Hospital Linens Inventory Control Re-engineering Based on RFID

Yuan-Yuan Jiao, Yi-Wen Zhen
School of Business
Nankai University
Tianjin 300071, China

Roger J. Jiao
School of Mechanical & Aerospace Engineering
Nanyang Technological University
Singapore 639798

***Abstract*—Cost-conscious businesses have focused on using radio frequency identification (RFID) systems to enhance the efficiency in the supply management/logistics process. RFID's application in hospital business processes is increasing rapidly and a number of safety-critical clinical applications have been prototyped. Unlike barcode systems, it is necessary to implement Business Process Reengineering (BPR) with an innovative spirit on the fundamental processes before implementing RFID to achieve greater synergy. This paper presents a based-RFID business process reengineering framework. And then Tan Tock Seng Hospital, the second largest acute care general hospital in Singapore, is used as a case study to analyze and implement linens inventory control process reengineering.**

***Keywords*—business process re-engineering, linens inventory control, radio frequency identification, hospital**

I. INTRODUCTION

Radio frequency identification (RFID) systems have received increased attentions from academicians and practitioners [1]. Cost-conscious businesses traditionally have focused on using RFID systems to enhance the efficiency in the supply management/logistics process [2]. RFID's application in hospital business processes is increasing rapidly, and a number of safety-critical clinical applications have been prototyped [3]. Britton (2007) suggest that RFID technology could be used to track the location of equipment in a hospital [4]. RFID is rapidly becoming the standard for hospitals to track inventory, identify patients, and manage personnel [5].

Unlike barcode systems, it is necessary to implement Business Process Reengineering (BPR) with an innovative spirit on the fundamental processes before implementing RFID to achieve greater synergy [6]. BPR has been considered as a multidimensional problem solving approach, emphasizing on significant improvements in the organizational performance in terms of multiple parameters such as quality, cost, delivery, service level, etc. to gain competitive advantage [7].

BPR requires a fundamental theoretical framework and a proven, reliable methodology, which is generally applicable and repeatable. However, inspection of the literature and company observation showed that there was no standard or typical BPR methodology and different methodologies and various forms of BPR were being proposed [8]. BPR projects are considered to be high risk due to their high management complexity, enterprise-wide impact, and steep project cost [9]. A new trend is the use of Business Process Simulation in both the design and the evaluation phase of re-engineering projects. The simulation model should be used to continually monitor and evaluate the process for continuous improvement [10].

Towards this end, this paper proposes a RFID-based business process re-engineering framework. And then Tan Tock Seng Hospital, the second largest acute care general hospital in Singapore, is used as a case study to analyze and implement linens inventory control process reengineering.

II. RFID-BASED BUSINESS PROCESS RE-ENGINEERING FRAMEWORK

The RFID-based business process re-engineering theoretical framework consists of four primary steps, as illustrated in Fig. 1.

A. *Field Investigations and Case Studies (Drivers)*

To identify the needs, mandate and compliance with business partners and suppliers, the framework starts with broader preliminary field investigations and narrows down to more detailed case studies.

1) Preliminary field investigations: This is the business process familiarization stage, which comprises a simple walk through all interest sites, data analysis and interviews with the staffs on the ground. Preliminary field investigations will eventually highlight the problem areas and attempt to classify them in various workflows systematically.

2) Detailed case studies: This stage of the framework attempts to map out the current business process flowchart and initiate possible streamlining of existing processes. In addition, a more detailed field investigation will be carried out to take into consideration of all resources, infrastructure setup and the entire business processes. Eventually this section aims to develop a more detailed analysis of the selected problems.

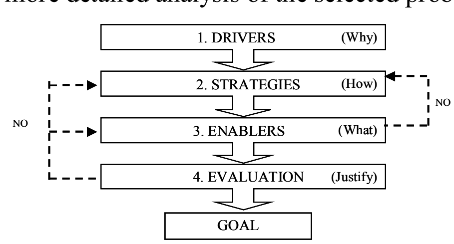

Figure 1. RFID-based business process reengineering framework

B. Process Re-engineering via RFID (Strategies)

According to the analysis of the current business process, areas where RFID related policies can re-strategize the workflow should be identified.

1) RFID touch points of current business process: The biggest strategic benefits from RFID come from its abilities to improve the business process. The process touch points where RFID can improve the process flow are described as follows.

