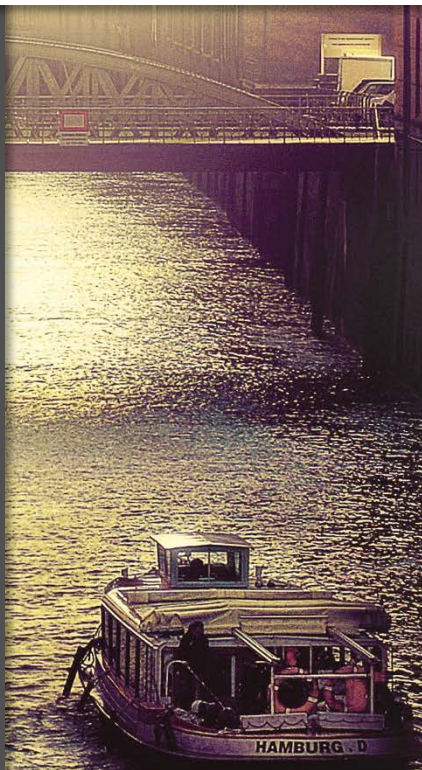


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Transforming Blood Supply Chain Management with Internet of Things Paradigm

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Internet of Things (IoT) paradigm has transformed the traditional healthcare system into the smart one. The IoT-based healthcare system is able to connect all available resources to operate healthcare services via the internet network. It would maximize the utilization of healthcare resources such as blood and blood products, which are scarce resources. Blood supply chain is a challenging system to manage, which researchers usually study for improved methodologies to boost its operation efficiency. Thus, this paper applied a content analysis in order to propose guidelines for enhancing and transforming the blood supply chain management based on the theoretical considerations in the IoT paradigm. The implementation strategies are provided to point out the issues that blood utilization and blood operational decision makings can be improved. Finally, the IoT-based framework of blood supply chain management is proposed to conceptualize the interactions between things, humans, processes, and service operations in the blood supply chain management.

Keywords: Blood Supply Chain; Internet of Things; Healthcare Services; Logistics Management

1 Introduction

Internet of Things (IoT) has been highlighted as a new intelligent tool for the ICT industry. IoT incorporates advance technologies that facilitate applications, devices, and objects to communicate among themselves through the connected networks (Tarouco et al., 2012). The IoT technologies mainly consist of information generation, collection and sharing as well as big data management and service application. Initially, the IoT has been used in the transportation tracking, information pricing of products, and map navigation. However, the advance technologies such as wireless, cloud based network, smart phones, wearable devices, and high speed connection have incorporated these IoT services into daily life activities. The IoT paradigm has applied multidiscipline knowledge and transformed the service platform to be more intelligent. It has become a useful tool in the market and its popularity has been on the rise after the introduction of many new concepts such as Smart City, Smart Home, and Smart Health (Kang et al., 2015). According to the health context, the IoT has been widely used in various healthcare services (Fernandez and Pallis, 2014). In the IoT-based healthcare, there are interactions between things (applications) and humans (practitioners and patients) in order to obtain real-time data and support decision-making activities for care deliveries and other associated services. Several works have been conducted with the use of IoT technologies to the healthcare domain including pervasive healthcare (Schreier, 2010; Doukas and Maglogiannis, 2010), and drug interaction checking (Jara et al., 2010). Many researchers have raised the issue of the IoT capabilities in healthcare systems in order to develop medical applications based on the IoT technologies (Bui and Zorzi, 2011). Moreover, the IoT would increase the utilization of resources in the healthcare environment, for example, managing limited resources for elderly care in the community more effectively (Feki et al., 2013; Li et al., 2011). The IoT-based healthcare system is able to connect to available resources in order to operate healthcare actions via the internet network. According to the benefits of the resource mobility, this IoT concept could also be applied to manage other resources in the healthcare domain such as specimen, vaccines, and blood products.

