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RFID technology in healthcare and mass casualty incidents

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Defence R&D Canada – Ottawa
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Abstract

Nowadays, more and more hospitals and healthcare facilities are considering the use of radio frequency identification (RFID) technology to improve the ability to accurately identify and track patients, hospital staff, medical equipment, patient samples, and blood products. A number of case studies have demonstrated that RFID technology not only makes treatment safer and more efficient, but also has the side benefits of preventing identity theft and reducing paper work to cut costs. In addition to implementations in hospitals, RFID technology can be used in incidents with mass casualties to improve the effectiveness of first responders doing triage and treatment and transporting patients to nearby hospitals. The benefits can be substantial in terms of the “seven rights”: give the right medication to the right patient with the right dosage through the right route at the right time, and ensure that victims receive the right care at a mass casualty incident.

Résumé

De nos jours, de plus en plus d'hôpitaux et d'installations de santé envisagent utiliser la technologie de l'identification par radiofréquence (IRF) pour améliorer leur capacité à identifier et à suivre avec précision les patients, le personnel hospitalier, l'équipement médical, les échantillons des patients et les produits sanguins. Un certains nombre d'études de cas ont démontré que la technologie IRF, non seulement rend les traitements plus sûrs et plus efficaces, mais aussi qu'elle permet de prévenir le vol d'identité et de réduire les écritures et les coûts. Outre sa mise en œuvre dans les hôpitaux, la technologie IRF peut servir lors d'incidents avec pertes massives (IPM) de manière à améliorer l'efficacité des premiers répondants pour le tri, le traitement et le transport des patients vers les hôpitaux avoisinants. Les avantages peuvent être importants si l'on tient compte des points suivants : donner le bon médicament au bon patient avec la bonne dose, en suivant le bon protocole au bon moment et en s'assurant que les victimes reçoivent les bons soins lors d'un incident avec pertes massives.

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Executive summary

RFID technology in healthcare and mass casualty incidents

Qinghan Xiao; DRDC Ottawa TM 2008-131; Defence R&D Canada – Ottawa; July 2008.

Introduction or background: In collaboration with AMITA, DRDC Ottawa has been working on "Proof of Concept for In-field Operational Management of CBRNE (Chemical, Biological, Radiological, Nuclear, Explosive) Casualties Project". A major challenge is developing an efficient method to capture and communicate medical observations in mass casualty incidents (MCIs). Radio Frequency Identification (RFID, which has gained recent notoriety for improving supply chain processes, is being considered by the healthcare community for helping to enhance patient safety and improve business processes. Currently, there are several medical organizations that have started pilot RFID projects for applications such as asset tracking, equipment management, patient verification, blood matching, and drug counterfeit prevention. Based on reviewing RFID technology and highlighting RFID applications in healthcare, a scenario for using RFIDs in mass casualty incidents is presented., We believe that RFID is a promising technology for both day-to-day healthcare activities and CBRNE MCI operations.

Results: Our study finds that RFID technology can be employed in healthcare to track and verify patients, equipment, medication, and samples, and, therefore, to effectively address overall resource management and patient safety issues. A scenario is presented that uses RFID to triage mass casualty victims, track them from the incident to the area hospitals, and rapidly establish their injury and treatment file in the hospital information system. Not only does RFID technology help the first responders to classify and transport the victims effectively, but the proposed method allows family members to quickly determine to which hospital their injured relative was sent.

Significance: Patient safety is a widely discussed topic. According to one study, "America's healthcare-system-induced deaths are the third leading cause of the death in the U.S., after heart disease and cancer." [1] RFID technology has been successfully piloted by the healthcare community to manage resources, track patients, and reduce medication errors. As a result of our preliminary investigation into this novel area, we believe that RFID technology is the best choice to develop a solution for first responders. As a solution, we expect it to increase operational efficiency and improve response during an MCI.

Future plans: Based on the solution presented in this paper, we will conduct a detailed study to address the requirements and recommendations stated in "Proof of Concept for In-field Operational Management of CBRNE Casualties Project." We will also look at how RFID technology can be used to improve the effectiveness of first responders doing triage and treatment and transporting patients during MCIs.

Sommaire

RFID technology in healthcare and mass casualty incidents

Qinghan Xiao; DRDC Ottawa TM 2008-131; R & D pour la défense Canada – Ottawa; Juillet 2008.

Introduction ou contexte: En collaboration avec AMITA, RDDC Ottawa a travaillé au projet de « validation d'un concept pour la gestion opérationnelle des victimes d'un incident CBRNE (chimique, biologique, radiologique, nucléaire et à l'explosif) ». L'élaboration d'une méthode efficace de collecte et de diffusion des observations médicales lors d'incidents avec pertes massives (IPM) présente un défi de taille. L'identification par radiofréquence (IRF), qui a connu du succès récemment grâce à l'amélioration des processus liés à la chaîne d'approvisionnement, est présentement envisagée par la collectivité des soins de santé pour améliorer la sécurité des patients et les processus administratifs. Plusieurs organisations médicales ont commencé à mettre de l'avant des projets pilotes d'IRF, notamment le suivi des éléments d'actif, la gestion de l'équipement, la vérification des patients, la compatibilité des types sanguins et la prévention en matière de contrefaçon des médicaments. Fondé sur la révision de la technologie IRF et sur les applications IRF dans le domaine des soins de santé, un scénario visant l'utilisation de l'IRF dans le cas d'incidents avec pertes massives (IPM) est présenté. Nous croyons que l'IRF est une technologie prometteuse pour les activités quotidiennes de soins de santé et les opérations liées aux incidents CBRNE avec pertes massives.

Résultats: Notre étude révèle que la technologie IRF peut être utilisée pour le suivi et la vérification des patients, de l'équipement, des médicaments et des échantillons, et donc, pour traiter efficacement l'ensemble des questions liées à la gestion des ressources et à la sécurité des patients. Un scénario utilise l'IRF pour le tri des victimes d'incidents avec pertes massives, pour leur suivi à partir du lieu de l'incident jusqu'aux hôpitaux de secteur et pour enregistrer rapidement leur dossier (blessures et traitements) dans le système d'information de l'hôpital. Non seulement la technologie IRF aide les premiers répondants à classifier et à transporter les victimes efficacement, mais aussi la méthode proposée permet aux membres de la famille de trouver rapidement à quel hôpital le parent blessé a été envoyé.

Importance: La sécurité des patients est un sujet largement discuté. D'après une étude, « le système de santé constitue la troisième principale cause de décès en Amérique, après les maladies cardiaques et le cancer » [1]. La technologie IRF a été pilotée avec succès par la collectivité de la santé, de manière à gérer les ressources, suivre les patients et réduire les erreurs liées aux médicaments. Nous croyons, à la suite de notre enquête préliminaire dans ce nouveau domaine, que la technologie IRF est la meilleure pour élaborer une solution à l'intention des premiers répondants. Nous nous attendons à ce qu'elle augmente l'efficacité opérationnelle et améliore les interventions lors d'incidents avec pertes massives (IPM).

Perspectives: À partir de la solution présentée dans ce document, nous effectuerons une étude détaillée des exigences et recommandations formulées dans le projet de « validation d'un concept pour la gestion opérationnelle des victimes d'un incident CBRNE ». Nous analyserons également comment la technologie IRF peut améliorer l'efficacité des premiers répondants pour le tri, le traitement et le transport des patients lors d'un IPM.