- The first touch point is areas where human tasks can be automated and frequent data errors can be eliminated. These include any areas where human intervention is required to read a label or do manual counting and it is possible to put an antenna and RFID reader to automate the procedure. Because data errors are usually the result of human interaction, these are the areas throughout the process for improvement.
- RFID can be implemented at areas where the corporations can benefit from real-time data capture.
- RFID can come into play at areas where things must pass by a choke point. Reading data at these points will provide visibility of real-time volume flow and timing. If applications are set up with automated decision rules, RFID can enable these actions without human intervention and in real time.

2) Process resign scenarios: After the touch points are made certain, there is certainly a need to generate the process resign "To-be" scenarios according to BPR methods and RFID technical characteristics

C. RFID Solutions (Enablers)

The aim of this step is to select the right RFID system setups, which include careful consideration of the right frequency, tag, reader, middleware, configurations, etc. These solutions address directly to the strategies in the previous step and might need iteration at times.

RFID systems use various frequencies, but generally the most common are unlicensed low frequency (LF), high frequency (HF) and ultra high frequency (UHF). Microwave at 2.4 GHz is also used in some applications.

1) Tags: There are three types of tags: passive, semi-passive and active tags.

a) Passive tags: The RFID passive tag has no internal power supply and responds by a very small electrical current that is provided by the antenna of the incoming radio frequency signal. The benefits of a passive tag include unlimited life span, smaller size and the least expenses.

b) Semi-passive tags: The semi-passive RFID tag is quite similar to the passive tag. This type of tag has a small battery which allows the integrate circuit to be powered at all times. As the integrated circuit is powered, the tag can respond faster than the passive tag. However, due to the battery, semi-passive RFID tag has a limited life span.

c) Active tags: With their own internal power sources, active tags can power their communication in any integrated circuits and generate an outgoing signal. Active tags in general have a wider rage and a longer memory than passive tags and have the ability to store information that is sent by the transceiver. An active tag has a considerable life span of about five years.

2) Readers: The reader not only generates the signal that goes out through the antenna into space, but also listens for a response from the tag. Prior to installations, site assessment should be carried out to check for the ambient electromagnetic noise. It is very significant to consider how to make full use of existing infrastructures for easier installation. And the local area network access points, wireless access points, power supplies and so on are identified.

3) Middleware: RFID middleware, which is a critical component of any RFID system, captures the raw data from the reader and filters the useful data to back-end systems. Middleware plays an important role in getting the right information to the right application at the right time. The cost of middleware differs from vendor to vendor and is usually based on the number of installed locations, the complexity of the application and many other factors.

D. Simulation (Evaluation)

The final step in this framework is to validate the re-engineered model (To-be) against the previous (As-Is) model. The simulation serves as an evaluation of the feasibility of the RFID implementation. Simulation modeling is carried out in numerous steps and it is time-consuming. Many modeling products now exist in the market place, such as ARENA, ARIS ToolSet, FirstSTEP, Bonapart, PrimeObject, and CimTool.

III. Field Investigations and Case Studies of Linens Inventory Control Process

A. Field Investigations

Tan Tock Seng Hospital (TTSH), established in 1844, is currently the second largest acute care general hospital in Singapore. There are 20 Clinical Specialties ranging from Cardiology to Orthopedic Surgery and 15 Allied Health Services such as Physiotherapy and Vascular Surgical Services. This hospital is constantly striving to apply existing and new technologies, such as 3G, wireless connections, video packets, and RFID, to bring about better, safer and more efficient patient care.

All care of Linens, sending to the laundry, packing and storing clean Linens, as well as the distribution and collection of Linens to and from wards, are attended by the linens department in the Linens Room. In the linens department, there are 20 people assigned with different roles in facilitating the flow of the linens in the hospital. The cleaning process is sub contracted out to Singapore Corporation of Rehabilitative Enterprises (SCORE) who will assign a delivery truck to the linens department everyday. Their responsibilities include transporting soiled linens back to Changi Prison, doing the laundry and delivering clean linens back to the linens department.

The linens department of TTSH manages huge volume of bed sheets, pillow cases, towels, patients' garments and operation theatre garments daily. Therefore, it is extremely time-consuming and tedious to keep track and stock all these linens manually. Without real time visibility in the inventory level, it would be difficult to maintain the optimal level of inventory which will translate to high inventory cost. Another problem which the linen department faces is that the losses of linens, such as patients' garments and towels, are not being properly counted. This is due to the fact that the linen department has difficulties in assessing the number of linens sent out for washing.

B. Case Studies of Linens Inventory Control Process

1) Standard procedure for linens inventory control: Fig. 2 illustrates the standard operating procedures for linens inventory control.

