

Transforming Sterile Processing Departments by Service-Oriented Business Process Management

Xiaoyu Ma^{*}, Kai Yang

Industrial and Systems Engineering Department,
Wayne State University, 4815 4th street, Detroit, MI 48201.

E-mail: xiaoyu.ma@wayne.edu

E-mail: kai.yang@wayne.edu

^{*}Corresponding author

Abstract: One major cause that dramatically impacts patient safety is the use of unclean reusable medical equipment (RME), delivered from a sterile processing department (SPD). Unfortunately, current reprocessing practice is mostly driven by human labor and control, which is error-prone and inefficient. In this paper, business process management is proposed to support modeling, automating, monitoring, and analyzing sterile reprocessing procedures. The main contributions are: i) identifying the main factors in the current practice that compromise patient safety; ii) proposing a Service-Oriented business process modeling framework to publish, discover, reuse, and compose interoperable services for different purposes; iii) promoting healthcare workflow to control the execution status and identifying the key architectural requirements for a healthcare workflow system; iv) proposing a service-oriented architecture and validating it with our SPD workflow prototyping system, SPDFLOW. To our best knowledge, SPDFLOW is the first effort in exploring healthcare workflow technology in the SPD domain.

Keywords: Healthcare Workflows, Business Process Management, RFID, Sterile Processing Department, Reusable Medical Equipment, Patient Safety.

Reference to this paper should be made as follows: Ma, X.Y., Yang, K. (2012) 'Transforming Sterile Processing Departments by RFID-Based Business Process and Workflow Management in Healthcare (IJBPIIM), Vol. x, Nos. 1/2/3, pp.xx–xx.

Biographical notes: Dr. Xiaoyu Ma is a Research Associate in Healthcare Systems Engineering Group, Wayne State University. She worked as an Industrial Engineer for VISN 11 Veterans Affairs Center for Applied Systems Engineering (VA-CASE). She obtained her Ph.D. in Industrial Engineering from the Industrial and Systems Engineering Department at Wayne State University. Her main interests include operational decision support for RFID-based Business Process and workflow management in healthcare. She has published several refereed papers for designing healthcare workflow management and presented in ISERC, INFORMS and IEEE SCC conferences. Dr. Ma is a member of IIE, INFORMS, and IEEE, and a senior member of the Big Data and Scientific Workflow Laboratory.

Dr. Yang is a Full Professor in Industrial and Systems Engineering Department, Wayne State University. He is the Director of Healthcare Systems Engineering Group, Wayne State University. His research interests focus on healthcare system engineering, quality engineering, and Six Sigma. He is the author of 6 books, 5 of them are in the area of Six Sigma, one in the area of quality engineering. He is an associate editor of the International Journal of Six Sigma and Competitive Advantage. He served as the chairman of Edward Medal award committee of the American Society of Quality, and is a member of the Deming Medal award committee of the American Society of Quality. Dr. Yang received numerous research grants in the area of healthcare system engineering. Dr. Yang is a key academic faculty member in Veterans Affairs Center of Applied System Engineering.

1 INTRODUCTION

Patient safety, one of the nation's most critical healthcare challenges, has been recognized as an endemic concern by

the World Health Organization. Each year, one in ten patients around the world have been harmed and killed by medical errors [1]. The major threat to patient safety among the most common adverse events in healthcare is healthcare-associated infections. According to the Centers for Disease Control and Prevention, nearly 1.7 million healthcare-associated infections occur yearly, leading to approximately 99,000 deaths every year. Many of these healthcare-associated affections are due to unclean reusable medical equipment (RME), reprocessed from a sterile processing department (SPD), which comes into direct contact with patient skin, blood, and other body fluids and tissues. Many problems are compounded by the lack of effective business process management (BPM) with timely, accurate, and consistent data to monitor and control reprocessing operations automatically in SPD. Consequently, healthcare professionals and managers anticipate an appropriate and deliverable approach to reengineer an SPD business process, and visualize, trace and control its execution.

Recently, there is an increasing interest in applying business process management (BPM) concepts and workflow technologies in the healthcare industry, to automate processes, improve efficiency, eliminate medical errors, and thus improve patient safety [2]. According to Georgakopoulos et al. [3], workflow technology facilitates business processes management by providing methodologies and software to support the industry for modeling, reengineering, and executing business processes. It aims to track the routines of business processes, display the performance of each step, streamline process execution, and liberate human actors from routine work.

Although much research has been done on business processes in other industries [4-7], healthcare business process management poses many unique challenges when BPM and workflow technology are applied to healthcare [8, 9] as healthcare processes need to be patient-centered, policy-governed, quality-ensured, and event-driven, and the consequence of errors and inefficiency is more severe and costly. While some work has been done on healthcare workflow for some departments of a hospital [2, 10, 11], automating and managing the reprocessing procedures in SPD is a challenging task.

First, it is critical to share information, link distributed systems together, and manage heterogeneous devices and resources across different working areas. For example, a technician needs to know where each RME is and its status. Second, although current practice in the sterile processing department aims to follow the standard operation procedures (SOPs) that are derived from device manufactures, such conformance check is manual and relies on technicians' skills, experiences, and professional merits. Such manual policy conformance check is often error-prone and cannot ensure that each operation will be conducted in full conformance with SOP policies. Finally, the quality of RME need to be well managed during the whole reprocessing procedure, including selecting the right workflow to process, and checking the precondition of running a step, and performing smart rerun optimization.

To address these issues, we aim to develop several service-oriented business process modeling and healthcare workflow technologies to automate and streamline the cleaning, disinfection, and sterilization operations in the sterile processing department in our pilot facility (the Veterans Affairs Medical Center at Detroit). Meanwhile, recent developments in automatic data collection, such as Radio Frequency Identification (RFID), Zigbee, Wi-Fi, Bluetooth or Infrared, have provided a new opportunity to capture and manage real-time data from business processes [12-15]. In this paper, several RFID-based service-oriented healthcare BPM concepts and workflow technology are proposed as one attractive solution to automate and streamline the cleaning, disinfection, and sterilization operations in the sterile processing department.

The main contributions of this paper are:

- i) Based on an enhanced, interdisciplinary understanding of the current practice of a sterile processing department, the main factors and issues that compromise patient safety are identified.
- ii) The integration of Business Process Management (BPM) and Service-Oriented Architecture (SOA) is considered as a promising solution to support dynamic and flexible work practices in SPD. A five-level framework for service-oriented business process management is designed for SPDs to share information, integrate distributed systems, and manage heterogeneous resources among multiple stakeholders.
- iii) In the proposed pattern for healthcare business process management, the relationship between business process management and workflow technology is firstly discussed.
- iv) Healthcare workflow is proposed to control the execution status of complex and dynamic healthcare processes. The key architectural requirements for a healthcare workflow system for SPDs are identified.
- v) A service-oriented architecture is proposed for our SPD workflow prototyping system, SPDFLOW, which is validated with a case study. This research is the first effort in exploring healthcare workflow technology in the SPD domain (to our best knowledge).

The remainder of the paper is organized as follows. In Section 2, patient safety factors in SPDs are identified. In Section 3, a service-oriented healthcare business process management framework and a three-phase pattern of healthcare business process are designed for SPD. In section 4, we present key architectural requirements for SPDFLOW. In Section 5, the overall architecture for SPDFLOW is proposed and the advantages of Service-Oriented Architecture (SOA) in healthcare workflow are discussed. In Section 6, a case study in SPD of VA Medical Center at Detroit is provided. In Section 7, we review related work. In Section 8, conclusions and future work are discussed.