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Acknowledgements

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1 Introduction

In recent years, more and more hospitals and healthcare facilities are using RFID technology to improve their ability to accurately identify hospital staff and patients, track medical equipment, and manage blood products. The problem caused by patient misidentification is a critical challenge in healthcare, which is illustrated in the following quotes:

> *A young lady in her late twenties was going to surgery the next morning. She was on nothing by mouth. Due to error of misidentification, a tray was inadvertently given to the patient on the morning of surgery. Perhaps the patient thought it was okay, so she ate her food and said nothing. Later that morning, she was taken to surgery. During the procedure, she threw up and aspirated her vomits. She had a cardiac arrest and was later revived. It was too late because the sensory nerve damage had occurred. She sustained brain damage and became paralysed. The hospital took good care of her for a couple of years as part of the settlement. One day she was left unattended in the x-ray department while waiting for a procedure, and she was later found dead. Correct identification before issuing a food tray to the patient going to surgery could have prevented the tragedy [2].*

> *The risk of an adverse outcome from an erroneous transfusion is estimated to exceed the risk of acquiring infectious disease such as hepatitis or HIV by transfusion. Erroneous blood administration reportedly occurs in approximately 1 in every 12,000 units; the risk of fatal acute haemolytic transfusion reaction (AHTR) is around 1 in every 600,000 to 800,000 transfusions [3].*

> *Large hospitals lose hundreds of thousands of dollars worth of equipment each year and spend countless hours searching for patient care assets. This includes medical devices (such as infusion pumps, portable x-ray machines and patient monitoring devices), as well as other mobile assets such as wheelchairs, computers on wheels, stretchers and gurneys [4].*

All these problems can be resolved, in theory, by the application of RFID technology. The objective of this paper is to address the competing interests and concerns of using emerging technologies to improve patient safety, enhance information and product security, and reduce the costs in healthcare and life sciences.

The paper is organized in the following manner. First, a technology overview is presented that discusses RFID system components and frequency bands and makes a comparison between RFID and bar code technologies. Then, the paper looks at RFID applications in healthcare and life sciences, such as people and asset tracking, error reduction at point of care, and drug counterfeit prevention. Next, a scenario using RFIDs during a mass casualty incident is presented. Finally, the major benefits of implementing RFID technology are summarized:

- Increase patient safety
- Improve overall resource management
- Track the patients, assets, and patient samples in real time

- Enhance physical and logical security and patient privacy

From patient wristbands to tracking pharmaceutical inventories, RFID technology offers tremendous potential to improve patient safety, asset visibility, information security and operating efficiency for both healthcare organizations and first responders.

2 Technology Overview

RFID is an advanced automatic identification method that uses radio waves to detect, track, identify, and thus allow for the management of a variety of items. A typical RFID system contains one or more RFID tags, a reader, and a back-end sever [5, 6].

2.1 RFID Tags

RFID tags, also called transponders, can be categorized into two groups: active or passive. An active tag is powered by a battery inside the tag that assists in the transmission of the data on the chip to a reader which may be up to 100 feet away. A passive tag is actually powered by the RFID reader. When the tag comes within range of the reader, the reader's interrogation "wakes up" the tag, giving it enough power to transmit a response. Figure 1 shows a passive RFID tag architecture consisting of three parts:

1. The RFID chip contains memory to store information about the object to which the tag is attached, such as a medical device or hospital equipment.

2. The antenna consists of traces made of copper, aluminum or conductive ink (on paper). It allows the chip to both receive power from and transmit information to a reader using radio waves.

3. The packaging (or label) encloses the chip and antenna so the tag can be physically attached to the object.

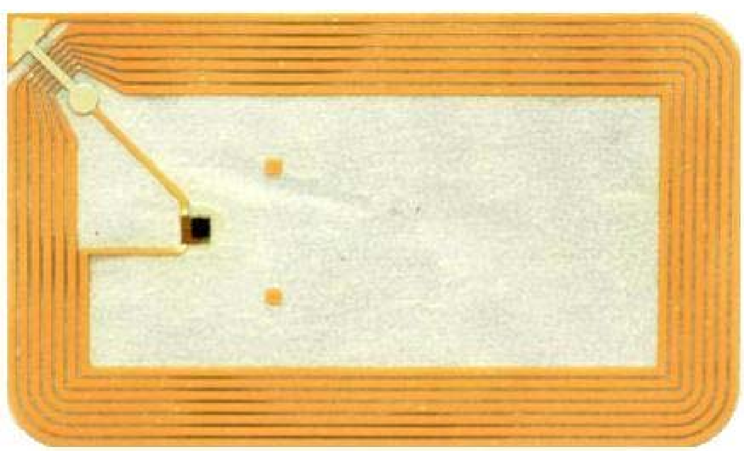

Figure 1: RFID tag architecture.

Unlike the other industries that handle goods, healthcare services face unique challenges in that they deal with people. Most of the manufacturing or retailing businesses use passive RFID technology while healthcare industry uses the more expensive active RFID tags to keep track of patients, staff and expensive equipment. To successfully implement RFID technology, it is necessary to understand the major differences between passive and active RFID tags (Table 1).

Table 1: RFID tags: Active vs. passive.

	Active RFID	**Passive RFID**
Tag battery	Yes	No
Tag power source	Internal to tag	Powered by reader via RF
Availability of tag power	Continuous	Only within field of reader
Required signal strength to tag	Low	High
Communication	Long range (100m or more)	Shot range (5m or less)
Sensor capability	Continuously monitor and record sensor input with date/time stamp	Read & transfer sensor data only when tag is powered by reader without date/time stamp
Data storage	Large (128 Kb or larger)	Small (typically 128 bits)
Life	Limited by battery	Unlimited
Cost	Expensive (around 15 dollars)	Inexpensive (5 to 25 cents)

Note that even though there are some universal readers, in general, active RFID tags designed by one company cannot be read by the readers made by another company or by readers running on different frequencies.

2.2 RFID Readers

RFID readers, also known as interrogators, are composed of an antenna used to communicate with tags and power passive tags via RF communication; an electronics module used to connect the reader to the host computer; and a control unit used to interact with the tag using the communications protocol and decode the data from the tag [7]. Readers can host internal or external antennas. With external antenna ports, readers can support two, four or six external antennas to meet the requirements to verify, inventory, monitor, and control a large number of valuable items located in one position or moving on a conveyor at high speed [8]. The readers can either be portable handheld units or fixed devices that can interrogate RFID tags within their read range to carry out the following tasks:

- Emit RF signals to and receive radio waves from the tag via an antenna or antennas
- Encode the data signals going to the tag, and decode the data received from the tag
- Convert the radio waves into digital information
- Perform anti-collision and error correction techniques, as well as security functions such as encryption/decryption and authentication
- Interact with the connected backend system

Figure 2 shows some examples of handheld and fixed RFID readers.

Figure 2: Various RFID readers.

2.3 Backend System

A backend system, sometimes referred to as the online database, is needed to collect, filter, and process the data. A backend database stores records of product information, tracking logs, or key management information associated with the RFID tags. It is critical for an RFID application to perform data collection, data management, and data analysis accurately and efficiently.

2.4 RFID Frequency Bands

Currently, RFID systems use a wide range of operating frequencies from low frequency to microwave frequency. The four primary radio frequency bands are low frequency (LF), high frequency (HF), ultra-high frequency (UHF), and microwave frequency (MW) [9]. Frequency is of primary importance when determining data transfer rates. In general, the higher the frequency, the higher the data transfer rate and the more expensive the system. The frequency bands' characteristics and application areas are illustrated in the following sub-sections.