2) Problems faced with existing linens inventory control process: There are the two problems in the "Open Cage" and "Linens Pickup Point" stage .

a) Low visibility of soiled linens sent out to sub contractor: The department faces a critical issue of poor visibility in the inventory level. This is largely due to the hygiene standard of minimal human contact with soiled linens. When soiled linens are delivered down from the air pressured pipes, they are packed into bundles for easy collection and accounting. However this hinders the counting process of individual pieces because it is time-consuming and non-hygienic to open up the bundles. The department estimates the number of total soiled linens sent out to the sub contractor. This gave rise to poor visibility of soiled linens sent out to sub contractor and hence it is impossible to track for losses during the cleaning process.

b) Low visibility of linens usage in the wards: Automatic Guided Vehicles (AGVs) deliver the daily linens requirements of the wards; however this is a replacement system instead of a replenishment system. The AGV will not account for the unused linens from the wards; instead it will bring the metal trolley with the unused linens back to the linens department for accounting. This signifies that the department needs to keep a higher pile level as compared to a replenishment system where the AGVs only need to replenish the used linens in the wards.

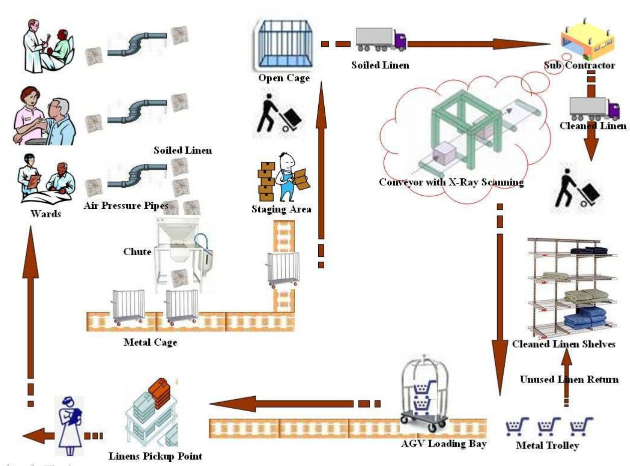

Figure 2. Standard operating procedure for linens inventory control

IV. LINENS INVENTORY CONTROL PROCESS REENGINEERING

A. RFID Touch Points in Linens Inventory Control Process

After the current business process is mapped out, it is necessary to identify the touch points where RFID can improve the current process.

1) Automating human tasks and eliminating data errors: The existing process requires staff from the linens department to manually count the soiled linens by estimating the number of linens in the bundles sent down from the wards through the air pressured pipes. This often does not reflect true quantity of soiled linens sent out to the sub contractor. Similarly, the department needs to manually count unused linens from wards everyday when AGVs deliver them back to the department. This process is time-consuming and may result in data errors. Well configured RFID stations in the linens department and in the wards will be able to rectify the above errors.

2) Passing by a choke point during a process: There are two problems in the linens department. Firstly, the soiled linens are collected through a centralized air pressured pipe system and are consolidated at the department. Establishing a RFID system where a reader and antenna is mounted on a conveyor belt will be able to automate the process of loading the soiled linens onto the delivery truck and at the same time provide visibility of real-time volume flow of soiled linens. Secondly, the problem of low visibility of linens usage in wards can be rectify by deploying a RFID station at the linens pick-up point since the pick-up point is a common choke point for all personnel to collect clean linens for their wards. A well deployed RFID station enables real-time volume flow of clean linens and also allow automated decision rule like formulating the linens replenishment quantity to be carried out.

3) Things in-bound from suppliers or partners: The first problem deals with the sub contractor of linens department, eventually they should establish a RFID system that is similar to the department. This is a feasible implementation because all the out-going soiled linens from TTSH go through the X-ray machine mounted on a conveyor belt upon the arrival at the sub contractor venue. By establishing an in-coming and out-going station, both TTSH and the sub contractor will be able to enjoy clear visibility in the process. Billing can be automated and losses can be counted instantaneously. In the second problem, we treat the wards as the sub division of the linens department. By establishing RFID stations at each linens pick-up point, the department will be able to establish the accurate daily linens usage of each ward.

B. Process Re-engineering

Three major changes are introduced to the process. Fig. 3 details the reengineered process via RFID applications.

1) Firstly, two RFID enabled conveyor belts are set up in the linens department. One is used to count total soiled linens before they are transported to the sub contractor and the other is used to count total cleaned linens from the sub contractor.