2 IDENTIFICATION OF PATIENT SAFETY FACTORS IN SPD

The sterile processing department is one primary department in a hospital, which has a separate and distinct area with specialized expertise and direct responsibility for both reprocessing soiled reusable medical equipment and providing ready-to-use (disinfected, clean, and sterile) reusable medical equipment to patient care areas. Figure 1

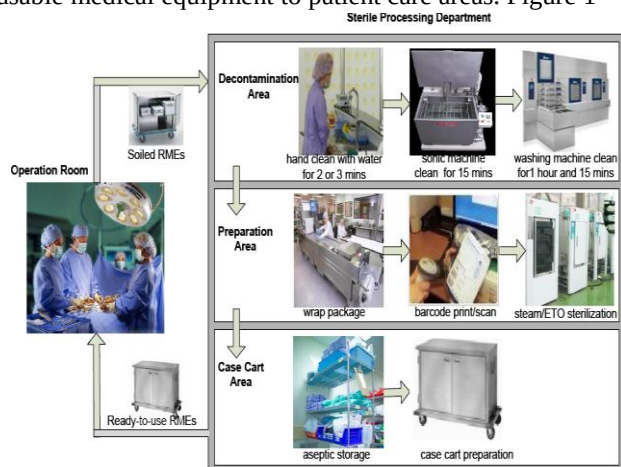


Figure 1 : A simplified business process in SPD

presents a simplified business process in a SPD. After being utilized in the operation room, soiled reusable medical equipment is collected in a case cart to the SPD through an elevator, which only transports dirty items. Based on the appropriate standard operation procedure rules, reusable medical equipment is disinfected in the decontamination area by some cleaning options, such as hand clean, sonic machine clean, and washing machine clean. In the preparation area, clean reusable medical equipment will be wrapped, packaged, and labeled by a new barcode, which shows the basic information of reusable medical equipment, such as item IDs, expiration dates when they should be reprocessed again no matter whether they have been used. Then, the sterilization step will be executed for several hours (such as 14 hrs for ethylene oxide (ETO) sterilization or 1 hr for steam sterilization) to destroy microorganisms or inanimate objects. In the case cart area, all the ready-to-use reusable medical equipment will be stored in the aseptic SPD inventory. When an order from the operation room arrives, a technician will build a case cart according to the ordered reusable medical equipment list for each operation room case. Finally, the prepared case cart will be sent back to the operation room by another elevator, dedicated to transport ready-to-use reusable medical equipment.

Any weaknesses in the SPD policies and oversight in governing reusable medical equipment will pose great risks to patient safety. Although the current practice in the SPD aims to follow the standard operation procedures derived

from device manufactures, based on our detailed investigation of SPDs, we found that there are many factors that can directly or indirectly compromise patient safety. Our analysis is summarized as a cause-effect diagram in Figure 2, in which six groups of major factors affecting patient safety are identified:

- **Reusable Medical Equipment (RME):**

Surgical-site infection can occur because surgical procedures breach the skin and allow bacteria to colonize and infect sterile tissues by using unclean or expired reusable medical equipment. Sometimes, clinics have to reactively cancel or postpone medical cases since the required reusable medical equipment is out of stock, delayed, broken, lost, misplaced, or mislabeled.

- **Process:**

Errors could occasionally occur during the SPD reprocessing procedures, such as skipping imperative steps, non-compliant operations, and operating based on wrong standard operation procedure rules. Without strict compliance check between the SPD operations and standard operation procedure standards, it is hard to verify each step and respond quickly and accurately to handle exceptions. Without real time display of detailed operations in all related working areas, the execution of right work procedures is difficult. Consequently, when work-in-process items are stocked in some temporary inventories that are not strictly aseptic, some of the previous operations have to be repeated. As a result, the reprocessing cycle time is prolonged, which will delay the supply of reusable medical equipment and postpone the schedule of an operation for a patient, causing the patient to wait and more severe conditions.

- **Policy:**

Standard operation procedure rules are the operation principles that guide staffs to complete the reprocessing operations thoroughly and consistently. Sometimes, the content of these paper-based documents are not comprehensible to describe all the operation requirements. SPD technicians may be misled by some inaccurate or ambiguous explanations to imperative steps. When an operation exception happens, the reasoning analysis is not included in the current version of standard operation procedure policy to intelligently help technicians to remedy the delinquent operations. Thus, these weaknesses of policy management cannot ensure that SPD operations are performed properly, which can result in unclean or damaged reusable medical equipment.

- **People:**

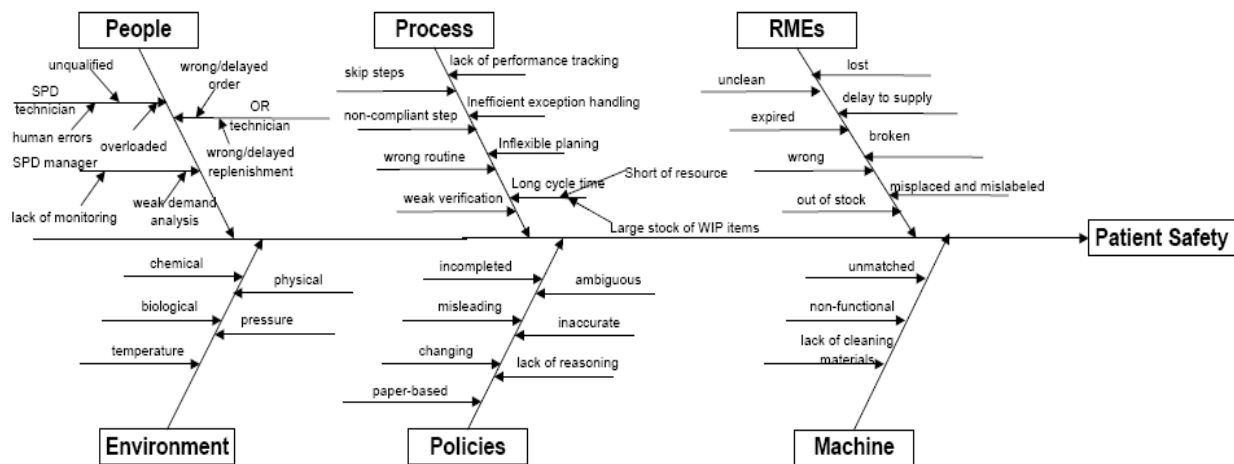


Figure 2 A cause-effect diagram to analyze the weak operation management in SPD and patient safety.

Three types of medical staffs, SPD technicians and manager, and operating room technicians are involved in the business process. Sometimes, SPD technicians cannot perform correctly because they are not qualified to reprocess the specific reusable medical equipment or too overloaded to concentrate on their work. Dynamic medical demands bring challenges to the SPD manager to analyze clinical demands and make flexible production plan to handle the exceptions to normal workflows when emergent orders arrive. Meanwhile, SPD managers cannot efficiently monitor and trace the reprocessing workflows running in the SPD floor. Wrong or delayed demands from operating room technicians will also introduce a risk to supply incorrect reusable medical equipment to patients subsequently.

• Machine:

Multiple types of machine failures could occasionally happen in an unforeseeable way when executing a workflow. For examples: machines might decay and fail due to their complexity; reusable medical equipment is sterilized in the wrong machine; or the procedure has to be ceased because of the shortage of raw cleaning materials. Such failures should be rectified to resume operations or prevent the results of unclean reusable medical equipment.

• Environment:

Each operation should be performed under a specific environment. If the chemical, biological, physical or temperature indicators of reprocessing environment are not as specified, the quality of ready-to-use reusable medical equipment cannot be guaranteed effectively.

3 SERVICE-ORIENTED HEALTHCARE BUSINESS PROCESS MANAGEMENT FRAMEWORK FOR SPD

Healthcare process management poses many unique challenges, including the complex conditions of healthcare environments, various physical and financial resource constraints, variations in patient conditions and treatments, policy and guideline conformance management, and flexibility and adaptivity to new requirements and emergency cases. To address these problems, healthcare

organizations need to explore reengineering solutions to streamline, automate, and control healthcare processes by sharing a seamless information flow among multiple stakeholders at different locations.

3.1. Service-Oriented Healthcare Business Process Management Framework for SPD

In order to improve the operational efficiency of a sterile processing department and reduce the risk of infections induced by reusable medical equipment, it is critical to share information, integrate distributed systems, and manage heterogeneous resources. A technician needs to know where each RME is and its status. Systems that work on different working areas and operation rooms need to be integrated. Different heterogeneous resources, including RFID-enabled RME, machines, and people, should be uniformly identifiable, locatable, and searchable. From one cycle of reprocessing and supply point of view, in order to supply high quality RME to the right patient at the right time, information concerning reprocessing orders and operation status should be easily accessible to each stakeholder. Otherwise, the lack of information will delay the processing of RME requests, disorder the sequence of operations in multiple working areas, increase the work-in-process inventory level, and prolong the cycle time in the sterile processing department. Meanwhile, under the complex and dynamic healthcare environment, the schedule of medical treatment might be updated in the last minute. As an RME supplier, a sterile processing department should have the flexible supply capability to handle unpredictable change and emergent cases.

