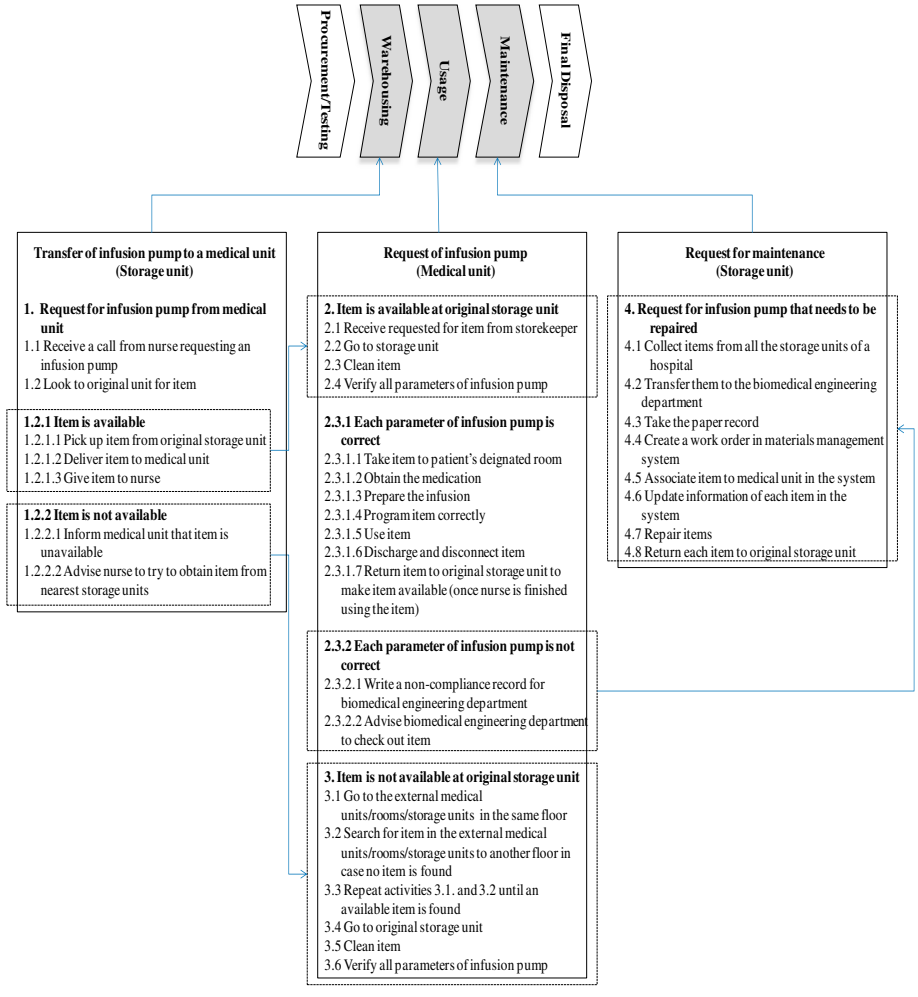

Figure 2. Current logistics processes for infusion pumps.

The infusion pumps are stored in a storage unit. This place furnishes medical unit with all necessary general and medical supplies. When a pump is needed and none are available on a medical unit, a nurse may call storekeeper to locate and deliver the requested device (e.g. 1.1). The MMS staffs will look for the device in designated storage unit (e.g. 1.2), take the device and give it to the nurse (e.g. 1.2.1). Sometimes the designated shelf for infusion pumps was entirely empty; hence, if any unit will call for an infusion pump the storekeeper will not be able to the supply equipment. For example, if none of the above pumps are available, the MMS will need to inform the medical unit (e.g. 1.2.2.1). In case of breakdowns, MMS staff has to advise the nurse to look for an infusion pump in external storage units in the same floor (e.g. 1.2.2.2).

The medical community reported that 'the problem is the delay to treat a patient and the patient health could be compromised when an infusion pump is not available when needed'. 'The patient cannot wait; the infusion pump must be acquired promptly'. In many occasions, nurses have to look through the halls and over many floors to find the equipment they need. The infusion pumps are mobile, moving between patient beds, medical units, storage units and wards. The medical staffs of the two hospitals are reported in semi-structured interviews that some cases it could take up 30 to 90 min per shift, on average, in searching for a pump – equating to nearly half a million dollars CAD per year in non-productive time due to ineffective asset utilisation. As mention by the staffs from the MMS, 'infusions pumps are often exchanged from one unit to another when nurses do not find an available device in the original storage unit'. In that case, 'the nurse checks out an item from an external unit, but don't return it to the storage of her unit'.

Thus the medical community may need to search for devices themselves, but another particularity is that nurses don't know which infusion pumps are cleaned and fully charged before use. As you see in the Figure 2, the simple act of cleaning and verifying this device could get complicated. The nurses have to follow the protocols before using on a patient (e.g. 2.3, 2.4, 2.3.1 and the related tasks). Because the cycle time for 'usage' process is generally too long to execute without causing patient care delays, the two hospitals have acquired additional asset to equilibrate for constantly misplaced or stolen infusion pump and have excess MMS staffs to compensate for time delays.

Furthermore, when the infusion pump doesn't meet the safety requirements or quality standards, the medical community has to report of non-compliance or failure in writing using the applicable form and advise the biomedical engineering department to check out item (e.g. 2.3.2). A collector from the department performs his cycles periodically by picking items (e.g. 4.1) and taking them to the department to be repaired (e.g. 4.7), and then returned to the original storage unit (e.g. 4.8).

The biomedical engineering department who did the maintenance needs to find it to maintain on a regular schedule. It is difficult for the maintenance staff to know the location of medical equipment when required for planned preventative maintenance. On average this can amount to 30 min per infusion pump. In the two hospitals for example, where approximately 324 infusion pumps require a scheduled inspection each year, this relates to more than 150 lost man-hours. This does not include the time involved in trying to locate this device that have become lost in the equipment management system, of which, in a typical district general hospital, there may be up to 30 at any one time.

For instance, nurses reported that 'the problem is the delay of the biomedical engineering department to do the maintenance. In some occasions, they have 10 to 15 pumps left in the department and no one is fixing them'. The maintenance activities are also delayed because the collector is not able to locate pumps to perform a periodic check or a scheduled maintenance. Therefore, the collector from this department needs to wait for a certain period of time until the pumps come back to the storage unit. From semi-structured interviews medical community pointed out that 'when infusion pumps is poorly maintained, patient safety is also compromised'.