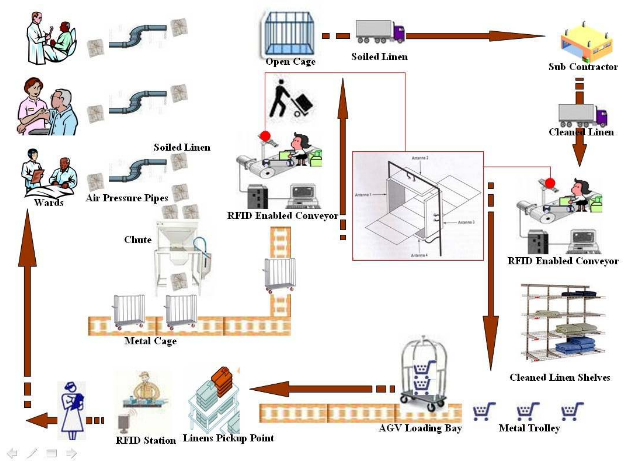

Figure 3. Re-engineered process workflow for linens inventory control

2) The second change will be the installation of RFID readers on the conveyor belts in the sub contractor vicinity. This will improve existing conveyor belt system which is currently utilized for X-ray scanning of unauthorized objects.

3) The third change would be the implementation of RFID stations near the linens pick-up points.

V. RFID Solutions for Linens Inventory Control Process

A. *RFID Passive Tags*

Primary consideration for the tag design should include the overall size and shape. Tags should be kept as small as possible for easy insertion and wearing comfort. Heat, pressure and solvent resistance are also important considerations because linens undergo high temperature and pressure during washing. Since there is a constraint for the search of a small tag in this case study, a well designed antenna configuration within a small surface will be the primary consideration.

The ideal tags would be passive tags. The recommended frequency for the system is 13.65MHz. Recommended tags are the RFID laundry tags “SMLD XX” from Synometrix and the Nano laundry tags “Ario™ 370-DL” from TAGSYS RFID.

B. *RFID Readers*

The suggestion of mounting the readers on a conveyor setup should consist of at least four antennas in a quad arrangement. This setup will give the RFID conveyor system vast advantages over a typical barcode conveyor solution. A recommended setup of the RFID conveyor system would be the “Reader tunnels” from TAGSYS RFID. This setup will be able to achieve accuracy up to 99.95% when the system reads 50 items in bulk at a speed of 12cm/sec. A recommended reader would be the SM-A9240 1 or 4 Port Reader.

C. *RFID Middleware*

The middleware must be able to strike a balanced combination of the following capabilities.

1) Reader and device management: The RFID middleware needs to allow users to configure, deploy and issue commands directly to readers through a common interface.

2) Data management: After RFID middleware captures EPC data from readers, it must be able to intelligently filter and route data to the appropriate destinations.

3) Application integration: RFID middleware solutions need to provide the messaging, routing and connectivity features required to integrate the data into existing Supply Chain Management (SCM), Enterprise Resource Planning (ERP), Warehouse Management (WMS), etc.

4) Partner integration: In this context, partners of the linen department are the sub contractor and suppliers. Hence the middleware must provide business-to-business integration features like partner profile management, support for business-to-business transport protocols, and integration with a partner’s data over communications such as EDI, web-based systems like AS1, eventually a well engineered system specifically for EPC data.

5) Process management and application development: In the proposed linens replenishment system, linens department can accurately know when the inventory level becomes critically low and send a machine generate message to its ERP system to order more products without human involvement.

6) Architecture scalability and administration: The middleware platform must include features for dynamically balancing processing loads across multiple servers and automatically rerouting data if a server fails.

Middleware needs to be distributed with the right level of logic place at the right location, or tier, in the architecture. Table I illustrates the architecture better in three main tiers: Edge Tier, Operational Tier and Enterprise Tier.

TABLE I. Three Tiers of RFID Middleware Architecture

TIER	*Functionality*	*Location*
Edge Tier: Serve as the first line of defense from the crowded network	Large volume of linens are expected to pass through the readers, this tier serve as basic filtering of noise and superfluous data from network, such as duplicated reads.	Close to or even on the readers themselves. Ideally host middleware logic in the readers themselves, taking away unwanted reads in the bud right at the source.
Operational Tier: More content based filtering that requires knowledge of other reads coming through the system	Decides where to route the data, either to local management system or up to the enterprise level. Raises flags when exceptions occur (e.g. when assigned linens are unaccounted after ward personnel check them out) (e.g. when total soiled linens do not tally with total cleaned linens) Store some RFID data in a database so monitoring application can track all traffic flowing through that site.	At individual sites, like wards stations (Linens pick-up points), sub contractor, conveyor belt system.
Enterprise Tier: Highest level, To accept data from operational tier and incorporate it into enterprise wide processes.	Connects with common enterprise applications and data stores, like SAP or a centralized product information database. Communicates data to external business partners like an advance billing notice for loss linens (subcontractor) or an advance order notice for new purchase (linen supplier)	One central data source where information can be harnessed for business decisions.