A Service-Oriented Architecture (SOA) is a set of principles and methodologies for software development based on published interoperable services that can be discovered, reused, and combined for different purposes. When adopting a business process and workflow management system in a dynamic and flexible environment such as healthcare, SOA is a promising solution to meet the requirements of flexibility, interoperability by registering, discovering, and combining reusable tasks as Web services.

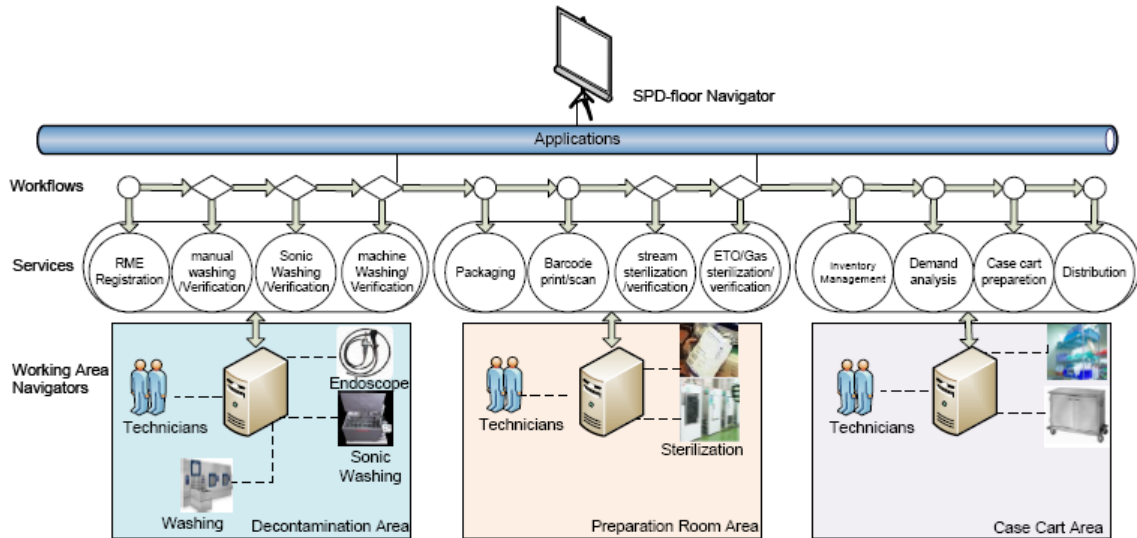


Figure 3 SOA-based Business Process Management Framework

This research applies SOA as the underlying foundation to develop our healthcare business process management system. The proposed SOA-based business process management framework is shown in Figure 3, which consists of five layers. For each working area, a working area navigator is in charge of managing all RFID-enabled resources as intelligent objects in that area, including RME, machines, and technicians, which are then abstracted as Web services and published in the second layer. The third layer integrates the underlying services, possibly provided by different working area navigators, as workflows, which are the building blocks of higher-level applications in the fourth layer. Applications aim to provide BPM auxiliary services such as adaptive planning, RME registration and grouping and process mining. Finally, the floor navigator integrates all information and systems into one integrative system for the management of the whole floor.

3.2. Business Process Management Pattern in SPD

Business process management is a holistic management approach [113] that promotes business effectiveness and efficiency while striving for innovation, flexibility, and integration with workflow technologies [114]. Through a set of methods, software and techniques, business processes involving human interaction can be edited, executed, and monitored. In this research, three main phases are involved in an SPD-targeted business process management pattern.

- *The pre-execution phase* involves a business analyst to interact with customers and business managers to identify the problems and requirements in the current practice, define business goals for business process improvements, and model them as interpretable business processes diagrams.
- *The execution phase* implements business processes as executable workflows. The workflow engine will

schedule and invoke tasks in workflows according to the specified workflow logic, and orchestrate both human tasks and automated tasks.

- *The post-execution phase* analyzes event logs produced from workflow execution for iterative process improvement. The monitoring of each workflow execution will produce a series of event logs. Process mining techniques can be used to analyze the event logs to identify performance bottlenecks for optimizations and improvements, or to re-engineer the entire business process cycle.

The key components of the business process management pattern are shown in Figure 4. In this paper, we mainly focus on discussing the pre-execution and execution design for SPD business process management.

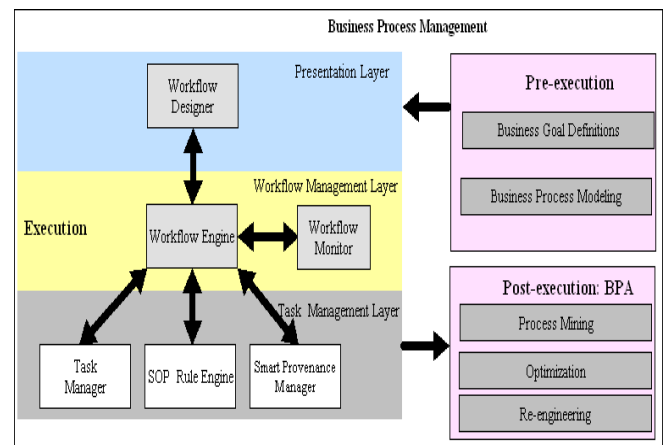


Figure 4 SPD Business Process Management Pattern.

3.2.1. Business Goal Definition: Key Requirements for Performance Management in SPD

The long-term goal of business process management in SPD is to reprocess the right soiled RME at the right working

areas by the right operations and supply them to the right end users at the right time. With an enhanced, interdisciplinary understanding of business process management in SPD by interviewing SPD staffs and observing processes, we identify the problem of current practice and then define the business goals for monitoring and controlling the reprocessing operations in SPD as follows:

- Event log should be designed as a process status tracking tool to capture and record any change of the business process status in SPD.
- Compliance check between SPD operations and SOP standards should be automatically executed by an intelligent subsystem. It aims to remind SPD technicians when such a check fails and help them to analyze the reasons and the consequential influence by this delinquent operation.
- The real-time inventory level, location and stocking time duration of WIP items should be recorded automatically. It aims to assist SPD technicians to closely control their working items and streamline their operations for cycle time reduction.
- Based on the priority of intraday medical treatments, adaptive workload plan should be made for each reprocessing area. Meanwhile, when multiple machines provide the same function, it should adaptively assign orders to these machines with load balancing in mind.

3.2.2. Business Process Modeling by BPMN

A business analyst then models the above business goal definitions as detailed business process diagrams using some graphical modeling language, such as Business Process Model and Notation (BPMN). BPMN is a standard graphical notation language [16] to specify business processes as Business Process Diagrams (BPD) [17], which can be easily understood by both technical users and business managers. These user-friendly diagrams include both activities and control and data flows among them. These conceptual diagrams are easily interpretable but not yet executable; they are the basis for discussions and refinement among business analysts, business managers, and technical developers (workflow engineers). Next, BPMN diagrams are mapped to computerized business processes (workflows) in some underlying executable business process language, such as Business Process Execution Language (BPEL) [18]. Consequently, BPMN serves as a common language to bridge the communication gap between business process modeling and workflow implementation.

Based on the definitions of the business goals for SPD, as a preliminary case study, some business processes are modeled for the three working areas. A BPMN diagram for operations in the decontamination area is shown in Figure 5, which is self-describing.

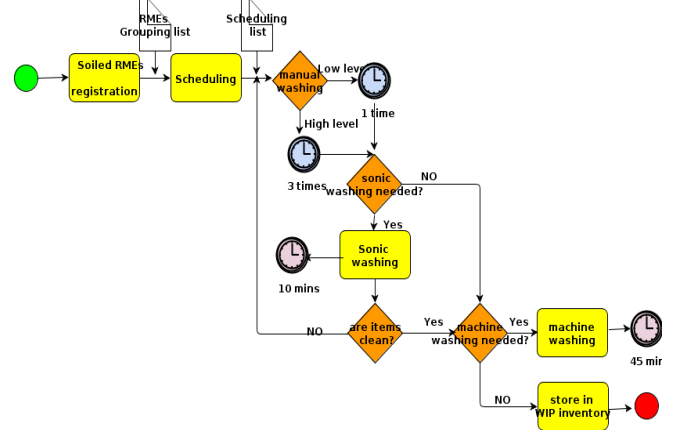


Figure 5 BPMN Diagram for Operations in the Decontamination Area.