4.4 *Findings from case study 1*

Based on the analysis of the current materials management processes in the previous figure, the following observations can be made:

(1) The 'warehousing' and 'usage' processes are fragmented between the materials management service and medical community, resulting in duplications and redundancies;
(2) None of the processes are performed automatically, some tasks are carried out semi-automatically (e.g. 4.4 to 4.6);
(3) The overall 'warehousing' and 'usage' processes require time-consuming for human interventions by the storekeepers and nurses. They don't have accurate information of the physical location that move across the hospital and between medical units;
(4) Amount of time is devoted by nurses to clean, charge, verify all parameters and programme the infusion pump before using, and store it at the original storage unit after using the item (usage process);

(5) Maintenance of infusion pump is not monitored at all. Also, it is unclear whether the current maintenance level meets the infusion pump maintenance regulations;
(6) The process of managing the mobile medical equipment warehouse, use and maintenance faces a high level of operational cost.

These SCM challenges are exacerbated by information management practices, demonstrating the urgency of a major reengineering and automation programme:

(1) No access to information identity (model), location, movement, status and maintenance history of this device, leading to major risk of trial-error efforts at making the pump deliver the right drug dosage as prescribed.
(2) Lack of real-time information (to identify and locate available equipment), resulting in underutilisation of assets.
(3) Inability to exchange assets information between hospital and between medical units (there is no record of equipment transfers).

Finally, logistics and information management challenges lead to health care outcomes that put patient life at risk, and are the very source of value added from process automation:

(1) Maintenance delay incurred in performing scheduled maintenance. For example, biomedical technicians from the biomedical engineering department are not able to locate infusion pumps in order to perform a recall or a scheduled maintenance.
(2) Service delay when medical staff is not able to timely respond to patient's health needs due to lack of available equipment.
(3) Staff time waste while searching for available needed infusion pumps is highly time-consuming activity.
(4) Unsatisfactory service resulting from long waits and wasted time searching for assets.
(5) Constant shortage of available infusion pumps at the storage unit. It was noticed that the designated shelf for IP was completely empty in some occasions.
(6) Security and safety issues linked to the lack of insight into the location and movement of assets.

5. Case study 2: automation of equipment location with RFID

The second case study builds upon lesson learned in the first one. It aims at developing a pilot project to implement RFID to automate equipment location. The pilot project first concerns infusion pumps as a high-value equipment, but aims at developing an infrastructure reliable for all equipment location across the two hospitals studied.

5.1 *RFID in hospitals*

Despite its potential, health care organisations are adopting RFID at a slower pace compared to other major industries. There is a currently paucity of research contributions concentrating on the technology implementation by hospitals. Although the literature on RFID in health care SCM does exist, its quantity is limited. The lack of a business case and lack of understanding on how RFID technology impacts business processes in these organisations constitute their main concerns for this research.

With RFID technology, mobile medical equipment become intelligent and trigger intelligent business processes that improve asset management. The adoption of RFID technology has the potential to resolve operational and managerial inefficiencies. Table 2 presents a non-exhaustive list of RFID opportunities to track mobile medical equipment in the context of the hospital environment.

5.2 *RFID strategy development*

This case study unfolded in three phases, as exposed in Table 3, following a methodology published prior to the study (Nabelsi and Stefanescu 2010; Nabelsi forthcoming-a).

The '*opportunity-seeking'* (Phase 1) is divided into five steps. This phase begins with the examination of the corporate motivations for RFID adoption. This step involved in identifying the current problem and the needs that triggered the pilot project. This phase also includes the identification of the specific asset that will be targeted by an RFID implementation, their critical activities and resources that support them (Steps 2 and 3). The actual supply chain dynamics and existing intra- and inter-organisational business processes must be mapped at this phase (Steps 4 and 5). The 'as is' processes were designed using the Aris Toolset software from IDS Scheer. These steps are analysed to gain a detailed understanding of which parts of the current processes work, which parts do not, and what is needed.

Table 2. Value of RFID in hospitals.

Operational processes	Managerial processes
• Automatic request for equipment • Automatic notification/alerts • Reduced time to find equipment • Increased utilisation • Reduced shrinkage/lost • Enhanced safety • Faster response to critical events • Reduced patient waiting time at point of care • Efficiency/process synchronisation • Real-time location tracking • Improved compliance with scheduled equipment maintenance	Automatic history, status Detect asset transition through chokepoints Identify and location continuously for servicing, preventive annual maintenance or recall, faster asset location for immediate use

Table 3. RFID strategy development process.

Detailed activities
Phase 1: Intra- and inter-firm opportunity seeking
Step 1 *Determination of the primary motivation* towards the use of RFID *(WHY?)*
Step 2 *Analysis of the product value chain* (PVC) activities specific to a given product *(WHAT?)*
Step 3 *Identification of the critical activities in the PVC*, *(WHICH* activities to select and *WHY?)*
Step 4 *Mapping of the network of firms supporting the PVC* to understand the relationships between the firms supporting the product *(WHO and WITH WHOM?)*
Step 5 *Mapping of 'As is' intra- and inter-business processes* for critical activities (*HOW* within and between organisations?). Time and motion data capture and analysis
Phase 2: Intra- and inter-firm scenario building integrating RFID technology
Step 6 *Evaluation of RFID opportunities* with respect to the product (level of granularity), to the firms involved in the SC and to the specific PVC activities
Step 7 *Evaluation of RFID potential applications* including scenario building and process optimisation 'As could be' (HOW within and between organisations?)
Step 8 *Mapping of intra- and inter-organisational processes integrating RFID technology*
Step 9 *Validating business processes and technological solutions integrating RFID technology* with key respondents. Feasibility analysis and evaluation of the challenges *including ERP and middleware integration, process automation and SC alignment*
Step 10 *Simulating several scenarios* for final choice of proof of concept
Phase 3: Scenario validation and demonstration
Step 11 *Proof of concept in laboratory* simulating physical and technological environments, and interfaces between SC players. Feasibility demonstration of RFID technology and evaluation assessment (ERP and middleware integration and process automation for all the SC members)
Step 12 *Beta Test in real-life setting.* Deployment of application and its appropriation by the different organisations involved and their staff

The second phase constitutes the '*scenario building'* to evaluate RFID opportunities. In this phase, several scenarios are evaluated regarding the implementation of RFID (Steps 6 and 7), business and technological concerns are evaluated (Step 8), business processes are redesigned to integrate RFID technology (Step 9) and several scenarios are simulated and are validated with key respondents (Step 10).