VI. Simulation of Linens Inventory Control Process

From the standard procedure for linens inventory control, the Arena's models are categorized into soiled linens process and clean linens process, which are modeled separately for accuracy of data collection and clearer visibility of linens flow. Despite that the two processes occur in parallel, they have two distinct flows with no interaction in any of the procedure.

A. *System Modeling of Linens Inventory Control Using Arena*

In this paper and study scope, the simulation software used is Arena (Version 8.01) simulation software from Rockwell Automation. Arena is one of the popular commercial software to analyze medium, complex or large-scale projects which comprise highly sensitive changes associated to supply chain, processes, manufacturing, logistics, warehousing, distribution and service systems.

During simulation, the models are allowed to run for a period of 156 (26 weeks × 6) replications because the linens department only operates for 6 working days in a week. The operation hours are from 8.00am to 4.30pm from Monday to Saturday. It forecasts a period of 6 months for accuracy of predicted data. The time unit of the simulations is in minutes.

1) *Soiled linens process:* Fig. 4 illustrates the Arena model of soiled linens process before RFID implementation. And Fig. 5 shows the Arena model of soiled linens process after RFID implementation.

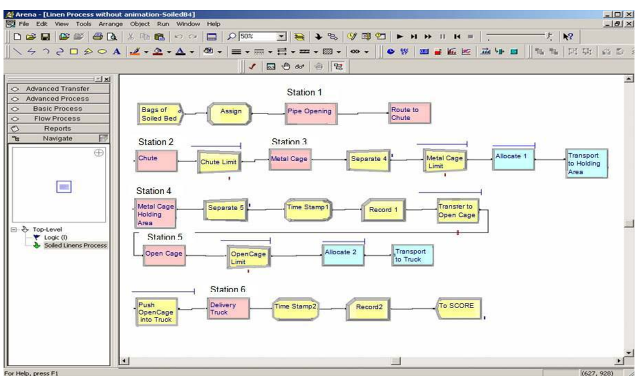

Figure 4. Arena model of soiled linens process before RFID implementation

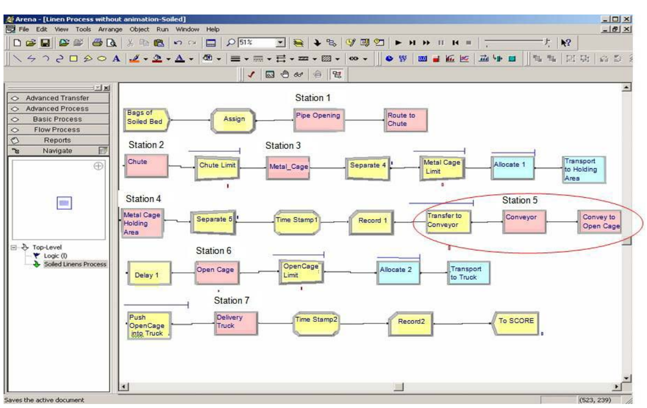

Figure 5. Arena model of soiled linens process after RFID implementation

2) *Clean linens process:* Fig. 6 illustrates the Arena model of clean linens process before RFID implementation. And Fig. 7 shows the Arena model of clean linens process after RFID implementation.

B. *Simulation Results and Analysis*

1) *Soiled linens process:* The main objective is to find out the time needed to complete the soiled linens process with RFID implementation. Table II and Table III show soiled linens process data and time interval before and after RFID implementation respectively. From Table II, the longer waiting time is expected. From Table III, the initial process takes an average of 39.19 minutes while the process with RFID takes an average of 44.23 minutes. The time increase is due to the additional process-transfer to Conveyor and the station-Conveyor. Thus with a slight trade-off in timing, the process with RFID implementation provides visibility for the soiled linens out to SCORE.