3.2.3. Execution Control: Healthcare Workflow Management

The modeled business process diagrams are then translated and implemented by some executable workflow language such as BPEL or SWL (Scientific Workflow Language)[19]. Each activity in the original business process diagram will be mapped to some concrete services or executable software programs. In contrast to a business process diagram, which is not executable, the resulting workflow is ready for execution. All the activities in a defined workflow will be orchestrated by the workflow engine, and their status can be monitored by a workflow monitor, verified by an intelligent rule engine, and handle exceptions smartly.

Under the dynamic healthcare procedure, it is hard to predict the coming events. Although the inputs are quite similar, the whole treatment process could be totally different. Healthcare workflow could serve as a pilot system to guide the operations based on instant status and SOP rules. The detailed design of a healthcare workflow system will be discussed in the following sections.

4. KEY ARCHITECTURAL REQUIREMENTS FOR SPDFLOW

To address the issues and weaknesses described in section 2, which lead to unclear reusable medical equipment and compromised patient safety, we propose to design and develop an innovative real-time healthcare workflow system to meet the following requirements.

R1: Heterogeneous Information Sharing:

A technician needs to know where each RME is and its status. Systems that work on different working areas and operation rooms need to be integrated. Different heterogeneous resources, including RME, machines, and people, should be uniformly identifiable, locatable, and searchable. From one cycle of reprocessing and supply point of view, in order to supply high quality RME to the right patient at the right time, information concerning reprocessing orders and operation status should be easily accessible to each stakeholder in SPDFLOW. Otherwise,

the lack of information will delay the processing of RME requests, disorder the sequence of operations in multiple working areas, increase work-in-process inventory, and prolong the cycle time in the sterile processing department.

R2: Heterogeneous System and Service Integration:

Under the complex and dynamic healthcare environment, the schedule of medical treatment might be updated in the last minute. As a ready-to-use RME supplier, a sterile processing department should have the flexible supply capability to handle unpredictable change and emergent cases from multiple end users in different clinics. In SPDFLOW, heterogeneous system and service integration should be developed to facilitate system integration, optimize resource usage, improve functionality reusability, and enhance process flexibility.

R3: Automated SOP Rule Conformance Check for Each Operation:

Non-conforming operations in SPD reprocessing and distribution procedures will increase the risks of bacterial contamination to RME. SOP describes the requirements of each step in detail, such as operation time period, temperature value within clean machines, times. For example, if an operation with normal-level disinfection is needed, then the first operation needs 3 minutes and no repeat is needed, on the other hand, if an intensive-level disinfection is needed, then the first operation needs 3 minutes and 3 iterations will be carried out. Such workflow varying and RME dependant parameters are very common in reprocessing operations, and if not verified carefully and correctly, can often lead to wrong steps and the skipping of important steps. Currently, SOP rule conformance check fully relies on technicians' skill, experience, and commitment. Such manual conformance check is error-prone and cannot fully ensure that each operation will be conducted fully in conformance with the SOP policies, leading to unclean RME that eventually compromise patient safety. In SPDFLOW, compliance check between SPD operations and SOP standards should be automatically executed by an intelligent subsystem. It aims to remind SPD technicians when such a check fails and help them analyze the reasons and the consequential influence by this delinquent operation. If approved, the workflow will continue to be executed automatically according to predefined routines.

R4: Event Signature:

One major cause that compromises patient safety in the sterile processing department is the use of unclean or expired RME that leads to healthcare associated infections. Skipping imperative steps and operating based on wrong reprocessing procedures are two significant errors which must be forbidden in SPD process management. It requires the SPD manager to cautiously monitor the real-time status of each activity execution and the whole workflow execution. In SPDFLOW, event signature should be designed as a process status tracking tool to capture and sign a change of the business process status in SPD. It aims to support the visualization of effective workflow control and

ensure all required tasks to be completed according to the right SOP operation routine.

R5: Smart Rerun Scheme:

In practice, one of remedial reactions to operation errors is to duplicate the previous steps of the reprocessing procedure. As we know, redundant duplications will increase the workload and cycle time in SPD and waste reprocessing resources. However, insufficient duplications could not reach the objectives of cleaning, disinfection and sterilization. In SPDFLOW, the intelligent selection and execution of optimal rerun steps should be included as a smart function. It aims to guide the SPD staffs to make up for the non-conforming operations.

R6. Failure handling:

Machines might decay and software functionality might fail due to their complexity. Such failures should be processed to resume operations or prevent unclean RME. Multiple types of operation failures could occasionally happen in an unforeseeable way when executing a workflow. In SPDFLOW, a function should be developed to provide the support for failure monitoring at multiple levels. It aims to catch, localize, and handle exceptions automatically or with minimal human intervention. For example, when the temperature indicator of steam sterilization machine does not correspond to the required value, an alarm message will send to an SPD staff for instant reminding or temperature could be automatically adjusted.

5. OVERALL ARCHITECTURE FOR SPDFLOW

The long-term goal of our SPDFLOW project is to develop a healthcare workflow system to automate and streamline the cleaning, disinfection, and sterilization operations in the sterile processing department. RFID technology is deployed to collect real-time data automatically about the location and identification of RME, SPD resources and indicators of an operation environment during the reprocessing procedures. In order to demonstrate the feasibility and flexibility of our proposed architecture of SPDFLOW, the advantages of adopting Service-Oriented Architecture (SOA) in SPDFLOW is firstly discussed. Then, the overall architecture for SOA-based SPDFLOW is presented with the description of each major subsystem.

5.1. Advantages of Service-Oriented Architecture in SPDFLOW

Healthcare is considered as one of the most promising fields to more readily see the benefits of SOA-based workflow management since it often involves multiple heterogeneous IT systems, their integration, and changing healthcare service requirements. SOA can have an impact on healthcare by enabling information sharing, facilitating system integration, virtualizing infrastructure resources, improving functionality reusability, and enhancing process flexibility. Based on these impacts, we identify the advantages of using SOA specifically for the development of SPDFLOW by publishing SPDFLOW subsystems, SPD

functionalities, and RFID-enabled intelligent objects as services. This advantage analysis is based on three levels: SPDFLOW with other healthcare systems, SPDFLOW subsystems, and task management in SPDFLOW.

1) Enabling collaboration between SPDFLOW and other systems via information sharing and integration

Under the complex and dynamic healthcare environment, the schedule of medical treatment could be updated at the last minute. As a primary hub in hospitals to supply various types of RME to different clinics, SPD should have the flexible supply capability to handle unpredictable change and emergent cases adaptively. In order to supply high quality RME to the right customers at the right time, all necessary information from SPD and multiple clinics should be easily accessed and transparent. It will help the SPD manager integrate information from various service providers and systems to optimize SPD reprocessing planning and control process performance, which aims to maximize the supply capability and increase the utilization rate of reprocessing resources. With SOA, SPD functionalities are wrapped as services with semantic description and registered in SPD-UDDI, so that they can be easily discovered, selected, and reused for SPDFLOW and other healthcare systems, such as ORFLOW (an operation room workflow management system) on dynamic and unpredictable demands. Information can be shared and integrated easily across SPD and other clinics. For example, SOA provides opportunities to transparentize the scheduling of operation room (OR) cases with related RME list from ORFLOW to SPDFLOW as they are packaged and shared as services. When an emergency order arrives that requires the processing of high-level disinfection workflow, SPDFLOW can schedule the reprocessing procedure adaptively for priority updates of RME demands by invoking required services. The reprocessing services for one piece of RME in a normal-level priority can be flexibly delayed or stopped, so that the sonic cleaning machine can become available for use by the emergency order first.

2) Facilitating SPDFLOW subsystem development by programming and platform independence.

SOA is considered as an emerging architectural paradigm for distributed system development with advantages of discoverability, reusability and interoperability by publishing each subsystem as a service [20, 21]. SOA enables development independence of six SPDFLOW subsystems by defining a group of programming language and platform independent interfaces. With SOA, all the functionalities from six SPDFLOW subsystems are encapsulated as services and registered in a specific service registry, such as SPDFLOW Universal Description Discovery and Integration (SPDFLOW-UDDI). Via these abstract and standard interface descriptions, each service exposed by SPDFLOW subsystems can be easily discovered from SPDFLOW-UDDI. Through standard communication protocols, each SPDFLOW subsystem can be reused by other healthcare workflow management systems. Meanwhile, SOA-enabled SPDFLOW supports service interoperability as service providers and service requestors

can be developed independently with different languages and in different platforms.