The final phase (*validate the scenarios*) is used for the demonstration and analysis of scenarios retained in the second phase, both in controlled conditions (proof of concept – step 11) and in a real-life setting (step 12).

5.3 *Value of RFID for infusion pumps logistics*

All health care professionals involved in our case study were aware of the potential benefits of using RFID technologies (Revere, Black, and Zalila 2010). Their primary motivation leading to the selection of this medical device is centred on operational inefficiencies, cost reductions, and improvement of medical service and patient safety. During the focus

groups sessions, all participants (Director of Product Management, Director of Materials Management Service and the Director of Biomedical Engineering) have chosen this mobile asset for different reasons:

(1) According to the Risk Assessment Matrix (RAM) used by the two hospitals to rank and assess the risks of assets, the infusion pump is considered high-risk device in terms of the threat as any failure of particular medical equipment could represent to a patient's health.
(2) Medical staff has to programme the correct medication dose and the correct time of delivery. Even when infusion pump is programmed correctly, unlimited changes in the rate can lead to patient harm. The infusion pump must not be left to run unattended.
(3) The infusion pumps are expensive equipment. Each infusion pump can cost as much as CAD$3000. The total value of this device for the two public hospitals is estimated at nearly one million dollars.
(4) These hospitals lost nearly 20% of its infusion pumps inventory during the past few years. They have to overbuy this device because they can't find it, they can't locate it. But because these assets are mobile, they have to overbuy on top of that during peak demand. Thus shrinkage and replacement of this equipment is very costly and missing one could have an adverse effect on patient care.
(5) In many occasions, Materials Management Service (MMS) is not able to fulfil medical wards demands for infusion pumps, resulting in recurrent complaints and dissatisfaction of medical staffs. Frequently, there is not enough stock of infusion pumps out the medical unit.
(6) Storekeepers at storage unit do not have visibility of pumps that rotate between medical units. The pumps are kept in the nursing areas and moved from patient to patient as needed. Occasionally, medical staff removes an infusion pump used to support a patient to another facility or is often misplaced in wards hallways, closets, rooms, etc.
(7) Nursing staff spend considerable time and effort looking for this medical device that is required in the treatment of patient support.
(8) This asset requires a level of maintenance because is considered high-risk equipment. An infusion pump that is passed its maintenance date, might not be working correctly.
(9) Failure to locate medical devices for scheduled inspection leads to significant numbers of devices not having regular scheduled inspections, with figures as 20% or higher in some instances. More worrying is the long-term lost the infusion pumps that may not have been inspected for two or more years.

5.4 *Infusion pumps tracking pilot project*

As illustrated in Figure 3, the plan for the third floor of the 'Hospital A' was used in the case study for the '*scenario building'* (Phase II) to evaluate RFID opportunities.

There are one laboratory (ward E) and four medical units: operating room (ward A), haemodialysis (ward B), haematology/oncology (ward C) and intensive care (ward D). A serial numbers of equipment is assigned in storage unit per medical unit. In the third floor, they have four storage units and the MRM system reported an inventory of 70 infusion pumps, more specifically, they have 53 pumps Abbott PLUM model and 17 pumps Abbott A+ model. The ICU has the higher number of this mobile medical equipment with 44 pumps.

With regard to the medical supplies, the MMS is responsible for warehousing activities, including receiving, put away, and picking of equipment, for distributing the equipment to wards and for restocking from wards. Indeed, wards A to E are co-located on the same floor, sharing a common entrance hallway and access to elevators which are the only two points of entrance to these medical units. When storage unit's storekeepers distribute infusion pumps to Wards D, they will access these wards by either of these entrance points. Moreover, when either of these units needs an infusion pumps and that there is a stock-out at original storage unit; their first choice for procuring their required equipment is the other ward, hence nurses from ward D will try to find an available pump in ward A, B or C and vice versa before looking for one at other units. The storage units are located in different hospital wings and on different floors.

5.5 *RFID integration scenario*

Based on a detailed planning of our integration scenario, we planned a set of IT infrastructure necessary to track infusion pumps throughout the chosen facilities.

The core of our scenario depends on RFID tags emitting a signal periodically, tracked by a series of location sensors installed at each floor. The transmitted tag data is accumulated, evaluated and summarised into dashboards in the form of graphs or virtual map position. The proposed technological scenario included as:

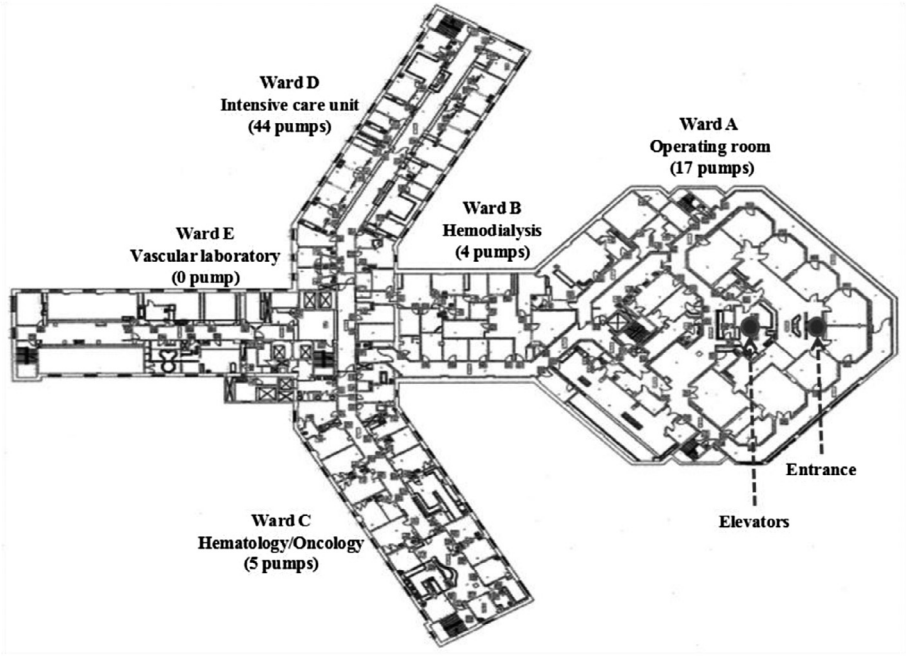

Figure 3. Plan for the third floor of the 'Hospital A'.