Blood is one of the most important resources in the healthcare system (Nagurney, Masoumi and Yu, 2012). Demand for blood usage caused by the illness of human is uncontrollable. Blood supply is also collected from human beings who have willingness to donate. Uncertainties in blood demand and supply are inevitable. Blood is perishable product, and its lifetime is within a short time period after collecting. The balance of blood demand and supply in the system has direct

impact on the survival of the patient. This makes the task of managing the blood supply chain to be a challenging one (Dobbin, Wilding and Cotton, 2009). Due to an increasing blood demand, new methods for improving blood supply chain management are necessary (Rytila and Spens, 2006). Consequently, the motivation of this paper is to incorporate the IoT paradigm in managing the blood supply chain in order to propose guidelines for elevating blood demand and supply fulfillment services.

2 IoT Applications in Healthcare Domain

The IoT-based applications in the healthcare domain can be classified into four main groups which are tracking, identification and authentication, automatic data collection, and sensing (Vilamovska et al., 2009).

2.1 Tracking

Tracking is to identify the flow of people or objects while transferring. The function involves the real-time tracking such as patient-flow monitoring, workflows in hospital departments, and tracking of motions through bottleneck points. Tracking is mostly applied to real-time inventory location tracing in order to maintain the available resources and usage monitoring. Particularly, it is used for materials tracking during operations, such as specimen and blood products.

2.2 Identification and Authentication

Mainly, this step assures accurate patient identification with matching medical record, proper treatment and medication in order to prevent any damage to any patient. Authentication is fundamental security protocol for medical practitioners to access patients' information. Moreover, the function is used as security protection to prevent the losses of medical resources.

2.3 Automatic Data Collection

Automatic data collection is functioned to collect data from various operational processes in order to minimize processing time, enhance automated process, improve care and procedure traceability, and heighten inventory management. This function is integrated with the radio-frequency identification (RFID) technology to collect comprehensive real-time health information of the patient with the medical applications through the connected networks.

2.4 Sensing

Sensors can be applied both for in-patient and out-patient care operations. Its functions have ability to drive the patient into the center of processes such as diagnosing conditions, providing patient health information, monitoring patient behaviors, and alerting patient drug prescriptions. Wireless access-based network systems can be used to reach the patient everywhere, with the support of bio-signal monitoring of wearable devices.

In the healthcare domain, the IoT-based applications consist of these four aforementioned main functions. This paper has incorporated this paradigm to propose the guidelines to improve performances in blood service operations.

3 Blood Supply Chain Management

Managing the blood supply chain is one of the challenging operations research problems in the supply chain literature (Pierskalla, 2005). Practically, blood service operations involve blood collection, processing, inventory management, distribution, blood-banking management, and transfusion. Blood Center collects whole blood from donors, processes it into blood products at a Regional Blood Center and distributes them to hospitals in the network in order to transfuse to the patient. The main objective is to maximize blood utilization by minimizing both blood shortage and outdate rates in the system. The diagram of blood supply chain processes is shown in Figure 1.

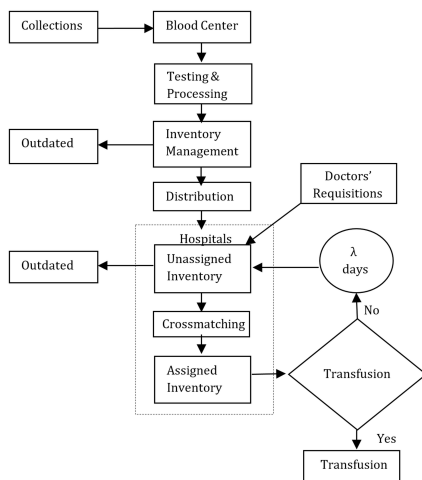


Figure 1: Blood supply chain diagram

3.1 Regional Blood Center

Regional Blood Center (RBC) has principal operations for blood collection, processing and testing, production, inventory management, and distribution to hospitals. Blood collection is to acquire the whole blood from donors, including donor recruitment and promotion. Collected whole blood units are tested in the laboratory for infectious agents and negative blood units. Then they will be processed into blood products and kept in the RBC storage facility. RBC is responsible for managing this inventory and allocating available blood units to hospitals according to requisitions from their local blood banks.