3) Virtualizing Infrastructure Resources and SPD functionalities in SPDFLOW Task Manager

Two main service components are managed by the SPDFLOW task manager, which are SPD functionalities and real-time data management functionalities from RFID-enabled intelligent objects. These two types of service components require different execution environments and management systems. For example, three working area navigators are designed to manage the operations in the decontamination, preparation, and case cart areas in SPD. Different heterogeneous resources, including RME, machines, and people, should be uniformly identifiable, locatable, and searchable by multiple types of auto-ID/RFID devices [22]. These devices have unique communication interfaces and protocols. It is crucial to create a standard model to wrap different types of devices as uniform units. SOA enables the SPDFLOW task manager to virtualize all SPD functionalities and various types of RFID-enabled intelligent objects by wrapping them as services. Via an abstract interface defined by WSDL, services from the two types of service components can be published, discovered, reused, and composed for different purposes. The details of the SOA-enabled SPDFLOW task manager will be discussed later.

5.2. Architecture Design of SPDFLOW

The overall architecture of SPDFLOW is shown in Figure 6. It consists of six subsystems that deal with specific requirements for SPD workflow management. According to the workflow reference architecture proposed by Workflow Management Coalition (WfMC) [23], the SPD workflow designer in the presentation layer is deployed to model and design SPD reprocessing procedures. In the workflow management layer, the SPD workflow engine communicates with other subsystems by interfaces I_{WD} , I_{WM} , I_{TM} , I_{RE} , and I_{SPM} . In the task management layer, a service oriented task manager is designed to manage functionalities provided by three working areas, RFID-powered RME and machines as services; a standard operation procedure (SOP) rule engine is developed to automate rule conformance check; a smart provenance manager is innovated to enable provenance-based quality control of RME. In the intelligent object management layer, all the RFID-powered resources are governed by an intelligent object manager, which automatically collects real-time information of identification and locations from RFID-enabled intelligent objects. This information will then be exposed by the intelligent object manager to the task manager as services. In the following section, the architectural details of major SPDFLOW subsystems are discussed.

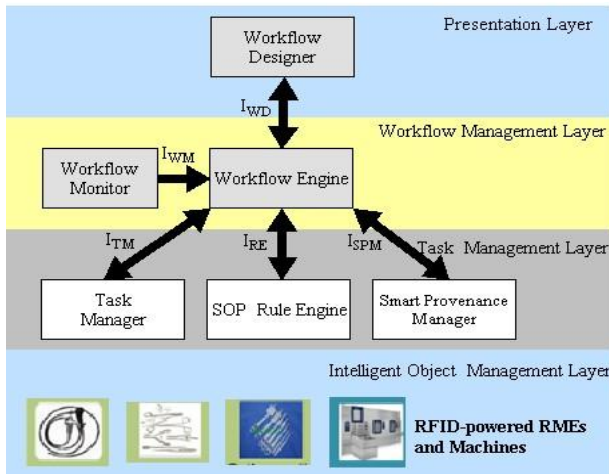


Figure 6 Overall Architecture of SPDFLOW

- **SPDFLOW Workflow Designer:**

It provides a user-friendly graphical interface to design and modify SPD workflows. An SOP expert can drag and drop published services into the design panel and link them together in parallel or sequential patterns to model reprocessing procedures. It aims to provide the workflow definition function in SPDFLOW. These process definitions model standard operation procedures that an SPD technician is required to follow strictly. It ensures that the right procedures will be done. These definitions will also include descriptions that prescribe exception handlers to deal with situations in which procedures are not executed as expected, including what should be notified if some exceptions cannot be handled by the system automatically.

- **SPDFLOW Workflow Engine:**

It is the center of SPDFLOW that supplies a run-time environment where process instantiation and activation are achieved. It is used to create and manage the data flows and control flows of an SPD reprocessing procedure, display the workflow status, and record particular aspects of the workflow, such as data provenance [24]. When major events occur, the workflow engine is notified to invoke the following steps. For example, a soiled piece of RME being collected from the operation room for reprocessing, a working schedule being made, and a verification step being proved are all examples of events in the SPD operation management that require the workflow engine to process. The workflow engine can perform both human tasks, which involve human input and interaction, and automated tasks, which do not require human intervention. For example, when the water cleaning time is not long enough as SOP rules require, an alarm can be automatically sent to on-duty SPD technicians.

Within the SPDFLOW Workflow Engine, each workflow status is collected and stored via I_{WM} to provide the foundation for event signature (R4) and exception handling in the Workflow Monitor component. There is an interface I_{TM} to supply the communication between the Workflow Engine and the Task Manager, which separates workflow scheduling from each task execution. At many times, a complex decision among multiple options should be made

based on the execution performance of a running process. The SOP Rules Engine is called by the Workflow Engine through I_{RE} to analyze the decision logic. Finally, all provenance information is collected by the Workflow Engine and stored in the Smart Provenance Manager via I_{SPM} .

- **SPDFLOW Workflow Monitor:**

It records and reports the execution status of an SPD workflow. They are historical data which are useful for SPD performance management, such as the completion time for a task, the stock time of WIP items in one working area.

- **SPDFLOW Service-oriented Task Manager:**

It shows which tasks are in the queue to be carried out for processing. By selecting a task, an SPD technician can retrieve a predefined workflow and begin to perform a service. Under a hectic, multidisciplinary and dynamic clinical care environment, service oriented architecture is applied as the underlying foundation to manage SPDFLOW tasks (R1, R2). As described above, the tasks from two types of service providers (RFID-enabled intelligent objects and SPD working areas) should be managed by the SPDFLOW task manager, as shown in Figure 7.

In order to build up an execution and platform independent environment, SOA is deployed to encapsulate multi-types of SPD functionalities and RFID devices with different parameters, such as frequency (UHF, HF), device type (passive, active RFID, Zigbee or Wi-Fi). RFID-enabled SPD staffs, RME and SPD machines and three working area functionalities are wrapped as uniform services. The

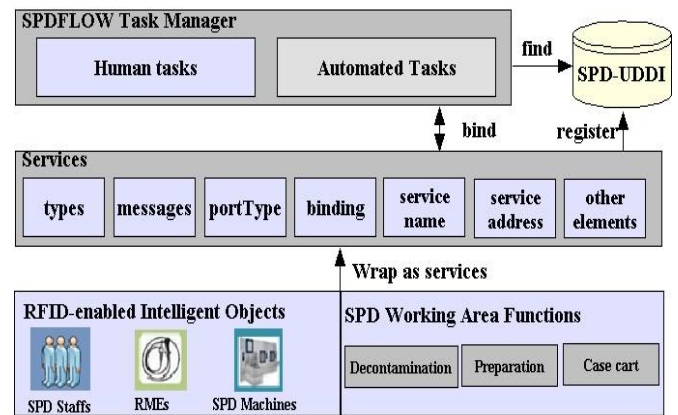


Figure 7 SOA enabled SPDFLOW Task Manager.

standard interface format defines primary information about each service by a WSDL file, including elements such as types, messages, port type, binding, service name and address. It enables service accessibility.

The service registry (such as SPD-UDDI) serves as a platform-independent framework for describing, discovering, and integrating services from multiple service providers. Through a semantic description, each registered service can be invoked over the Internet. Considering the requirements of SPD operation management, tasks can be divided into two groups. One group is human tasks, which

cannot be fully automated by this SPDFLOW system, such as clean result verification that the SOP rule engine cannot check. For example, SPD technicians should physically verify whether the body tissue is still on a bistoury scalpel after washer machine cleaning. Human tasks require human interaction to achieve the operation requirements. Another group is fully automated tasks, which can be executed by SPDFLOW itself. For example, when the verification fails, an alarm message can be sent automatically to SPD technicians for reminding. The SPDFLOW task manager provides functions for these two types of task management, including registration, searching, execution and data management for the SPDFLOW task manager.

- **SPDFLOW SOP Rule Engine:**

It is the intelligent subsystem that is innovated in the SPDFLOW to assist and guide end users to react correctly to real-time events of SPD workflows. Event-Condition-Action rules (ECA rules) are developed in the SOP Rule Engine to govern and constrain each reprocessing operation in the business processes of the sterile processing department. Via a logic-based event calculus and an ECA rules language, paper-based SOP rules are transformed to electronic SOP policies that are event-driven, logic-based, and action-oriented in the Rule Engine. In terms of ECA rules, the SOP requirements and actions that need to be taken when requirements are violated are encoded in this rule engine. It can communicate with the SPD reprocessing workflow engine to automate the compliance check between SPD operations and SOP requirements (R3). Some smart functions are developed to guide SPD technicians to remedy delinquent operations.