(1) Wi-Fi access points, positioned somewhere in the corridor of each of four selected wards, one access point in the common entrance of the wards A to E, one access point in each storage location and one RFID reader per ward.
(2) Seventy Wi-Fi-based RFID active tags (e.g. 17 RFID tags – operating room, 4 RFID tags – hemodialysis, 5 RFID tags – haematology/oncology and 44 RFID tags – intensive care.
(3) One enterprise tracking server and software that provides a layout plan of the coverage zone displaying real-time information of assets tagged.

With a location tracking using Wi-Fi-based RFID tags, when we tag the pumps, we can basically make them available to the maintenance personnel, to the medical unit, to the staff that need to find, locate and use that equipment versus when is unavailable for use. And basically make sure the system helps, make sure that they're properly maintained and that the hospitals are getting a high rate of utilisation.

With the active tags that are attached to individual pieces, MMS staffs are able to record the exit of equipment from the storage unit towards all medical units, as well as the return of equipment to be accounted as available inventory. Given the actual lack of visibility on equipment location outside the storage unit; storekeepers cannot comply with medical units' demand for infusion pumps due to repeatedly stock-outs.

5.6 *Findings from case study 2*

Our second case study allowed us to accurately identify the scale and scope of value added from automating materials management with RFID.

Building upon our RFID strategy development process, we identified further upward process integration challenges, which prompted the pursuit of case study 3:

(1) The final phase is used for the demonstration and analysis of scenarios retained in the Phase II, both in controlled conditions, and especially using proper integration to all materials and PISs (Step 11).
(2) Warehousing, usage and maintenance processes are reproduced in a similar physical and technological environment to that found in the hospital. The main goal is to demonstrate the feasibility of RFID technology and assess the ERP and middleware integration, process automation, information flow and human resources impact for all health care professionals involved in these processes. The equipment is acquired, calibrated and configured, and the business rules are identified and configured in various middleware applications and integrated with the ERP engine. Finally, dry-run tests are conducted to validate the IT and process integration.

6. Case study 3: integration of pharmacy inventory

The first 2 Case Studies focused on internal logistics, but are linked to case study 3, dealing with hospital pharmacy and supply chain integration. While the strategic purpose was to ensure stronger SCM practices in the upward part of the supply chain, it became clear during the case analysis that the most valuable aspects of this project would be the downstream integration with other drug and materials management practices. Hence this case is a complement to cases 1 and 2, as it pertains to ensuring a complete patient-oriented and end-to-end integration of a hospital supply chain.

SCM and inventory automation are necessary for lean and agile patient-oriented processes. If upstream (sourcing) activities are not integrated with downstream (consuming) activities, then SCM inefficiencies will off-set any lean/saving efforts by internal logistics. The same way, patient-oriented care cannot be performed effectively if SCM is not agile enough to adapt to internal logistics speed. Internal and external process synchronisation is essential for lean and agile principles to be effective.

6.1 *Supply chain structure*

All steps and personnel of the supply chain were interviewed. They are represented in Figure 4, which illustrates the stakeholders involved in the hospital pharmacy supply chain network, and shows their intra- and inter-organisational relationships. The pharmaceutical manufacturers (M1, M2 and M3) represent the first level in the supply chain. D1 (third level), which has large demand requirements, receives shipments direct from the manufacturer (M1), whereas M2 distributes the supplies of medicine directly to the hospitals (H1 and H2).

It further highlights that M3 has a business relationship through a third-party logistics provider that represents the second level in the chain, the regional group purchasing organisation (GPO). In this case study, the two public hospitals (H1 and H2) use regional purchasing group in order to coordinate negotiation processes and to select the providers for the common products consumed. The role of GPO is to negotiate lower costs of goods and services for several hospitals that are members. In general, hospitals may leverage economies of scale by consolidating their purchasing power.

Figure 4 also shows that GPO works with manufacturer (M3) and distributor (D2) to create effective purchasing opportunities. The pharmaceutical supply chain terminates when the drugs reach the wards within the hospital at the pharmacy warehouse (PW). Each PW is responsible for monitoring and managing their own inventory. If certain pharmaceutical products are not in stock at the H1, the supply manager can contact the supply manager at the H2 to check their availability. When the products are in stock, they will be picked, packed and shipped. All preparation and delivery

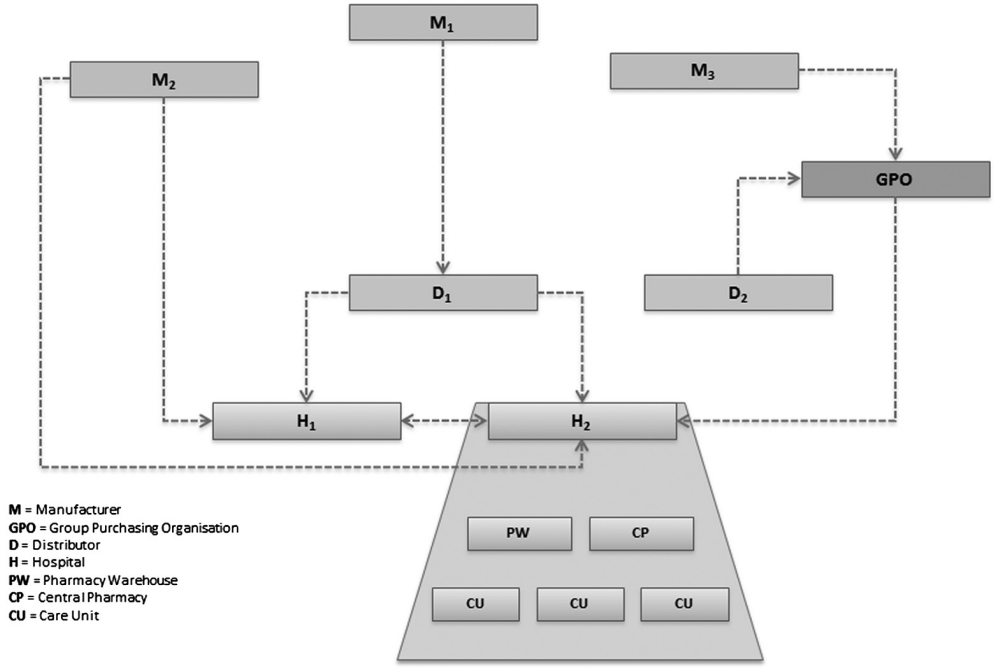

Figure 4. Pharmaceutical supply chain structure.

activities around medicines are undertaken by the central pharmacy (CP) of each hospital. The medicines are then delivered to the corresponding care unit.