2.4.1 Low frequency

This type of tag first came into use in the early 1980's is in a long waveband of 125 to 135 kHz. The advantages and limitations of RFID within this frequency band are as follows:

- Excellent for use in most manufacturing environments
- Works well around metal
- Not influenced by liquids and is resistant to rain
- Large memory chips and FRAM (Ferroelectric Random Access Memory) available
- Short effective distance
- Slow communications speed
- Reasonable cost

Typical applications include:

- Factory automation
- Automobile immobilizers
- Chip keys
- Portable database applications

2.4.2 High frequency

The popularity of high frequency tags is mainly due to their low cost, fast communications speed and large data storage. This waveband resists water, dust, and other environmental factors and has the following characteristics:

- Good for use in most manufacturing environments
- Standardized in all countries
- Works around metal
- Not influenced by liquids
- Large memory chips
- Short effective distance
- Low cost

Typical application areas include:

- Factory automation
- Access control
- Portable database applications
- Preferred frequency for pharmaceutical manufacturers and logistics

2.4.3 Ultra-high frequency

Ultrahigh-frequency tags operate around 865-868 MHz in Europe and 902-928 MHz in the US and can be read at longer distances than high-frequency tags with faster communication speeds; hence, the UHF band is emerging as the preferred band for supply chain applications. UHF tags are susceptible to interference from moisture, metal, and other environmental conditions. Therefore, systems must be configured according to the installation environment. The major advantages and limitations are as follows:

- Near field UHF system provides the same tolerance of water and metal as an HF system
- Long read range and high reading speed
- Questionable for use in many manufacturing environments
- Not a standardized frequency for all countries
- Strong material influence

The tags in this frequency band are typically used in the following areas:

- Cordless phones
- UHF tags for logistics applications

2.4.4 Microwave frequency

The 2.45 GHz waveband uses the same frequency band as microwave ovens and wireless LANs (802.11b/g). RFID systems operating at 2.45 GHz are characterised by directional reading, long reading range, high passage speed, good immunity to electromagnetic interference (EMI), and very high tolerance to dirt [10]. The advantages and limitations of RFID within this frequency band include:

- Suitable for all manufacturing environments
- Standardized frequency for all countries
- Not influenced by surface material
- More expensive than low frequency RFIDs (125 kHz and 13.56 MHz)

Their typical applications are:

- Factory automation
- Parking and access control
- Vehicle logistics (public transportation)

Table 2 summarizes characteristics of the different RFID frequency bands with their potential applications in healthcare service.

Table 2: RFID frequency bands and corresponding application areas.

	LF	HF	UHF	MW
Frequency	30-300 KHz	3-30 MHz	300-1000 MHz	2-30 GHz
Typical RFID Frequencies	125-134 KHz	13.56 MHz	433.92MHz (Active) 865-956 MHz	2.45 GHz 5.8 GHz
Read Range	0.5 m	up to 1.5m	433 MHz → up to 100m 865-956 MHz →0.5m to 5m	Passive ≈ 3 m Active ≈ 15m
Data Transfer Rate	Less than 1 kilobit per second (kbit/s)	≈ 25 kbit/s	433-956 MHz→30kbit/s 2.45 GHz →100 kbit/s	Up to →100 kbit/s
Common Applications	Access control, animal identification, inventory management, vehicle immobilizers	Smart cards, contact-less access and security, item level tracking, library books, airline baggage	Logistics case/pallet tracking, baggage handling	Railroad car monitoring, automated toll collection
Healthcare Applications	Medical wristbands, access control, inventory control, wake-up active RFID tags	Smart card, medical wristbands, access control, inventory control, item level tracking	Real-Time Locations Services (RTLS), asset tracking, infant / patient monitoring, sensors	RTLS, nurse call stations, utility monitoring

2.5 RFID Tags vs. Bar Code Labels

Barcode technology has been widely used in medicine and healthcare. The Health Industry Bar Code (HIBC) Standard, introduced in the USA in 1984, was designed for critical applications such as medical product identification and device tracking [11]. In general, bar code technology has the functions of tracking, inventory management, and validation, which can benefit healthcare service in the following areas:

- Improving patient registration and admission processes by use of bar codes on
  - patient forms and record
  - wristbands and labels

- Ensuring a higher level of patient safety by using bar code on
  - medical devices
  - medical/surgical supplies
  - test results and patient's drug history including allergies and side effects
  - identifying care givers, clinicians and patients
- Improving product supply logistics and material management process by using bar code for
  - receiving, shipping, and inventory control
  - tracking reusable equipment, product returns, and recalls
- Improving the accuracy of medication charge by use of bar code on supply items to capture charges

Experiments have shown that bar code technology can bring a significant improvement in quality of patient care, clinical efficiency, and cost reduction. A case study provided by McKesson Provider Technologies indicated [12] that

> *After a tragic medication mistake, Mary Lanning Memorial Hospital moved quickly to maximize the power of bar-code scanning and automation technologies to help prevent that type of error from occurring again. Now, with an integrated pharmacy system and "five rights" (right patient, right drug, right dose, right route and right time) bar-code checking, the provider has achieved an impressive 91% reduction in medication errors. The hospital has also reduced costs related to medication errors by 70%, improved medication charge accuracy by 86%, and won the 2006 VIP Award for medication management.*

RFID is similar in concept to bar code identification and is able to perform the functions that bar code can provide. Furthermore, RFID offers vast improvements over bar code technology with respect to line-of-sight, long-range, high-speed readability and rewriteability. Compared to bar code, RFID technology does not require a direct line of sight for reading; it can read multiple tags simultaneously at longer distances; and it eliminates the need for human intervention, saving time and improving accuracy. Even after having used bar code labels successfully, people are still interested in investigating whether RFID solutions could increase the efficiency and reliability of their current bar-code applications. It is reported by RF Design in 2004 [13] that

> *For more than two years, GUH's Outpatient Infusion Service has used a barcode solution as standard practice for double-checking and verifying blood transfusions. GUH is interested in learning whether RFID solutions can increase the efficiency and reliability of transfusion safety in instances where a barcode ID isn't as effective. For more than two years, GUH's Outpatient Infusion Service has used PDC bar code solutions as standard practice for double checking and verifying blood transfusions. Today, GUH is interested in learning whether RFID solutions can increase the efficiency and reliability of transfusion safety in instances where bar code ID isn't as effective.*

Bar code and RFID solutions in healthcare co-exist and both have their role to play. Since an RFID tag is more expensive than a bar code label, RFID technology will not completely replace bar code technology. It is hard to say, definitively, which technology is better because they each have a different set of attributes. Table 3 lists a brief comparison between barcode labels and RFID tags.

Table 3: Bar code labels vs. RFID tags.

Bar Code Labels	RFID Tags
Optical	Radio frequency
Data transfer requires line of sight and proper scanning angle	No line of sight required in any direction
Limited data with static information	High data capacity with changeable information
Can only indicate the type of object	Available to identify each individual item
Can be easily damaged causing no read	Contactless and highly durable
Low reading speed with manually scan	High reading speed with automatically detect
Must have minimum size and be visible	In the long-term, the tag will be invisible
Can only be read one-by-one	Simultaneous reading of many tags
Can easily be replicated	Secure data storage
Simply to apply with large installed base of readers	Complex to implement as a new system
Inexpensive	Expensive
No privacy issues	Issues around privacy of data

3 RFID in Healthcare

In recent years, a number of applications of RFID in healthcare have been tested, validated, and implemented. Interest in using RFIDs is driven by demands for patient safety and cost efficiency which result from being able to accurately locate and track both equipment and staff in a hospital. Typical applications include: identifying patients, managing medical devices, preventing theft, locating medical equipment, and tracing and authenticating nurses and physicians. Figure 3 illustrates typical RFID application in a hospital environment.