- **SPDFLOW Smart Provenance Manager:**

Provenance-based smart reasoning techniques are developed in the smart provenance manager to preventively reduce errors, proactively improve workflow management, and efficiently produce high-quality ready-to-use RME. A provenance-enabled smart checker is to ensure that the right RME is performed by the right workflow (R4). All historic and current provenance information of an RME is automatically tracked and recorded, including their group information. In addition, the procedure requirements are encoded as smart workflow rules. The smart checker, based on these smart workflow rules, will check the information of the RME, and make sure that the proper workflow has been chosen for a particular piece of RME. If a wrong workflow is chosen, the workflow will stop the RME from the pipeline and a notification will be sent to the responsible technician for exception handling. If the technician does not respond in a timely manner, then another notification will be sent to the next person in the escalation chain, such as the floor manager.

To ensure that each operation in a workflow is performed exactly according to the requirements for that operation (R3), a provenance-based smart verifier is included to verify that each step is started only when all the conditions for the RME is already satisfied, including the necessary steps that should have been performed earlier, and the right

parameters are set, and so on. It is critical to catch and locate the delinquent operation step and decide the necessary rerun steps to remedy the nonconforming operations (R5). A provenance-based smart rerun algorithm is running in the smart provenance manager: 1) to identify under what conditions rerun should be invoked, and 2) to select the optimal steps for smart rerun in terms of cost and time so that the overall objective of high-quality and high-throughput RME can be achieved.

6. IMPLEMENTATION AND CASE STUDY

In this section, we present our prototype system, called SPDFLOW (stands for Sterile Processing Department workFLOW)[25], a healthcare workflow prototyping system that supports a preliminary mechanism for operation process management in the sterile processing department at the Veteran Affairs Medical Center in Detroit. SPDFLOW is developed upon the web-based VIEW (stands for Visual scIentific Workflow) workflow system [26, 27]. SPDFLOW not only enables a workflow engineer to design workflows, but also provides a runtime system to execute healthcare workflows on a dedicated SPDFLOW server. As a Web-based healthcare workflow system, no installation, upgrade, and maintenance are required for end users. One can use SPDFLOW simply via an Internet browser, such as Firefox and IE. Inherited from VIEW, the SPDFLOW system features a Service-Oriented Architecture [21]. First, we reuse a workflow designer to visually design workflows, a workflow engine to execute workflows, a workflow monitor to monitor the status of workflow execution and handle run-time exceptions. Second, three new subsystems: the SOA-based task manager, the SOP rule engine, and the smart provenance manager are developed to control the SPD reprocessing performance. Third, some functions from the RFID-enabled smart object management system are encapsulated as services.

A case study for the SPD decontamination working area is shown in Figure 8. The workflow task ‘registration’ is used to record the basic information of soiled RME, such as ID, due date. The reprocessing schedule is made by task ‘workflow scheduling’ based on the priority of demands. The SOP rule engine and smart checker will be called to assist SPD technicians to select one of the two manual cleaning options (high-level and normal level) based on the specific SOP requirements. A condition parameter C is set to automatically decide whether the sonic machine cleaning is needed based on the messages from the smart checker function. When one step is finished, a smart verifier helps SPD technicians verify whether the cleaning results for the RME is satisfactory, such as loop function. When it is not approved, the smart rerun function will inform SPD technicians to repeat sonic machine cleaning or all previous steps. The multiple steps for sonic machine cleaning are encapsulated into a task by SPDFLOW. This demo system shows how SPDFLOW automates and streamlines the cleaning, disinfection, and sterilization operations in the sterile processing department.

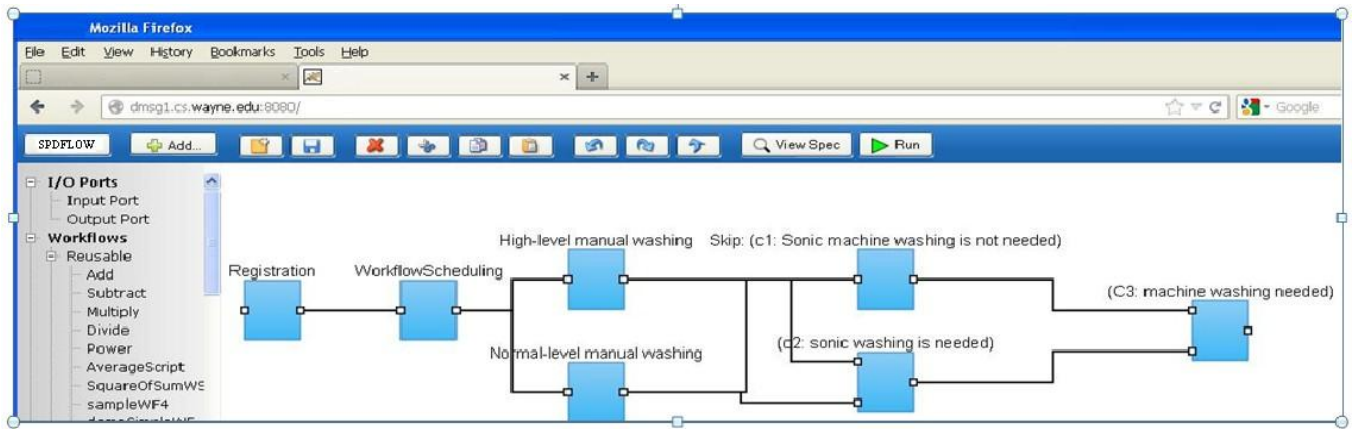


Figure 8: A case study for the SPD decontamination working area.

7. RELATED WORK

7.1. Healthcare Workflow Management

Workflow is the computerised facilitation or automation of a business process, in whole or part[23]. A workflow management system is a system that completely defines, manages, and executes the workflow through the execution of software whose order of execution is driven by a computer representation of the workflow logic[23]. Currently, workflow technology is explored as diverse and rich technologies applied to numerous types of business processes in industries, such as e-commerce [28], virtual company [29] and manufacturing systems[22, 30, 31].

Workflow technology has recently become an important IT trend in many healthcare enterprises [10, 11, 32-35]. Hospitals are embracing this technology to increase operational efficiency, improve healthcare quality, and ensure patient safety. However, research in healthcare workflow is still in its infancy, facing many new challenges that are characteristics of the healthcare domain[2, 34]. To address the challenge of evolving patient conditions, the notion of adaptive workflows was proposed with support of context-aware activities [36], process adaptivity [37, 38], and exception handling [39]. Reijers et al. extended previous work on workflow and flexibility patterns and presented a methodology to discover, explore, select, and realize processes that possess the required degree of flexibility in the healthcare domain [40]. To ensure patient privacy, Russello et al. presented a framework in which patients can control the disclosure of their medical data by consent and needs [41]. To improve healthcare workflow security, Koufi et al. proposed an event-based dynamic authorization model that synchronizes authorization flow with the progress of workflow execution [11]. Finally, a number of case studies were reported that shared early experiences and pitfalls of workflow automation in healthcare [33, 42-44]. However, none of the existing work investigated the automation of sterile processing procedures, preventive SOP rule conformance check, and proactive elimination of medical errors that are proposed in this project.

7.2. SOA-based Business Process Management in Healthcare

Service-oriented architecture (SOA) is a set of principles and methodologies for designing and developing software in the form of interoperable services, which can be published, discovered, reused, and composed for different applications[45, 46]. SOA has become the foundation for developing software as a service (SaaS) [45] in the industry. Some researchers have investigated various approaches of using SOA for enabling information sharing [47], mobile device access[48, 49], and system integration [50, 51].

The integration of Business Process Management (BPM) and Service-Oriented Architecture (SOA) is considered as a promising solution to support dynamic and flexible work practices by registering, discovering, and combining reusable services [52]. Hu et al. presented an SOA-based adaptive workflow framework to handle the emergency event in Tourism Information Change Management[53]. Healthcare process management is considered as a potential field to more readily see the benefits of SOA-based workflow management since the workflow of medical cases are dynamic and unpredictable. Juneja et al. concluded that service oriented architecture (SOA) can improve information delivering and data sharing among multiple stakeholders in care processes [54]. Some researches adopted SOA directly as the basis for many healthcare information systems [55-59] and to address the interoperability challenge of healthcare systems [47, 60].