In summary, we have multi-tier supply chain loops. ILs are activities and their inter-relationships between the internal functions that manage the flow of drugs into the hospital. IL includes various activities such as ordering, storage, inventory management, receiving, replenishing, preparing, checking and dispensing Rx to the points of care. An ELs is the intra-relationships between one hospital and another hospital, between manufacturer and its downstream partners, and between GPO and hospital. The activities related to EL are purchasing, negotiating and delivering goods and services for the health care facilities.

One key finding is that IL and EL activities impact directly the efficiencies of SCM, and will in turn enable or impede patient-oriented care that attempt to implement agile and lean principles. Collaboration among supply chain partners is key to accomplishing measurable care process transformation.

6.2 *Pharmacy information systems*

The pharmacy departments rely on medical and administrative applications:

(1) The PIS
(2) Automated dispensing system (ADS)
(3) Unit dose dispensing system (UDDS)
(4) Pneumatic tube system (PTS)
(5) Materials information system (MIS)
(6) Electronic data interchange (EDI)

The CP of each hospital uses PIS, ADS, UDDS and PTS, while PW and Materials Management Department (MMD) of each hospital use MIS and EDI.

Integration of all IS modules is a first step towards SCM agility. Systems obviously require common product indexing codes, meet sizes and quantities that match patient needs and clinical practices, and must ensure traditional Just in Time inventory efficiency and effectiveness principles are respected. As such, any lack of integration between internal logistics (MMD), interface units (CP), and external SCM processes (PW), could hamper gains from bed-side and clinical process improvements.

6.3 *Findings from case study 3*

We report in Tables 4 and 5 on the internal and external supply chain constraints. They were confirmed by interviews and observations, along with verifications inside SCM systems at every step of the chain (indicated by # in tables).

These tables demonstrate the direct links between cases 1 and 2 (internal logistics) and case 3 (external-facing logistics), and how lean (efficiency/quality) and agile (adaptive/responsive) priorities can be met only if these constraints are resolved. Patient-oriented care processes require supportive SCM abiding to strong principles of fully-integrated and seamless sourcing-inventory-using processes. All the constraints reported in these tables have direct or indirect impact on patient care, and also impact the adequacy of pharmaceutical and medical supplies, along with their timely availability.

In addition, these process constraints are directly related to various IS integration issues. During system audits performed as part of this research project, several manual iterations of Extract, Transform, and Load (ETL) were required to integrate data from 5 source systems. While all personnel believed that the hospitals EA was sufficiently documented, a Failure Mode and Effects Analysis (FMEA) revealed that most of the constraints identified had their source in the incoherent use of different product identifications across systems, as well as none of the naming nomenclatures conforming to ministry regulations.

An SCM BPM initiative can therefore detect these constraints early by automating systems documentation audit. It could rely on the constraint patterns identified in our tables, and pinpoint which EA component influences the FMEA.

In addition, data indicates that health care SCM exhibits several constraints at all levels of the EA. Further research is presently under way to help detect these inconsistencies by FMEA in BPM project planning, relying on a more robust EA feasibility assessment technique.

In response to this conclusive evidence, our research team is designing prototypes reusing standard-compliant ontologies, such as the HL7 Clinical Document Architecture, allowing more adaptive BPM by detecting constraints with limited information in the ETL stage (Khan et al. 2014).

Table 4. Constraints in the internal supply chain.

#	Supply chain activities and constraints
1	Plan and determine inventory requirements (needs)
	• No planning daily and weekly needs
	• Planning the inventory is performed by artisanal way
	• Visual count of medication by nurses combined with an assessment of consummation to care units
	• Requests are not streamlined, the needs are measured by glance
	• Checking the inventory is done manually
	• List of common products of care units is not regularly updated in the system
2	Internal order
	• High proportion of requests get made several times a day via the telephone by the care units and CP to PW
3	Requisition
	• High volume of medication that is not encoded and/or properly coded in the system
	• High proportion of requisitions created in the system
4	Withdraw products from inventory
	• Regular taking by CP staff from PW, by nurses from another care unit, from CP or from PW without requisition
	• Non-regular use in system for inventory outputs
	• Multiple Product Handling
	• Difficult to identify products to care units for outlet
	• Accumulation of stocks to care units and pharmacy
	• Products are not harmonised
5	Create order
	• Non-regular use of EDI interface to transmit the Purchase Order (PO) to the distributor
	• The print the PO via the system to validate the information
6	Receive shipments
	• Limited space and handling by double of equipment
	• Inadequate reception area and cluttered
7	Store and classify
	• No product visibility to care units
	• Hardware and mislabelled shelf, may generate waste of time for the caregiver to find products
	• Storage and classification of products by the caregiving staff to the care units
	• Inadequate and cluttered storage area into care units
	• Accumulation of products into care units, pharmacy and warehouse (too much inventory)
	• Problems of storage space into the care units
	• Lack of device to store and classify products
	• Limited space

7. Discussion and conclusion

This research project focused on the practice of SCM in health care and how the use of IT is transforming internal and external logistics towards patient-oriented care. With the increasing importance of IT to enable lean and agile change in hospitals, a number of lessons can be drawn beyond case studies of equipment location and pharmacy inventory integration.