3.2 Hospital Blood Bank

Each hospital blood bank (HBB) has to manage blood inventory and its operations within the hospital. Doctors put requests for the certain amount and groups of blood products for patients' treatments. When available blood products are assigned for any patient, these units will be crossmatched to verify the compatibility with each particular patient. Crossmatched units will be stored in the assigned inventory and these units may not always be used because either doctors may postpone operations or there are blood units left after patients' treatments. These un-transfused units will be returned to the unassigned inventory if they do not expire. The period between blood crossmatching and releasing any unused units is called "a period for reserving blood". The longer this period is, the higher the probability that blood will expire before its actual use. Finally, the crossmatched units will be transfused to the patient for treatment.

4 Transforming Blood Supply Chain Management with IoT Paradigm

Blood supply chain is a challenging system to manage, which researchers usually study for improved methodologies to boost its operations. Most of the related works were involved with the use of operations research to study the associated problems in the context. There was also a literature review paper in the supply chain management of blood products (Beliën and Forcé, 2012) which presented

a structured review in different perspectives for managing blood service operations. However, this paper investigated a few number of papers related to the technological issues and it did not provide trends in the technology aspect.

Moreover, there are some works related to the study of using RFID in the blood operations for tracking (Dvais et al., 2009), inventory management (Xu, Lian and Yao, 2013), and quality and safety (Briggs et al., 2009; Hohberger et al., 2012). These previous works pointed out the benefits of using this technology in managing blood. According to the arising trends in technologies, it would be beneficial to consider the possible advantages from using the IoT paradigm in the blood supply chain management. Thus, this paper applied a content analysis method to review the related works as well as investigating the blood service organizations in order to identify the opportunities for enhancing the blood supply chain performance based on the theoretical considerations in the IoT paradigm.

In practical, there is an implementation of RFID for blood management in each blood bag labeled in order to prevent medical errors in blood transfusion. It also provides blood tracking to the origin and to ensure the quality of blood products during the storage and transportation. However, the capabilities of IoT-based applications can be extended by the implementation of the RFID and the other functions to enhance the blood service operations more efficiently. This paper provides conceptual guidelines in transforming blood service operations management to enhance blood utilization with the IoT-based applications paradigm.

4.1 Tracking

4.1.1 Inventory count and location tracking

There are two main blood inventory storages in the supply chain, RBC and HBBs. RBC has to operate its inventory in order to fulfill demands from the HBBs in its network. In practical, there is a collaboration system between the RBC and the HBBs that helps managing blood supply throughout the network. However, in some developing and underdeveloped countries, there are not any efficient systems to track down the blood units from the donors to the patient. This issue could lead to the shortage of blood units in some hospitals where their HBBs' systems do not connect to the system of the RBC and the systems of other hospitals in the network. Real-time inventory count would be applied to check the collaborative inventory in order to automated count the overall blood stock levels

in the HBBs. Hence, the RBC can obtain these counted blood stock data for future blood collection and replenishment planning. Moreover, the location tracking of each blood unit would enhance blood transshipment among the HBBs in case there are any blood emergency demand requests made from the HBBs and the RBC cannot supply enough blood units to respond to those requests.

4.1.2 Safety and traceability

The blood traceability system is an online platform which is connected into the RFID-blood bag and barcode. It is able to integrate the sharing information and coordination among blood service organizations in the supply chain in order to mitigate blood transfusion risks to the patient, such as human error, incorrect blood products, and errors in medication administration (Dzik, 2007).

4.2 Identification and Authentication

4.2.1 Auto ID/bar code enabled transfusion administration

The identity check between each patient and particular blood product is the crucial task to avoid mistake in the transfusion. The RFID-blood bags and the traceability system can ensure that the right blood type with the correct quantity is always delivered to the right patient when there is a request (Koshio and Akiyama, 2009). The right information and the right process of transfusion are to be secured for the safety of the patient by using auto ID at the transfusion. RFID is used to guarantee that the right process is conducted according to the medical standard of transfusion. In case there are any complications after blood transfusion, this function is able to trace back information to the donor of that particular blood unit/product. Hence, RFID and barcode have capabilities of improving patient safety through managing transfusion activities and traceability of blood products to authenticate the right process and information.