However, none of the existing work studied the sterile processing department to automate and manage functionalities provided by three working areas and intelligent heterogeneous objects. In this paper, we explored healthcare workflow technology to control the execution status of dynamic healthcare business processes and a Service-Oriented business process modeling framework to publish, discover, reuse, and compose interoperable services for different purposes.

8. CONCLUSIONS AND FUTURE WORK

This paper is a major extension in the direction of Service-oriented business process management of a preliminary conference paper [61] with the following contributions:

First, we explored the main factors and issues that affect patient safety in SPD operation management. Second, in the new section 3, a five-level framework for service-oriented business process management is designed for SPDs to share information, integrate distributed systems, and manage heterogeneous resources among multiple stakeholders. In the proposed pattern for healthcare business process management, the importance of execution status control is firstly emphasized as a key to handle complex and dynamic healthcare processes. Third, we proposed a healthcare workflow system as a deliverable solution to manage the execution phase of reprocessing procedures. The key architectural requirements for a healthcare workflow system for SPDs were identified. Fourth, Service-Oriented Architecture was applied to the SPDFLOW system development to enable collaboration between SPDFLOW and other systems via information sharing and integration; to facilitate SPDFLOW subsystem development by programming and platform independence; to virtualize RFID-based infrastructure resources and SPD functionalities as services in the SPDFLOW task manager. Fifth, based on the key architectural requirements for SPDFLOW, the six subsystems in the SPDFLOW architecture were designed. Finally, a new case study in the decontamination working area is validated by a new web-based SPDFLOW demo system. This research is the first effort in exploring service-oriented business process management and healthcare workflow technologies in the SPD domain to improve the quality of RME and ensure patient safety.

Ongoing work includes further implementation in other working areas, the design of the ECA-based SOP rule engine to achieve compliance check and support the verification of more RME reprocessing procedures for continuous quality control. We will also focus on the research on managing heterogeneous devices and resources across different workflow areas based on SOA. Events will be detected by analyzing real-time information from RFID-enabled intelligent objects. A smart provenance manager will be deeply explored to verify skipped steps and right workflow routine. After implementing the SPDFLOW prototype system in one SPD, we will focus on the performance comparison between traditional business process management in SPD and improved solutions by SPDFLOW system.

Acknowledgments

This research has been made possible through the financial contribution of Veterans Engineering Resource Center (VERC), the Veterans Health Administration. We are most grateful to managers and staffs in SPD and OR in VA John D. Dingell Medical center, Detroit, MI for information collection. Special appreciation to Dr. Shiyong Lu for his patient guidance about workflow management and steadfast encouragement to complete this study. Many thanks to all members of the VIEW research group, especially for Andrey Kashlev for designing the web-based VIEW system. We are also grateful to the two anonymous reviewers for their constructive suggestions and helpful comments.

Reference

1. Hoff, T., Jameson, L., Hannan, E. and Flink, E. (2004) 'A Review of the Literature Examining Linkages between Organizational Factors, Medical Errors, and Patient Safety', *Med Care Res Rev*, Vol. 61, pp. 3-37.
2. Emanuele, J. and Koetter, L. (2007) 'Workflow opportunities and challenges in healthcare', *BPM & Workflow Handbook 1*, pp.157.
3. Georgakopoulos, D., Hornick, M. and Sheth, A. (1995) 'An Overview of Workflow Management: From Process Modeling to Workflow Automation Infrastructure', *Distributed and Parallel Databases*, Vol. 3, No.2, pp. 119-153.
4. Van Der Aalst, V.M., Ter Hofstede, A.H. and Mathias Weske, M. (2003) 'Business process management: A survey', *Business process management*, pp. 1-12, Springer Berlin Heidelberg.
5. Reijers, H.A. (2003) 'Design and control of workflow processes: business process management for the service industry', Verlag Berlin, Heidelberg Springer.
6. González-González, I., Serradell-López, E. and Castillo-Merino, D. (2012) 'The Implementation of Process Management: A System to Increase Business Efficiency - Empirical Study of Spanish Companies', *International Journal of Knowledge Society Research*, Vol. 3, No.1, pp. 14-25.
7. Hull, R., Mendling, J. and Tai, S. (2012) 'Business process management', *Information System*, Vol. 37, No.6, pp. 517.
8. Lenz, R. and Reichert, M. (2007) 'IT support for healthcare processes – premises, challenges, perspectives', *Data & Knowledge Engineering*, Vol. 61, No. 1, pp. 39-58.
9. Alexandrou, D. and Mentzas, G. (2009) 'Research Challenges for Achieving Healthcare Business Process Interoperability', in *eHealth, Telemedicine, and Social Medicine, eTELEMED09*. international conference on pp 58-65, IEEE.
10. Dhieb, A.B. and Barkaoui, K. (2011) 'On the Modeling of Healthcare Workflows Using Recursive ECATNets', in *Business Process Management Workshops*, pp 99-107, Springer Berlin Heidelberg.
11. Koufi, V., Malamateniou, F., Mytilinaiou, E. and Vassilacopoulos, G. (2010) 'An Event-Based, Role-Based Authorization Model for Healthcare Workflow Systems', in *eHealth*, pp.221-228, Springer Berlin Heidelberg.
12. Lu, B.H., Bateman, R.J. and Cheng, K. (2006) 'RFID Enabled Manufacturing: Fundamentals, Methodology and Applications'. *International Journal of Agile Systems and Management*, Vol. 1, No.1, pp. 73-92.
13. Curtin, J., Kauffman, R.J. and Riggins, F.J. (2007) 'Making the 'most' out of RFID technology: A research agenda for the study of the adoption, usage, and impact of RFID', *Information Technology and Management*, Vol.8, No.2, pp. 87-110.
14. Ma, X., Yang, K. and Brayley, K. (2011) 'RTLS-based ubiquitous healthcare system design and implementation. White Paper in RFID Journal.
15. Ngai, E.W.T., Moon, K.L., Riggins, F.J. and Yi, C.Y. (2007) 'RFID research: An academic literature review (1995-2005) and future research directions', *International Journal of Production Economics*, Vol.112, No.2, pp. 510-520.