The distinctive findings in cases 1, 2 and 3 can be summarised as follows. Cases 1 and 2 focused on internal logistics, while case 3 focused on external-facing logistics. The first 2 demonstrated a close interdependency, analysing the process constraints in internal materials management, and exploring the benefits of using RFID, in controlling the location of a particularly strategic pharmaceutical supply and medical equipment, infusion pumps. Case 3 approached hospital supply chain improvement from a holistic perspective, asking how the internal logistics processes analysed in cases 1 and 2, as representative of the overall role of supplies in clinical processes, depend directly and indirectly on the quality of internal and external SCM processes.

In this discussion section, these results are further developed into a new research agenda, emphasising the real challenges of leveraging IT for lean and agile integration, where information and process architecture requires more automated testing to effectively overcome constraints, and implement truly patient-oriented care processes.

Table 5. Constraints in the external supply chain.

#	Supply chain activities and constraints
1	Receipt of products • Errors in invoices (price, quantity, sites) • Reception of expired products
2	Service level • Product without contract difficult to replenish even if it is the same product • Phone calls and frequent emails for inquiries and other • Processing time is long • High frequency to contact the distributor (products out of stock, error code, format, resupply time, etc.)
3	Process • Receipt of the confirmation of the Purchase Order by fax rather than by email • Tracking of orders difficult • Management of backorders
4	Information on the platform • Incompatible product keys in databases of pharmacy, inventory, distributors and billing. • Incomplete description of products (size, price, code P, DIN, etc.) • Error on the product codes • Inventory does not reflect reality (quantity is not often updated) • No information for loans for expired products for each supplier • No information on outstanding (out of stock?) products and replenishment delay • No access to the invoice number from the distributor platform • No information on the order history
5	External information • Command performed regularly with another distributor • Consultation for each order on distributor platform on information of products and their availability in stock

7.1 *patient-oriented SCM*

The health care industry is inherently global as most high-end medical products, drugs and equipment are manufactured by multinational suppliers (Narayana, Pati, and Vrat 2014). Health care product development, manufacturing, distribution and GPO are increasingly integrated through inter-organisational information systems in order to optimise made-to-stock replenishment processes (Uthayakumar and Priyan 2013). Hospitals must adjust their SCM practices while improving patient health outcome, as they must meet ever increasing economic and performance pressures brought by changes in national health policies (Chen, Preston, and Xia 2013).

As demonstrated in many other industries, these improvements require that health care organisations adopt new SCM practices, processes and systems, especially concerning internal operations (Kelle, Woosley, and Schneider 2012). A strategic value perspective can serve as an anchor to reengineering hospital supply chains towards a lean and agile model, and help ensure policy compliance (Baboli et al. 2011).

Yet, SCM can only be successful if it is truly patient-oriented, namely ensuring that products and services are timely, and follow demand instead of supply priorities (Nabelsi forthcoming-b). From prior studies, we have found that this perspective can only be reached based on thorough management of inter-professional collaboration and performance management (Nabelsi 2007).

The present research helped develop the organisational and technological infrastructure necessary to develop a strategic framework for patient-oriented SCM. It allows us to integrate the evolving economics of the health care industry, the emerging dynamics of global supply chains, and the broad SCM approaches required to realign hospitals on patient health outcomes (Hellström, Lifvergren, and Quist 2010).

7.2 *Lean and agile SCM strategies*

Our study of SCM and IT challenges in public hospitals has led us to conclude that health care policies at various levels, promoting lean and agile strategies, must be driven by outcomes, all of which having measurable performance metrics (Nabelsi 2011). But a more inclusive and coherent approach is necessary to ensure patient health outcomes,

requiring lean project leaders to go beyond mere process control and optimisation (Waring and Bishop 2010). Health care executives, as they set lean and agile policies, and select the most appropriate managers to lead these projects, must be more conscious of the actual difficulties of implementing an agile and lean perspective, with renewed attention to BPM and IT PM methods in the context of health care SCM (Narayana, Kumar Pati, and Vrat 2014).

The high-risk, high-complexity and high-unpredictability of this sector warrants greater attention to how knowledge and learning can serve as dynamic capabilities to ensure constant process innovation (Helfat and Peteraf 2014). However, innovation in the health care sector, even when motivated by efficiency and productivity objectives, should always be aligned with patient-oriented imperatives, which in turn must be the focus of IT strategies to enable change (Brandao Brandao de Souza 2009).

As such, lean and agile approaches must lead towards a truly patient-oriented and fully (end-to-end) integrated health care process and pathway (Røsstad et al. 2013). SCM practices must be aligned with this process so as to enable patient-centred care trajectories as opposed to fixed care protocol with supply constrains (Ozkaynak et al. 2013). Integrated health care trajectories, from a patient's viewpoint, are particularly suitable for the evaluation of continuity of care, and guiding supply policies in order to support this goal (Eason et al. 2012).

7.3 *IT risk management in SCM*

Health care organisations are faced with numerous opportunities to implement innovative IT solutions, which are exacerbated by the inherent complexity of constant changes throughout the health sector (Sturmberg, O'Halloran, and Martin 2012). Each one offers to solve old challenges with new approaches, but also opens new risks, to the extent that personnel can fully leverage IT on a daily basis, depending to what extent IT solutions properly addressed these risks from the start of their EA design.

In the case of SCM, hospitals must leverage IT to move faster and deeper into an end-to-end integration of supply chains (Samuel et al. 2010). They must move from the established paradigm of bulky, static, and proprietary systems, and adapt to new technologies, e.g. cloud computing, end embrace a new IT paradigm with complex, dynamic and open systems. In the particular case of pharmacy inventory and equipment location, SCM systems must rely on common information models that overcome the risks of discrepancies and incoherence throughout the supply chain (Bertolini et al. 2014). SCM must also be made more responsive and agile, especially using rules-driven solutions from empirical or evidence-based knowledge extraction and recommendation engines (Duan, Street, and Xu 2011).

As observed in our case studies, the effectiveness of IT project risk management, especially in the case of high-risk projects such as RFID integration, depends on an accurate model of risk factors internal and external to the project, including end-users, vendors, systems and infrastructure (van der Togt, Bakker, and Jaspers 2011). The evidence collected, as our 3 cases build upon one another, echoes the findings of other studies focused on projects of similar complexity (Li et al. 2008). IT project teams are confronted to new forms of risk difficult to manage with traditional methods and standards (Poulymenopoulou, Malamateniou, and Vassilacopoulos 2013). New risk modelling approaches are required, better reflecting the systemic complexity and dynamics of the interactions between all the layers of EA (Meker and Barlas 2015).