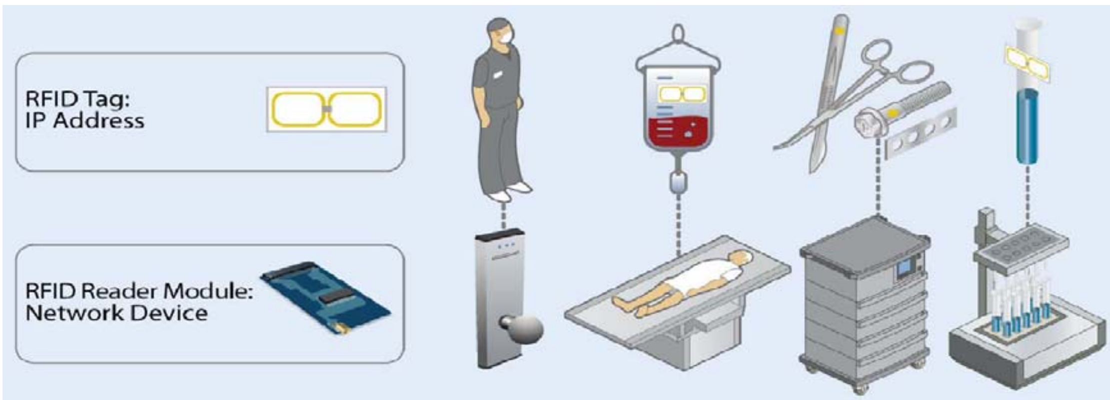

Figure 3: RFID applications in hospital [14].

3.1 Patient Identification and Care

Patient misidentification has been recognized as a root cause of many errors that occur in hospitals, such as medical errors, transfusion errors, testing errors, wrong person procedures. To address these problems, the primary RFID application in the healthcare system is the use of RFID badges and wristbands to identify patients, doctors, nurses, and visitors. In this section, we present a number of examples that demonstrate how implementation of RFID technology can dramatically reduce the risk to patients' safety.

In 2003, the U.S. Navy implemented RFID technology to more efficiently track the status and location of hundreds of wounded soldiers, refugees, prisoners of war, and others arriving for treatment at Fleet Hospital Three in Southern Iraq. The project is named as the Tactical Medical Coordination System (called TacMedCS) and it allows medical professionals to use RFID-enabled wristbands to identify patients, whose status, location and medical information can then be updated automatically on the system's electronic whiteboard (Figure 4). Not only does the electronic system help medical professionals simplify labour-intensive hospital administration, reduce errors, and provide better medical care, but it also allows the information to be transmitted to commanding officers to aid in battlefield planning. As a result, the TacMedCS has been able to provide more timely and efficient casualty tracking information and critical unit operational status as compared to existing methods [15].

Figure 4: RFID-enabled wristband [16].

On January 4, 2007, Precision Dynamics Corporation (PDC) and Hewlett-Packard (HP) announced the successful implementation of an RFID patient management system at Chang-Gung Memorial Hospital (CGMH)—part of a seven-facility, 8,800 bed health system in Taiwan—to enhance patient safety and streamline hospital procedures [17]. The system consists of PDC Smart Band® RFID Wristbands, HP RFID PDA readers, handheld readers, and printers. Since CGMH has 96 operating rooms (ORs), it implemented the RFID system in the ORs to "improve patient safety by verifying and positively identifying patients, gathering real-time data, reducing risk of wrong-site and/or wrong-patient surgery, and ensuring compliance with hospital patient safety procedures or standard operating procedures" [17]. The PDC Smart Band is a wristband with an embedded RFID tag that enables patient information to be stored and transferred to and from RFID readers, information systems, and medical devices. The wristband uses the passive 13.56 MHz (HF) read/writable RFID chip to store encrypted medical data including the patient's name, medical record number, sex, age, and doctor's name. For increased patient privacy, the patient information stored on the wristband is protected by the password and only authorized doctors and nurses can access the data. Not only does the RFID system automate many manual functions of the traditional OR processes, but it also helps verify that the five rights of medication safety are met: right patient, right medication, right dose, right time, and right route, as well as the added benefits of right surgery and right surgical site. Figure 5 illustrates the OR patient ID process at CGMH. It shows the areas in which RFID is used to verify data and procedures, as well as to record time-stamps. It is claimed that “Since the system implementation, CGMH has achieved 100% accuracy in patient identification in the OR—a major achievement in the advancement of patient safety” [18].

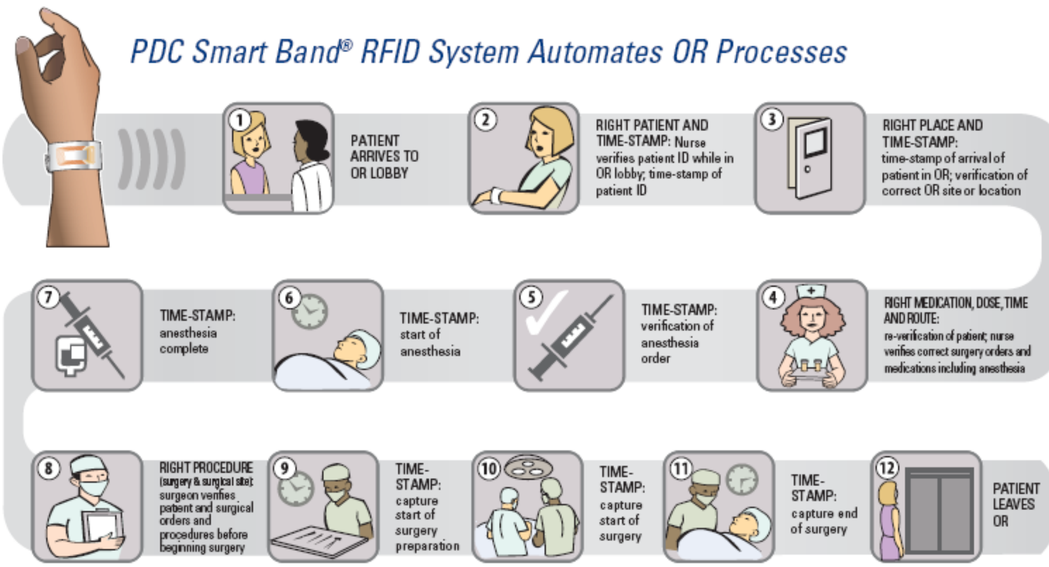

Figure 5: RFID based ID in OR in CGMH [18].