16. Business Process Model and Notation. Available from: http://en.wikipedia.org/wiki/Business_Process_Model_and_Notation.
17. Simpson, R.C. (2004) Final Report NASA Faculty Fellowship Program 2004: Johnson Space Center.
18. White, S.A. (2004) 'business process modeling notation, in specification of BPMN v1.0', business process management initiative.
19. Fei, X. and Lu, S. (2012) 'A dataflow-based scientific workflow composition framework', IEEE Transactions on Services Computing, Vol.5, No.1, pp.45-58.
20. Erl, T. (2005) service-oriented architecture concepts, technology and design. Englewood Cliffs: Prentice Hall.
21. Lin, C., Lu, S., Lai, Z., Chebotko, A., Fei, X., Hua, J. and Fotouhi, F. (2008) 'Service-oriented architecture for VIEW: a visual scientific workflow management system', in IEEE 2008 International Conference on Services Computing (SCC 2008), Vol.1, pp.335-342.
22. Zhang, Y., Huang, G., Qu, T. and Ho, O. (2009) 'Agent-Based Smart Objects Management System for Real-Time Wireless Manufacturing', Proceedings of the 6th CIRP-Sponsored International Conference on Digital Enterprise Technology, pp. 1709-1721, Springer Berlin Heidelberg.
23. Hollingsworth, D. (1994) The workflow reference model. The Workflow Management Coalition.
24. Lim, C., Lu, S., Chebotko, A., Fotouhi, F. (2011) 'Storing, Reasoning, and Querying OPM-Compliant Scientific Workflow Provenance Using Relational Databases', Future Generation Computer Systems (FGCS), Vol.27, No.6, pp.781-789.
25. Ma, X., Yang, K. (2012) 'RFID-based healthcare workflow management in Sterile Processing Department', in Industrial and Systems Engineering Research Conference (ISERC), Orlando, Florida.
26. Chebotko, A., Lin, C., Fei, X., Lai, Z., Lu, S., Hua, J. and Fotouhi, F. (2007) 'VIEW: a visual scientific workflow management system'. 2007 IEEE Congress on Services, pp.207-208.
27. <http://viewssystem.org>.
28. Lazcano, A., Schuldt, H., Alonso, G. and Schek, H. (2001) 'WISE: Process based E-Commerce'. IEEE Data Eng. Bull. (DEBU), Vol.24, No.1, pp. 46-51.
29. Liu, L. and Pu, C. (1998) 'Methodical Restructuring of Complex Workflow Activities', in Data Engineering, 1998. Proceedings., 14th International Conference on, pp.342-350.
30. Huang, C.Y. (2012) 'Distributed manufacturing execution systems: a workflow perspective', Journal of Intelligent Manufacturing, Vol.13, No.6, pp. 485-497.
31. Zhang, Y.F., Huang, G.Q. and Qu, T. (2010) 'Agent-based workflow management for RFID-enabled real-time reconfigurable manufacturing', Int. J. Computer Integrated Manufacturing (IJCIM), Vol.23, No.2, pp. 101-112.
32. Elnahrawy, E. and Martin, R.P. (2010) 'Studying the utility of tracking systems in improving healthcare workflow', in Pervasive Computing and Communications Workshops (PERCOM Workshops), 2010 8th IEEE International Conference on, pp 310-315.
33. Neumann, C.P. and Lenz, R. (2010) 'The Alpha-Flow Use-Case of Breast Cancer Treatment - Modeling Inter-institutional Healthcare Workflows by Active Documents', in Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE), 2010 19th IEEE International Workshop on, pp. 17-22.
34. Song, X., Hwong, B., Matos, G., Rudorfer, A., Nelson, C., Han, M. and Girenkov, A. (2006) 'Understanding requirements for computer-aided healthcare workflows: experiences and challenges'. in Proceedings of the 28th international conference on Software engineering, pp. 930-934.
35. Song, X., Hwong, B., Matos, G. and Rudorfer, A. (2007) 'Understanding and Classifying Requirements for Computer-Aided Healthcare Workflows', in Computer Software and Applications Conference, 2007. COMPSAC 2007. 31st Annual International, pp.137-144.
36. Ardissono, L., Di Leva, A., Petrone, G., Segnan, M. and Sonnessa, M. (2006) 'Adaptive Medical Workflow Management for a Context-Dependent Home Healthcare Assistance Service', Electr. Notes Theor. Comput. Sci. (ENTCS), Vol. 146, No.1, pp. 59-68.
37. Van Hee, K., Schonenberg, H., Serebrenik, A., Sidorova, N. and Van Der Werf, J.M. (2008) 'Adaptive Workflows for Healthcare Information Systems', in Business Process Management Workshops, pp. 359-370.
38. Browne, E.D., Schrefl, M. and Warren, J.R. (2004) 'Goal-Focused Self-Modifying Workflow in the Healthcare Domain', in System Sciences, 2004. Proceedings of the 37th Annual Hawaii International Conference on, pp.10.
39. Bandt, M., Kühn, R., Schick, S. and Meyer, H. (2011) 'Beyond Flexibility - Workflows in the perioperative Sector of the Healthcare Domain'. Electronic Communications of the EASST, Vol.37.
40. Reijers, H.A., Russell, N., van der Geer, S. and Krekels, G. AM. (2010) 'Workflow for Healthcare: A Methodology for Realizing Flexible Medical Treatment Processes', Business Process Management Workshops, pp. 593-604.
41. Russello, G., Dong, C. and Dulay, N. (2008) 'Consent-Based Workflows for Healthcare Management', in Policies for Distributed Systems and Networks, POLICY 2008, IEEE Workshop on, pp. 153-161.
42. Koppar, A.R. and Sridhar, V. (2009) 'A Workflow Solution for Electronic Health Records to Improve Healthcare Delivery Efficiency in Rural India', in eHealth, Telemedicine, and Social Medicine, 2009. eTELEMED'09. International Conference on, pp.227-232.
43. Becker, J. and Janiesch, C. (2008) 'Restrictions in Process Design: A Case Study on Workflows in Healthcare', in Business Process Management Workshops, pp.323-334, Springer Berlin Heidelberg.
44. Murray, M. (2003) 'Strategies for the Successful Implementation of Workflow Systems within Healthcare: A Cross Case Comparison', in System Sciences, Proceedings of the 36th Annual Hawaii International Conference on, pp. 10.
45. Laplante, P.A., Zhang, J. and Voas, J.M. (2008) 'What's in a Name? Distinguishing between SaaS and SOA', IT Professional, Vol. 10, No.3, pp. 46-50.
46. Lin, C., Lu, S., Fei, X., Chebotko, A., Pai, D., Lai, Z., Fotouhi, F. and Hua, J. (2009) 'A reference architecture for scientific workflow management systems and the VIEW SOA solution', IEEE Transactions on Services Computing (TSC), Vol.2, No.1, pp. 79-92.
47. Hussain, M., Afzal, M., Ahmad, H.F., Khalid, N. and Ali, A. (2009) 'Healthcare Applications Interoperability through Implementation of HL7 Web Service Basic Profile', in Information Technology: New Generations, ITNG'09, Sixth International Conference on, pp. 308-313.
48. Ng, W.S., Teo, J.C.M., Ang, W.T., Viswanathan, S. and

- Tham, C.K. (2009) 'Experiences on developing SOA based mobile healthcare services', in Services Computing Conference, APSCC, IEEE Asia-Pacific, pp. 498-501.
49. Kang, H. H., Kim, S.R., Kim, K.D., Kim, D.K. and Yoo, S.K. (2007) 'Cooperative Mobile Healthcare Information Support System Using Web Services over Wireless and Wired Network', in Cooperative Design, Visualization, and Engineering, pp.323-330, Springer Berlin Heidelberg.
50. Sahay, R., Fox, R. and Hauswirth, M. (2008) 'Ontologising Interaction Behavior for Service-Oriented Enterprise Healthcare Integration', on Web Services, ECOWS'08. IEEE Sixth European Conference, pp.165-174.
51. Sahay, R., Fox, R. and Hauswirth, M. (2009) 'Semantic Service-oriented Design and Development Methodology for Enterprise Healthcare Integration', in Proc. of 5th International Conference on Web Information Systems and Technologies, WEBIST, pp. 159-166.
52. Adams, M., Ter Hofstede, A.H.M., Edmond, D. and Van Der Aalst, W.M.P. (2006) 'Worklets: A Service-Oriented Implementation of Dynamic Flexibility in Workflows', in On the Move to Meaningful Internet Systems 2006: CoopIS, DOA, GADA, and ODBASE, pp. 291-308, Springer Berlin Heidelberg.
53. Hu, T., Li, J.H. and Wang, Q.S. (2008) 'Adaptive workflow based on SOA and its application in Tourism Information Change Management', in Networking, Sensing and Control, ICNSC, IEEE International Conference on, pp. 1185-1189.
54. Juneja, G., Dournaee, B., Natoli, J. and Birkel, S. (2008) 'Improving Performance of Healthcare Systems with Service Oriented Architecture', Available from: <http://www.infoq.com/articles/soa-healthcare>.
55. Yu, W.D., Joshi, A., Patel, J. and Mehta, V. (2011) 'A SOA Service Governance Approach to u-Healthcare System with Mobility Capability', in Communications (ICC), 2011 IEEE International Conference on, pp.1-6.
56. Goede, P., Frasier, L. and Thraen, I. (2010) 'An Image-Centric, Web-Based, Telehealth Information System for Multidisciplinary Clinical Collaboration', in Web-Based Applications in Healthcare and Biomedicine, pp. 77-100, Springer US.
57. Yu, X. (2009) 'A web services based approach for aviation emergency response', in Services Computing Conference, APSCC, IEEE Asia-Pacific, pp.435-439.
58. Kart, F., Moser, L. E. and Melliar-Smith, P.M. (2008) 'Building a Distributed E-Healthcare System Using SOA', IT Professional, Vol.10, No.2, pp. 24-30.
59. Sloane, E., Leroy, G. and Sheetz, S.D. (2007) 'An Integrated Social Actor and Service Oriented Architecture (SOA) Approach for Improved Electronic Health Record (EHR) Privacy and Confidentiality in the US National Healthcare Information Network (NHIN)', in AMCIS.
60. Daskalakis, S. and Mantas, J. (2008) 'Evaluating the impact of a service-oriented framework for healthcare interoperability', Studies in health technology and informatics, Vol.136, pp.285.
61. Ma, X.Y., Lu, S.Y. and Yang, K. (2012) 'Service-Oriented Architecture for SPDFLOW: A Healthcare Workflow System for Sterile Processing Departments', in Services Computing (SCC), 2012 IEEE Ninth International Conference on, pp.507-514.