Consequently, SCM reengineering projects must take into account that each IT application area (e.g. enterprise systems, networking, data centres, mobile solutions, etc.) require distinct risk models in order to capture adequately the realities of project management and deliverables in each field. Risk models must attempt to integrate more tightly the technical and organisational facets of IT decision-making (Aloini, Dulmin, and Mininno 2007).

As well, the quality of IT project risk management is directly dependent on a project team's risk knowledge. Integrated Knowledge Management (KM) practices and systems must be customised for IT projects, ensuring a truly patient-oriented perspective is reflected throughout the team's knowledge (Teixeira, Ferreira, and Santos 2012). It is essential for that purpose to integrate technology, process and learning capabilities, which are too often disjointed in most IT projects (Bjørnson and Dingsøyr 2008).

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Stéphane Gagnon http://orcid.org/0000-0001-7732-9849

References

Aloini, Davide, Riccardo Dulmin, and Valeria Mininno. 2007. "Risk Management in ERP Project Introduction: Review of the Literature." *Information & Management* 44 (6): 547–567. doi:10.1016/j.im.2007.05.004.

Baboli, Armand, Julien Fondrevelle, Reza Tavakkoli-Moghaddam, and Ali Mehrabi. 2011. "A Replenishment Policy Based on Joint Optimization in a Downstream Pharmaceutical Supply Chain: Centralized Vs. Decentralized Replenishment." *The International Journal of Advanced Manufacturing Technology* 57 (1–4): 367–378. doi: 10.1007/s00170-011-3290-x.

Bertolini, M., M. Bevilacqua, F. E. Ciarapica, and L. Postacchini. 2014. "Business Process Reengineering of Drugs Storage and Distribution: A Case Study." *International Journal of Procurement Management* 8 (1–2): 44–65. doi: 10.1504/IJPM.2015.066287.

Birk, Susan. 2007. "Automated Deliveries Lower Costs on FTEs." *Materials Management in Health Care* 16 (9): 48–51.

Bjørnson, Finn Olav, and Torgeir Dingsøyr. 2008. "Knowledge Management in Software Engineering: A Systematic Review of Studied Concepts, Findings and Research Methods Used." *Information and Software Technology* 50 (11): 1055–1068. doi:10.1016/j.infsof.2008.03.006.

Black, Ashly D., Josip Car, Claudia Pagliari, Chantelle Anandan, Kathrin Cresswell, Tomislav Bokun, Brian McKinstry, Rob Procter, Azeem Majeed, and Aziz Sheikh. 2011. "The Impact of eHealth on the Quality and Safety of Health Care: A Systematic Overview." *PLoS Medicine* 8 (1): e1000387.

Brandao de Souza, Luciano. 2009. "Trends and Approaches in Lean Healthcare." *Leadership in Health Services* 22 (2): 121–139.

Chen, D. Q., D. S. Preston, and W. Xia. 2013. "Enhancing Hospital Supply Chain Performance: A Relational View and Empirical Test." *Journal of Operations Management* 31 (6): 391–408. doi:10.1016/j.jom.2013.07.012.

Duan, L., W. N. Street, and E. Xu. 2011. "Healthcare Information Systems: Data Mining Methods in the Creation of a Clinical Recommender System." *Enterprise Information Systems* 5 (2): 169–181. doi:10.1080/17517575.2010.541287.

Eason, K., M. Dent, P. Waterson, D. Tutt, and A. Thornett. 2012. "Bottom-up and Middle-out Approaches to Electronic Patient Information Systems: A Focus on Healthcare Pathways." *Informatics in Primary Care* 20 (1): 51–56.

Eisenhardt, Kathleen M. 1989. "Building Theories from Case Study Research." *Academy of Management Review* 14 (4): 532–550.

Haux, Reinhold. 2010. "Medical Informatics: Past, Present, Future." *International Journal of Medical Informatics* 79 (9): 599–610. doi:10.1016/j.ijmedinf.2010.06.003.

Helfat, Constance E., and Margaret A. Peteraf. 2014. "Managerial Cognitive Capabilities and the Microfoundations of Dynamic Capabilities." *Strategic Management Journal* 36 (6): 831–850. doi:10.1002/smj.2247.

Hellström, Andreas, Svante Lifvergren, and Johan Quist. 2010. "Process Management in Healthcare: Investigating Why It's Easier Said than Done." *Journal of Manufacturing Technology Management* 21 (4): 499–511.

Jiang, Lihong, Ling Li, Hongming Cai, Hua Liu, Jingyuan Hu, and Cheng Xie. 2014. "A Linked Data-based Approach for Clinical Treatment Selecting Support." *Journal of Management Analytics* 1 (4): 301–316. doi:10.1080/23270012.2014.988762.

Kelle, Peter, John Woosley, and Helmut Schneider. 2012. "Pharmaceutical Supply Chain Specifics and Inventory Solutions for a Hospital Case." *Operations Research for Health Care* 1 (2–3): 54–63. doi: 10.1016/j.orhc.2012.07.001.

Khan, W. A., A. M. Khattak, M. Hussain, M. B. Amin, M. Afzal, C. Nugent, and S. Lee. 2014. "An Adaptive Semantic Based Mediation System for Data Interoperability among Health Information Systems Systems-level Quality Improvement." *Journal of Medical Systems* 38 (8): 1–18. doi:10.1007/s10916-014-0028-y.

Kowalski, Jamie C. 2009. "Needed: A Strategic Approach to Supply Chain Management." *Hfm (Healthcare Financial Management)* 63 (6): 90–98.

Kumar, Sameer, and Krista Aldrich. 2010. "Overcoming Barriers to Electronic Medical Record (EMR) Implementation in the US Healthcare System: A Comparative Study." *Health Informatics Journal* 16 (4): 306–318.

Li, L., and W. C. Benton. 2006. "Hospital Technology and Nurse Staffing Management Decisions." *Journal of Operations Management* 24 (5): 676–691. doi:10.1016/j.jom.2005.06.001.

Li, L., L. Xu, H. A. Jeng, D. Naik, T. Allen, and M. Frontini. 2008. "Creation of Environmental Health Information System for Public Health Service: A Pilot Study." *Information Systems Frontiers* 10 (5): 531–542. doi:10.1007/s10796-008-9108-1.