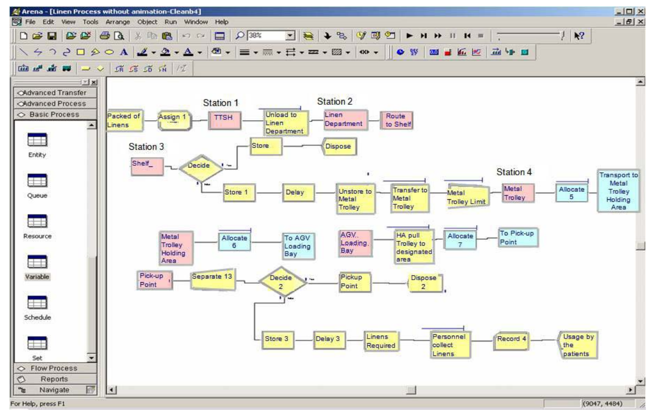

Figure 6. Arena model of clean linens process before RFID implementation

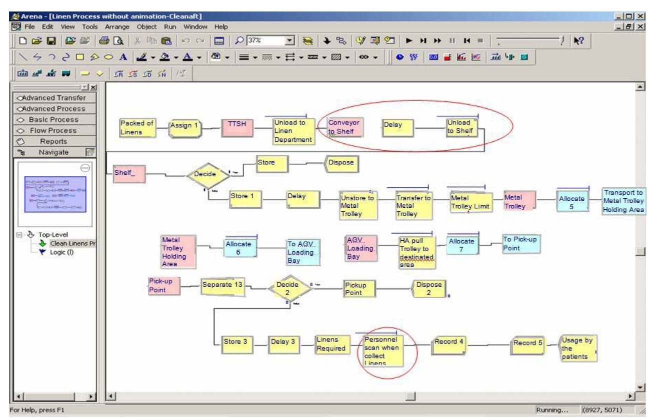

Figure 7. Arena model of clean linens process after RFID implementation

TABLE II. Soiled Linens Process Data before and after RFID Implementation

	Before	***After***
Wait Time	6426.12	6068.83
Transfer Time	513.5	556.99
Total Time	130.05	125.8
Number In	471.36	489.67
Number Out	426.51	457.5
WIP	53.951	45.6579

TABLE III. TIME INTERVAL FOR SOILED LINENS PROCESS BEFORE AND AFTER RFID IMPLEMENTATION

	Before	*After*
Soiled Linens Start Time	261.11	263.43
Soiled Linens Stop Time	300.3	307.66
Actual Time Taken	39.19	44.23

2) Clean linens process: Table IV and Table V show clean linens process data and time interval before and after RFID implementation respectively. From Table V, the time taken for the clean linens before RFID implementation is 339.75 minutes while that after RFID implementation is 371.23 minutes. With the additional processes-unload to shelf and scan linens when collected and stations-conveyor, the process took 31.48 minutes more to be completed. Time delay is due to the scanning of the RFID tags on each individual packed linens when unloaded into the shelf and when personnel scan it when linens are needed in the wards. Further studies are needed to justify the longer time spend in the clean linens process to clearer visibility of the linens level. For the clean linens process before RFID implementation, the numbers of packed linens is not recorded. In the process after RFID implementation, the packed linens are count and recorded. From the Table V, the packed linens are recorded as 2247.79. This figure is the numbers of packed linens requested and scanned by the personnel for patients' usage.

VII. CONCLUSIONS

Hospitals are pursuing technology advancements to stay at the pinnacle of the healthcare service providers and to meet patient satisfaction in service provision. One of the ways is RFID technology implementation in operations and processes of the hospital's workflow. RFID have assumed an important role in supporting logistics and supply chain management processes because of their ability to identify, categorize, and manage the flow of goods and information throughout the supply chain.

TABLE IV. CLEAN LINENS PROCESS DATA BEFORE AND AFTER RFID IMPLEMENTATION

	Before	*After*
Wait Time	171.57	155.78
Transfer Time	4.0842	3.5853
Total Time	176.86	160.56
Number In	6326.31	6317.85
Number Out	6171.03	6168.67
WIP	857.3	783.28

TABLE V. TIME INTERVAL FOR CLEAN LINENS PROCESS BEFORE AND AFTER RFID IMPLEMENTATION

	Before	*After*
Packed Linens_Time_Interval	339.75	371.23
Packs of Linens out	-	2247.79

Business Process Re-engineering has been a holistic approach to supply chain management and a lot of research is being done to come up with the most appropriate framework. This paper presents the fundamental framework of business process reengineering based on RFID, which can help tremendously to implement RFID to achieve greater synergy with an innovative spirit on the business process.

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