3.2 Medical Asset Tracking

3.2.1 Asset tracking and management

Healthcare facilities invest a lot of money in upgrading and maintaining expensive medical devices and many of them need to be shared across departments. It has been reported [19] that

> *Long before the recent mandates related to RFID in the supply chain, the problem of managing and tracking assets has plagued hospitals and healthcare facilities worldwide. Even the typical 200 bed facility has at least several thousand assets, ranging from IV pumps to wheel chairs that they must not only account for, but ensure their availability when needed to treat a patient …… RFID offers a solution to this problem. Utilizing active RFID, tags can be placed on those assets which are most valuable, whether due to cost or operational necessity.*

Not only does an RFID asset tracking system enable healthcare providers to solve the problems of lost, misplaced, and underutilized medical equipment, it also quickly provides the location of the highly mobile medical equipment, such as infusion pumps and wheelchairs. The implementation of RFID technology means that medical professional can get the required equipment fast, which is extremely important in an emergency situation with mass casualties. Delays in obtaining crucial medical equipment can obviously affect patient care and safety. It is reported in [20] that:

> *Equipment that is lost or stolen costs hospitals millions per year. Various sources report that hospitals lose between $4,000 and $5,000 per bed, per year in 'shrinkage.' Theft alone can cost a large hospital more than $1M per year. … Missing equipment wastes time; one source estimates that 30 minutes per employee, per shift is spent looking for lost equipment. Up to 40 percent of biomedical technician time may be spent searching for equipment to service. Staff members have reported having to spend more than 20 minutes looking for a wheelchair, while others hoard chairs in their department.*

A significant feature of RFID technology is that active tags can piggyback on Wireless Fidelity (Wi-Fi) networks. A hospital may easily use Wi-Fi-based RTLS to track the location of equipment if it already has a Wi-Fi network throughout the facility. AeroScout is the first provider to couple RFID with standard Wi-Fi networks to accurately locate and manage assets and people. Recently, it developed an enhanced version of Wi-Fi-enabled RFID real-time location system (RTLS).

Figure 6: RFID tagged hospital assets [21].

RFID asset tracking system provides a primary solution that tags equipment with a unique identification number (Figure 6). An RFID reader can transmit the equipment's location data to a backend server and display the data on a floor plan of the hospital. It can even display the history of locations where the equipment has been kept as well as identify the staff who handled the equipment. The management software can track valuable assets throughout a hospital in real-time, check for potential thefts, and schedule equipment maintenance and repair (Figure 7).

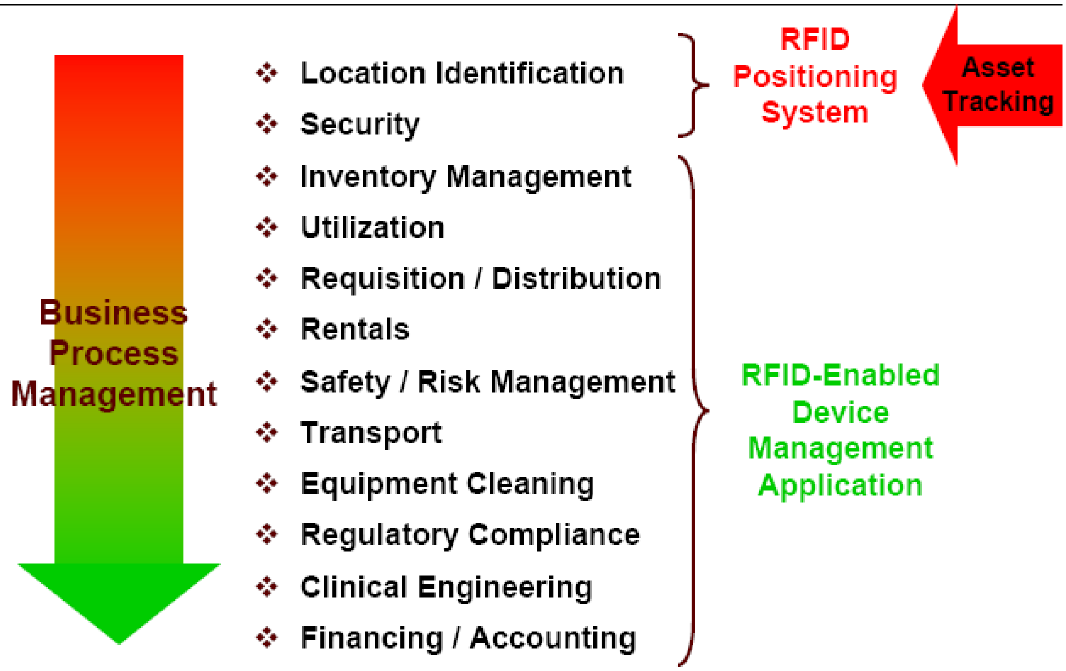

Figure 7: Asset management [22].

3.2.2 Surgical instrument tracking

The US Navy has developed an automated instrument tracking system to track thousands of items in its portable fleet hospitals and expeditionary medical units. Each of fleet hospital needs about 450 twenty-foot containers to store more than 10,000 unique items [23]. In 2004, the Navy Expeditionary Medical Support Command (NEMSCOM), in conjunction with the Navy AIT Project Office, began looking for a solution to improve readiness, increase inventory accuracy, boost speed of deployment, and enhance total asset visibility. NEMSCOM has evaluated the possibility of integrating Automatic Identification and Data Capture (AIDC) into medical logistics business processes, and adopted a combination of technologies ─ RFID, 2-D InfoDot barcodes, and contact memory buttons. An InfoDot label is laser-engraved with a two-dimensional Data Matrix ECC200 barcode. It can encode as much data as a traditional barcode while taking up only one-tenth the space, which makes the InfoDot an ideal identification solution for small-parts tracking. Figure 8 shows the InfoDot label with its applications in surgical instrument tracking. It has been reported that "the growing prominence of auto ID technologies in

US Navy field hospitals is key to improving the tracking and monitoring of critical medical assets" [24]. A significant return on investment has been achieved. The project "saved an estimated $1.2 million dollars during the first hospital rotation through better tracking" [23].

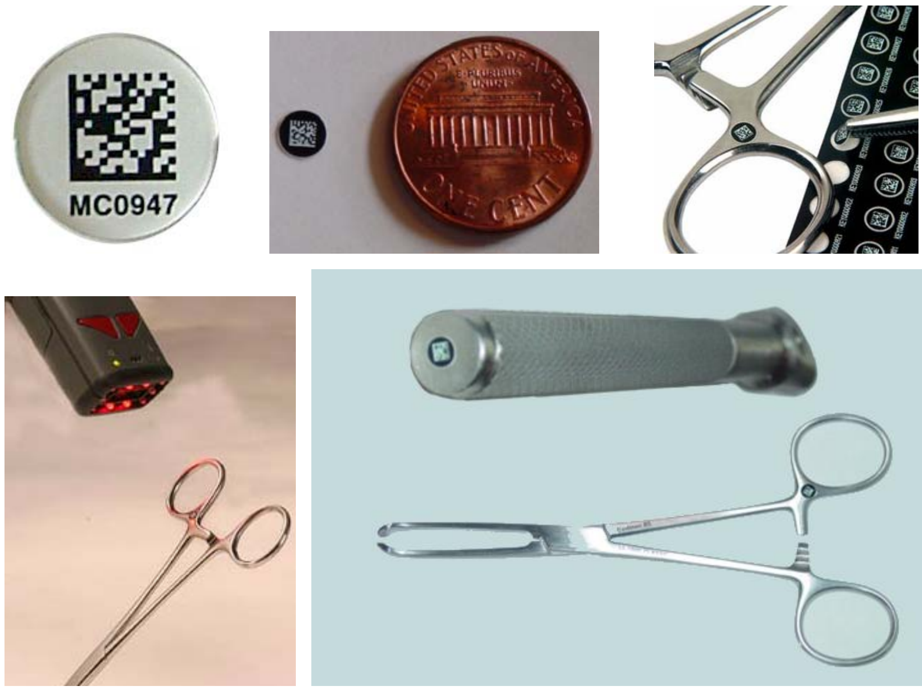

Figure 8: Info dot used in surgical instrument tracking [24].