Meker, T., and Y. Barlas. 2015. "Dynamic Consequences of Performance-based Payment Systems in Public Hospitals." *Systems Research and Behavioral Science* 32 (4): 459–480. doi:10.1002/sres.2338.

Menon, Nirup M., Ulku Yaylacicegi, and Asunur Cezar. 2009. "Differential Effects of the Two Types of Information Systems: A Hospital-based Study." *Journal of Management Information Systems* 26 (1): 297–316.

Nabelsi, Véronique. 2007. "*Processus De Réapprovisionnement Dans Le Secteur Hospitalier: Collaboration Et Performance*." PhD thesis, Industrial Engineering, École polytechnique de Montréal.

Nabelsi, Véronique. Forthcoming-a. "Integrating RFID into Products and Business Processes to Improve Asset Management in Hospitals." *International Journal of Business and Systems Research* 5 (2): 97–117.

Nabelsi, Véronique. 2011. "Performance Measurement in the Healthcare Supply Chain." *International Journal of Services, Economics and Management* 3 (2): 137–156.

Nabelsi, Véronique. Forthcoming-b. "Towards Integrated Patient-driven Agile Supply Chains in Healthcare." In *Customer-oriented Global Supply Chains: Concepts for Effective Management*, edited by Ephrem Eyob, 1418–1436. Hershey, PA: IGI Global.

Nabelsi, Véronique, and Florina Stefanescu. 2010. "Impact of RFID Technology on Health Care Organizations." In *Encyclopedia of Healthcare Information Systems*, edited by Nilmini Wickramasinghe and Eliezer Geisler, 695–704. Hershey, PA: IGI Global.

Narayana, Sushmita A., Rupesh Kumar Pati, and Prem Vrat. 2014. "Managerial Research on the Pharmaceutical Supply Chain – A Critical Review and Some Insights for Future Directions." *Journal of Purchasing and Supply Management* 20 (1): 18–40. doi: 10.1016/j.pursup.2013.09.001.

Ozkaynak, M., P. F. Brennan, D. A. Hanauer, S. Johnson, J. Aarts, K. Zheng, and S. N. Haque. 2013. "Patient-centered Care Requires a Patient-oriented Workflow Model." *Journal of the American Medical Informatics Association* 20 (E1): e14–e16. doi:10.1136/amiajnl-2013-001633.

Oztekin, Asil, Foad M. Pajouh, Dursun Delen, and Leva K. Swim. 2010. "An RFID Network Design Methodology for Asset Tracking in Healthcare." *Decision Support Systems* 49 (1): 100–109.

Park, Kyung W., and Cheryl Dickerson. 2009. "Can Efficient Supply Management in the Operating Room save Millions?" *Current Opinion in Anaesthesiology* 22 (2): 242–248.

Poulymenopoulou, M., F. Malamateniou, and G. Vassilacopoulos. 2013. "Specifying Process Requirements for Holistic Care." *Informatics for Health and Social Care* 38 (3): 302–312. doi:10.3109/17538157.2013.764308.

Revere, L., K. Black, and F. Zalila. 2010. "RFIDs Can Improve the Patient Care Supply Chain." *Hospital Topics* 88 (1): 26–31.

Røsstad, T., H. Garåsen, A. Steinsbekk, O. Sletvold, and A. Grimsmo. 2013. "Development of a Patient-centred Care Pathway across Healthcare Providers: A Qualitative Study." *BMC Health Services Research* 13 (1): 1–9. doi:10.1186/1472-6963-13-121.

Samuel, Cherian, Kasiviswanadh Gonapa, P. K. Chaudhary, and Ananya Mishra. 2010. "Supply Chain Dynamics in Healthcare Services." *International Journal of Health Care Quality Assurance* 23 (7):631–642.

Strauss, Anselm, and Juliet M. Corbin. 1990. *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Thousand Oaks, CA: Sage.

Sturmberg, J. P., D. M. O'Halloran, and C. M. Martin. 2012. "Understanding Health System Reform – A Complex Adaptive Systems Perspective." *Journal of Evaluation in Clinical Practice* 18 (1): 202–208. doi:10.1111/j.1365-2753.2011.01792.x.

Tai-Seale, Ming, Caroline J. Wilson, Laura Panattoni, Nidhi Kohli, Ashley Stone, Dorothy Y. Hung, and Sukyung Chung. 2014. "Leveraging Electronic Health Records to Develop Measurements for Processes of Care." *Health Services Research* 49 (2): 628–644.

Teixeira, L., C. Ferreira, and B. S. Santos. 2012. "User-centered Requirements Engineering in Health Information Systems: A Study in the Hemophilia Field."*Computer Methods and Programs in Biomedicine* 106 (3): 160–174. doi:10.1016/j.cmpb.2010.10.007.

van der Togt, Remko, Piet J. M. Bakker, and Monique W. M. Jaspers. 2011. "A Framework for Performance and Data Quality Assessment of Radio Frequency IDentification (RFID) Systems in Health Care Settings." *Journal of Biomedical Informatics* 44 (2): 372–383. doi:10.1016/j.jbi.2010.12.004.

Uthayakumar, R., and S. Priyan. 2013. "Pharmaceutical Supply Chain and Inventory Management Strategies: Optimization for a Pharmaceutical Company and a Hospital."*Operations Research for Health Care* 2 (3): 52–64. doi:10.1016/j.orhc.2013.08.001.

Waring, Justin J., and Simon Bishop. 2010. "Lean Healthcare: Rhetoric, Ritual and Resistance." *Social Science & Medicine* 71 (7): 1332–1340. doi:10.1016/j.socscimed.2010.06.028.

Xu, L. D. 2011. "Enterprise Systems: State-of-the-art and Future Trends."*IEEE Transactions on Industrial Informatics* 7 (4): 630–640. doi:10.1109/TII.2011.2167156.

Xu, E., M. Wermus, and D. B. Bauman. 2011. "Development of an Integrated Medical Supply Information System." *Enterprise Information Systems* 5 (3): 385–399. doi:10.1080/17517575.2011.566630.

Yin, Robert K. 2014. *Case Study Research: Design and Methods*. Thousand Oaks, CA: Sage.