3.3 Blood Product Management

3.3.1 Challenges

Apart from the equipments, RFID technology can be employed to track blood samples, maintain blood stocks, and reduce blood transfusion errors. The Boston Globe [25] reported that

> *A patient in Virginia switched beds to be near the window, then died after the hospital gave her a blood transfusion with her roommate's blood type. A Florida woman died after receiving the wrong blood because a technician mislabeled her blood sample. In St. Louis, a man underwent successful heart surgery only to die in recovery after staff mistook him for someone else and grabbed the wrong blood bag.*

Blood transfusion is a complex process in which a simple error could lead to death. Alfonso Gutierrez, UW-Madison's RFID lab director, cited a 2005 U.S. Department of Health and Human Services report of 1,322 national medical treatment centers that together reported more than 32,000 transfusion-related adverse reactions in 2004 [26]. Mistransfusion, the transfusion of blood to the wrong patient, occurs with one in 19,000 units [27]. The risk of death by fatal acute haemolytic transfusion reaction is 1 in 600,000 [28] to 800,000 [27] transfusions.

3.3.2 Bar code on the blood bag

Currently, blood centres in developed countries typically use bar codes to track blood products. For example, John Radcliffe Hospital in Oxford, UK decided to trial the Neoteric BloodTrack system to evaluate the potential role that bar code technology could have in increasing transfusion safety in 2000. Bedside systems were used for process controls to identify the patient by reading the bar code on the wristband. The system ensures that the blood sample taken for cross-matching is correctly labeled and the right blood unit is given to the right patient to improve patient safety at the point of transfusion (Figure 9).

Figure 9: Matching bar code to ensure the right blood unit is given to the right patient [29].

3.3.3 RFID tag on blood bag

Unfortunately, barcodes require a direct line of sight to be scanned and can only store a limited amount of information. As mentioned in Section 2.5, GUH in Washington DC has been using RFID to check and verify blood transfusions [13]. “Bar-code identification solutions are very valuable to institutions like GUH,” explains Dr S. Gerald Sandler, Director of Transfusion Medicine. “However, RFID technology offers the promise of improving the efficiency and reliability of conventional double checks for matching blood transfusions with the correct patient”. A reason of using RFID is because “Barcodes are unsuitable for bedside checks because they require line-of-sight so that a handheld laser can read a flat surface with the code. This constraint represents an important practical obstacle, especially in operating rooms where the patient is covered with surgical drapes” [30].

Figure 10: RFID tagged blood bag [31].

The use of RFID tags has been proposed to track and trace blood products. Hospitals in several countries have already started pilot projects with RFID-tagged blood bags. A blood bag embedded with an RFID tag contains a unique identification number that is used to query a database and information on the contained blood type. The identification number is linked with a secure database with details about the blood's origin, its designated purpose and, once dispensed, its recipient. Figure 10 shows an example of RFID-enabled blood bags. During administration, an RFID wristband will be assigned to a patient with his or her name, ID, and blood type, etc. When scanned, the wristband can identify the patient and help provide details of his or her medical history, treatment to date, and blood type. The data from the patient's wristband and the blood bag must match in respect of blood type, blood sugar level, present condition etc., before the transfusion can proceed [3]. In addition, the RFID–tagged blood bag, when read, will alert the medical staff if it doesn't match the patient's blood type (Figure 11). With this solution, the risk of patients receiving the wrong type of blood can be reduced, and the process of blood inventory management becomes easier and less time-consuming.

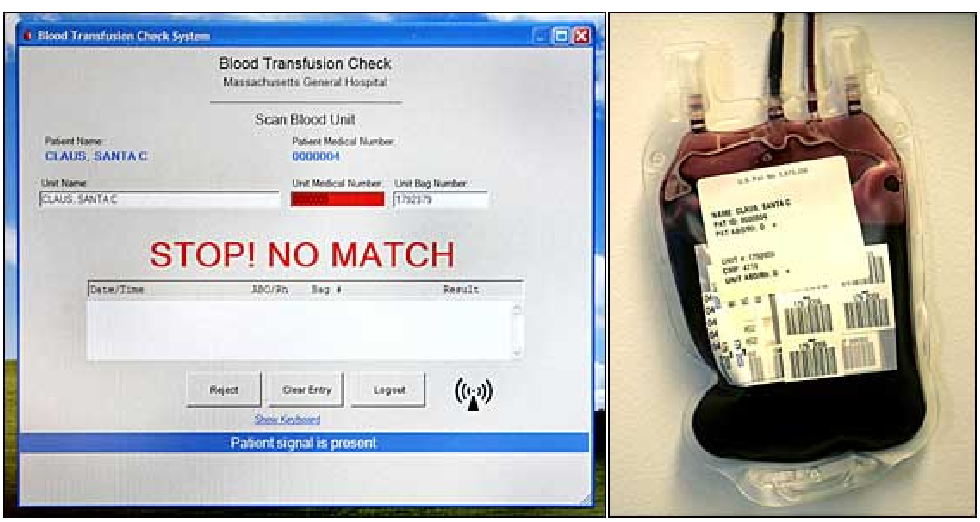

Figure 11: Blood automated verification/matching [25].

3.3.4 Blood temperature monitoring

Blood products are temperature sensitive and must remain in a certain temperature range at all times. Red blood cells last only six weeks under constant refrigeration and shipment at 1°C to 10°C; the shelf-life of platelets is about 5 days if maintained at 20°C to 24°C [32]; and blood products become useless if they are not stored within strict temperature parameters (between 2°C to 6°C) [33].

Considering productivity, quality, and safety issues, Rodeina Davis, Vice President-CIO of the Blood Center of Wisconsin, indicated that "RFID might be helpful in tracking the time and temperature of blood bags starting from the time of donation and proceeding through manufacturing, testing, labeling, and shipping to hospitals" [34]. RFID tags combined with sensors have been developed to collect environmental parameters, such as temperature, humidity, moisture, light, and vibration, or system runtime parameters, such as speed, and GPS location. The RFID in Healthcare Project Web site discussed the benefits of attaching temperature-sensitive RFID tags to blood bags [35]:

> *European legislation requires blood and blood components to be traceable from donor to recipient and vice versa. The use of temperature-sensitive RFID tags offered a solution here: The tags can easily be attached to blood bags and can easily be read. The use of active RFID tags also contributed to patient safety by allowing the localization of a blood bag. This combination of active and temperature-sensitive tags allows continuous objective monitoring of the entire chain passed through by a product, from the transfusion lab right through to the administration to the patient or the return of the product to the transfusion lab. By following the use in the operating theatre or in intensive care the actual use of blood products was easily determined, improving the completeness and reliability of transfusion records.*

It is worth mentioning that Siemens in cooperation with several partners have developed an RFID-based solution for the comprehensive monitoring of blood donations [36]. The device is equipped with a temperature sensor that makes it possible to consistently monitor the temperatures to allow doctors and nurses to confirm that the blood has been stored properly (Figure 12). Donated blood needs to be processed into red blood cells, blood platelets, or plasma. As mentioned above, different temperature parameters are required with different blood products. RFID sensor tags can monitor the temperature in real-time at each step: donation, processing, testing, distribution, storage and transfusion. The RFID chips on blood bags need to withstand extreme stresses.

Figure 12: Temperature monitor [36].

3.4 Counterfeiting

The pharmaceutical industry, one of the world's largest manufacturing industries, produces drugs for the care of both humans and animals. The industry's major activity is the manufacturing and distribution of pharmaceutical products to the public. Currently, pharmaceutical manufactures use bar code technology as a means to improve medication safety. However, Vivek Khandelwal, principal RFID solutions manager for Sun's RFID Business Unit, pointed out that "For the pharmaceutical industry, using bar codes to secure the drug supply chain is impractical and inefficient because bar codes have limitations around item level identification and require manual intervention" [37]. RFID technology has generated a lot of interest in the pharmaceutical industry for the following tasks:

- Ensure patient safety
  - Counterfeit protection
  - Drug pedigree and regulative compliance (FDA Guidelines)
- Improve supply chain efficiency
  - Prevent theft
  - Reduce inventory cost
  - Monitor drag storage environment
  - Track clinical trial and fast drug recall

Among these tasks, counterfeit protection is extremely important because the World Health Organization (WHO) estimates that 5-8 per cent of worldwide trade in pharmaceuticals is counterfeit [38]. A report by The Centre for Medicines in the Public Interest estimated counterfeit drug sales will grow 13 per cent a year to reach $75 billion in 2010, a 92 per cent increase from 2005. By using emerging RFID technology, pharmaceutical companies and distributors are able to deal with the multiple challenges of ensuring patient safety and streamlining business.

Figure 13: Pfizer using RFID to fight fake Viagra [39, 40].

In February 2004, the U.S. Food and Drug Administration (FDA) published a report “Combating counterfeit drugs” to encourage the pharmaceuticals using RFID to detect and tackle counterfeit drugs and gradually adopting RFID in drug supply chain at the item-level by 2007 [41, 42]. Since Viagra is one of the most counterfeited drugs on the market, Pfizer launched a project to secure the supply chain by tagging Viagra with RFID in January 2006. As each bottle of Viagra moves down the packaging line, a label with a passive HF tag is applied (Figure 13). According to the company, this pilot program enables Pfizer to track and trace the product from the manufacturing process to the supplier and even to the customer. “As of April 2006 only RFID tagged bottles of Viagra are available. Pharmacists and wholesalers use the RFID tags to authenticate the drug,” said Peggy Staver, Director of Trade Product Integrity of Pfizer [43].

RFID technology has been evaluated by the FDA as the most-promising track-and-trace technology to dealing with the drug-counterfeiting problem [21]:

> *We think that investments right now to speed the development of 21st century technologies like RFID that can reliably provide a drug pedigree that cannot be easily be faked and can do so at lower cost, is the right way to go to get to an effective, comprehensive system as quickly as possible.*

3.5 RFID Surgical Sponge

Based on a study at Stanford School of Medicine, a new type of RFID-tagged surgical sponge has been created to prevent inadvertently leave sponges and other materials inside of a surgery patient. According to Alex Macario, MD, MBA, professor of anesthesia who led the study, an estimated 1,500 objects, such as clamps, sponges, and other tools (Figure 14), are left inside patients after surgery in the U.S. each year, while “two-thirds of all objects left in the body cavity are sponges” [44].

Figure 14: An example of medical supplies found inside surgery patients [45].

According to another study in Massachusetts, “foreign objects were left in the body in one out of every 10,000 surgeries. Those objects resulted in 57 deaths in 2000” [46]. Here, we look at two examples: “A Baltimore woman is suing Baltimore's Sinai Hospital because she said a doctor left sponges, gauze and plastic material in her abdomen after surgery six years ago. LaShawn McClary is seeking $5 million in damages from Sinai, Owings Mill's Femi-Care Surgical Center and Doctor Sheo Sharma” [47]; and “Admitted to a Macon, Ga., hospital in 2004 for surgery for diverticulitis of the colon, Lucille Davis, then 67, left with an undetected and dangerous souvenir: a surgical sponge. Last month the error resulted in a $10 million settlement” [48]. For comparison, a cost-benefit study found that the RFID sponges cost $71.06 while standard sponges cost $68.24 per surgical case respectively [49]. The RFID chip embedded in the sponge has reduced from the size of a nickel in the Stanford test to approximately the size of a penny (Figure 15).

Figure 15: An RFID tag is the size of a penny [50].

A hand-held wand scanner has been developed to detect RFID-tagged surgical sponges (Figure 16). With the wave of the wand pass over the patient, doctors or nurses could detect the existence of sponges that should not be in the body of the patient.

Figure 16: Wand scanner (left) and RFID-tagged sponges [51].

4 RFIDs in A Mass Casualty Incident (MCI)

Beyond the medical applications, RFID technology can be used to track people during critical events such as terrorist attacks, mass casualty incidents, natural disasters, and day-to-day accidents. Mass casualty incidents require rapid and efficient triage, location, treatment and transportation of victims from the scene to area hospitals and are a significant challenge to first responders, such as firefighters, police, and emergency medical technicians. Currently first responder communities rely on paper triage tags, clipboards of notes, and voice communications to share information during mass casualty incidents. Most often, they mark the patient's triage status and record limited information on injuries and treatments administered in the field. This workflow has proven to be successful, but labor intensive, time consuming, and prone to human error [52]. The failure to adequately track the victims of Hurricane Katrina has revealed a major weakness in current national and local disaster preparedness plans. It made governments and private industries aware that existing paper-based tracking systems are incapable of managing information during a large-scale disaster [53]. In response to this challenge, RFID technology has been used in the development of next generation triage system to improve the effectiveness of emergency response. Figure 17 presents a scenario that uses RFID technology in a MCI event resulting from a CBRNE attack, natural disaster, or industrial accident. The event could involve hundreds or thousands victims in various conditions from the walking-wounded to deceased. Different from current applications, RFID tags are used in this scenario as triage tags to overcome limitations of the paper triage tags.

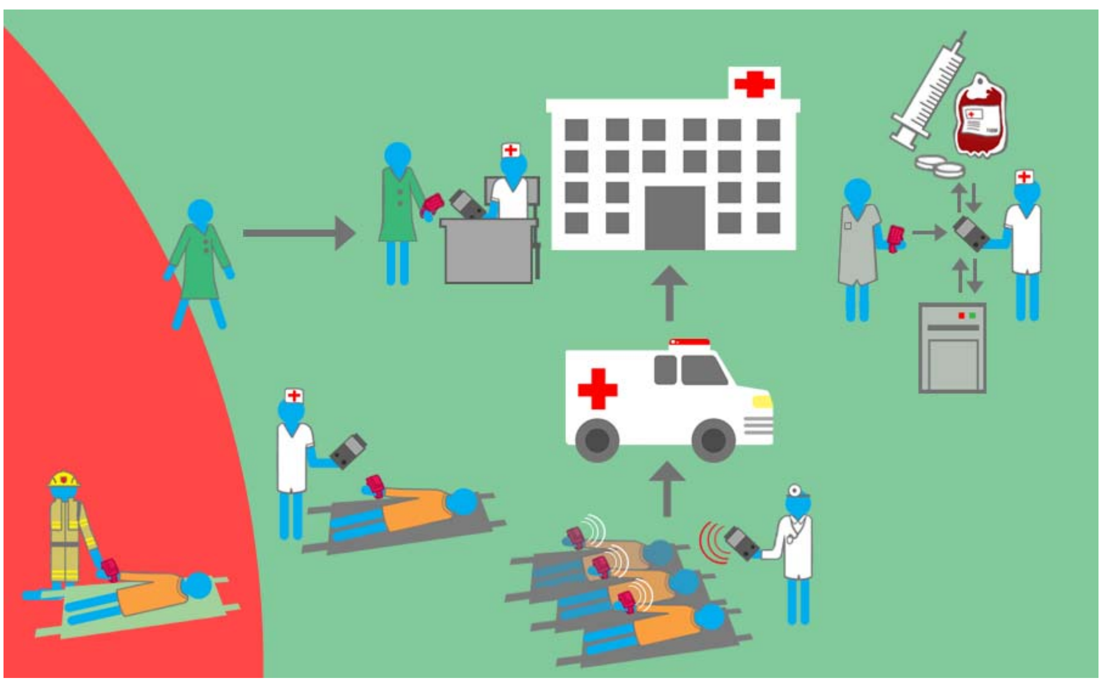

Figure 17: Scenario of using RFID in mass casualty incident.

The procedures in a situation where there are disaster victims are as follows:

- First responders attach RFID wristbands to each victim on the dirty side of the scene.
- After the victims are moved to the clean side of the scene, medical personnel will input relevant information about the patients' names, injury, status, and care provided in the field into the RFID wristbands.
- When the ambulances come to the assigned triage areas to transport the victims to the region's various hospitals, medical personnel use the RFID reader to pick up patients according to their priority.
- At the command post, incident command personnel can immediately obtain a complete view about the patients and their needs saved on an RFID backend server.
- In the ambulances, paramedics enter the care they are providing into the triage wristband.
- At the hospital, when administrative nurses scan the triage wristbands, the arriving victims' information is recorded and the victims are automatically registered into a centralized database.
- For 'walk-in' victims, administrative nurses tag them with RFID wristbands and input corresponding information, especially decontamination requirements.
- Searching the database, medical personnel can obtain a complete picture of all the patients, such as number of patients and their ages, degree of distress, and the care and treatment provided.
- Additional data, such as the treatments, test results and blood type, can be written into the RFID wristband for long-term care and risk assessment.

The above solution triages every casualty with a RFID wristband, properly tracks them from the incident to the end destination of area hospitals, and rapidly establishes their injury and treatment file within the hospital information system. Not only will it help the first responders to classify and transport the victims effectively, but the proposed method also makes family members able to quickly know to which hospital their injured relative was sent.

5 Conclusion

The healthcare community is always investing in new technology to improve patient care service, reduce human errors, and increase service efficiency. Since it has been successfully implemented by manufacturing, transportation, retail and other industries to track and verify items, the healthcare community has been seriously considering in recent years the use of RFID technology to enhance patient safety and improve business processes. The IDTechEx published a report entitled "RFID for Healthcare and Pharmaceuticals 2008-2018" in January 2008. According to the statistics of 2000 cases of RFID in action, the distribution of RFID applications in healthcare is shown in Table 4.

Table 4: RFID application distribution in healthcare [54].

Application	Number of case studies as a percentage of all RFID applications	Comment
People tagging	26%	Mainly patients for error prevention followed by staff for location/ alarm
Assets	16%	Mainly fixed assets and valuable consumables for preventing theft and misplacement, and for rapid location
Pharmaceuticals	13%	Trials and one rollout in 2005 for anti-counterfeiting, and one large application and many trials for error prevention
Blood	4%	Error prevention mainly
Other	41%	Cards, key fobs, pendants and badges for secure access, health records and payment. Supply chain management e.g. pallets, cases and vehicles

The benefits of RFID technology in the healthcare sector can be summarized as follows:

- Medical equipment tracking and management
  - Reduced time to find assets

  - Increased utilization
  - Reduced lost
- Patient identification and tracking
  - Reduced human errors
  - Improved patient care service
  - Read data without requiring direct line of sight
- Blood product management
  - Increased safety
  - Speed of response to critical events
- Pharmaceutical applications
  - Counterfeit drugs
  - Ensured patient safety
  - Improved inventory management
  - Faster product recalls

In order to efficiently use information and automate information flows to support first responder practices, this paper studied the potential of using RFID technology in mass casualty incidents. Instead of manually updating files, a victim's injury records can be stored in an RFID wristband that accompanies him or her throughout triage and may be updated during the transportation. The tag allows nurses and doctors to spend more of their precious time on patient care instead of on paperwork. Not only will the proposed method increase the efficiency of mass casualty workflow, but it will also provide more accurate records by reducing errors. Moreover, it makes it possible that nurses and doctors view any patient's complete record whenever they are close to the patient.

A further study will be carried out to investigate the technical solutions to address the requirements and recommendations stated in "Proof of Concept for In-field Operational Management of CBRNE Casualties Project" so that we can develop a prototype that uses RFID technology to optimize the effectiveness of first responders' triage, treatment and transportation of MCI victims.

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List of symbols/abbreviations/acronyms/initialisms

AHTR	Acute Haemolytic Transfusion Reaction
AIDC	Automatic Identification and Data Capture
CGMH	Chang-Gung Memorial Hospital
CBRNE	Chemical, Biological, Radiological, Nuclear, Explosive
EMI	Electromagnetic Interference
EPC	Electronic Product Code
FDA	Food and Drug Administration
FRAM	Ferroelectric Random Access Memory
HIBC	Health Industry Bar Code
HF	High Frequency
LF	Low Frequency
MCI	Mass Casualty Incident
MW	Microwave Frequency
NEMSCOM	Navy Expeditionary Medical Support Command
OR	Operating Rooms
PDC	Precision Dynamics Corporation
RFID	Radio Frequency Identification
RTLS	Real-Time Locations Services
TacMedCS	Tactical Medical Coordination System
UHF	Ultra-High Frequency
Wi-Fi	Wireless Fidelity
WHO	World Health Organization

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Nowadays, more and more hospitals and healthcare facilities are considering the use of radio frequency identification (RFID) technology to improve the ability to accurately identify and track patients, hospital staff, medical equipment, patient samples, and blood products. A number of case studies have demonstrated that RFID technology not only makes treatment safer and more efficient, but also has the side benefits of preventing identity theft and reducing paper work to cut costs. In addition to implementations in hospitals, RFID technology can be used in incidents with mass casualties to improve the effectiveness of first responders doing triage and treatment and transporting patients to nearby hospitals. The benefits can be substantial in terms of the "seven rights": give the right medication to the right patient with the right dosage through the right route at the right time, and ensure that victims receive the right care at a mass casualty incident.

De nos jours, de plus en plus d'hôpitaux et d'installations de santé envisagent utiliser la technologie de l'identification par radiofréquence (IRF) pour améliorer leur capacité à identifier et à suivre avec précision les patients, le personnel hospitalier, l'équipement médical, les échantillons des patients et les produits sanguins. Un certains nombre d'études de cas ont démontré que la technologie IRF, non seulement rend les traitements plus sûrs et plus efficaces, mais aussi qu'elle permet de prévenir le vol d'identité et de réduire les écritures et les coûts. Outre sa mise en œuvre dans les hôpitaux, la technologie IRF peut servir lors d'incidents avec pertes massives (IPM) de manière à améliorer l'efficacité des premiers répondants pour le tri, le traitement et le transport des patients vers les hôpitaux avoisinants. Les avantages peuvent être importants si l'on tient compte des points suivants : donner le bon médicament au bon patient avec la bonne dose, en suivant le bon protocole au bon moment et en s'assurant que les victimes reçoivent les bons soins lors d'un incident avec pertes massives.

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RFID, Patient Safety, Asset Tracking, Patient Verification, Blood Product Management, Mass Casualty Incident

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