4.3 Automatic Data Collection

4.3.1 Blood inventory management

Blood inventory is a crucial task in the supply chain. The main objective is to maximize blood utilization in such a way that blood shortage and outdated rates are at minimum levels. Using RFID and barcode to connect each blood bag to the blood inventory system can lead to the ability to manage blood information more efficiently. Real-time data of blood stock levels throughout the network would support blood collection planning for the RBC. The actual demand visibility can enhance an effective blood component production planning at the RBC in order to satisfy demands at each HBB. The blood operational costs are reduced because the RBC does not have to supply very large amount of blood units. Consequently, the blood outdated rate is minimized. Furthermore, using RFID and barcode to connect among the HBBs in the network can enhance the blood transshipment between the hospitals more rapidly when there are emergency demands in any specific groups needed and the RBC cannot response to these events.

4.3.2 Blood tracking and tracing

According to the use of RFID and barcode in the blood data connection, their functions completely support the blood tracking and tracing for expiration dates, blood shortage, and blood restocking requests at the HBBs. This smart network is capable of storing records of the dates and times of the blood expiration data so the RBC has the ability to track down the amount of blood units that are soon to expire. This information is beneficial for the RBC to set its blood rotation policy in order to minimize the number of expired blood units. Moreover, real-time blood tracking and tracing system will help the RBC to replenish its own inventory and allocate blood products to the hospital blood banks according to the specific demand from each hospital more efficiently.

4.3.3 Logistics management

Logistics activities in the blood supply chain management include blood collection, blood processing, inventory management, distribution, blood-banking management, and transfusion. The decision-making done in each process has direct impact on the subsequent processes. RFID and barcode can transmit relevant

data within the blood operations management and they will provide real-time information for supporting various types of operational decisions in the blood service organizations. This function is also applicable to manage the stochastic data of blood demand and supply in order to reduce the uncertainties in the blood supply chain management.

4.4 Sensing

4.4.1 Transportation monitoring

Temperature control during transportation is vital for maintaining blood quality. Using sensing technology and real-time temperature tracking in blood transportation can ensure the quality of blood products. The sensing devices implemented for temperature tracking and measuring during the blood transportation could help ensuring the blood quality control during transportation in real-time. Moreover, the integration of the RFID system and the location tracking technology can provide information on the routes that tend to have oscillated temperature, which may be harmful to blood quality.

4.4.2 Patient monitoring

It is necessary for the medical practitioners to be alerted if the patient suffers any complication symptoms after receiving blood. A wearable bio-signal device that binds the patient to the system can be used to monitor and transmit data automatically back to the medical staff for any prompt treatments during postoperative blood transfusions.

In summary, blood service operations can be enhanced by using IoT-based applications. Tracking is used to operate the inventory counting and location tracking as well as to prevent the potential mistakes in blood transfusion. Identification and authentication function is integrated with the RFID technology in order to ensure the standard of the transfusion administration. Moreover, the IoT-based technologies allow the data collection to be conducted automatically, particularly the real-time blood inventory information at each storage location. Blood inventory tracking and tracing data in real-time could systematically enhance the collaboration processes between the RBC and the HBBs. Finally, sensing is aimed to improve the quality of the blood supply chain management by monitoring the

temperature and locations of the blood products during transportation as well as monitoring post-transfusion reactions of the patient. The conceptual guidelines of transforming blood supply chain management with the IoT-based applications can be summarized in Table 1.

Table 1: Transforming blood supply chain management with IoT paradigm

IoT Applications	Blood Service Operations	Utilization
Tracking	Inventory count Location tracking Safety and traceability	Shortage minimization Transshipment utilization Safety and quality issues
Identification and authentication	Auto ID/bar code enabled transfusion administration	Safety of patients
Automatic data collection	Inventory management Blood tracking and tracing Logistics management	Performance improving Outdated minimization Performance improving
Sensing	Transportation monitoring Patient monitoring	Quality of blood Safety of patients

5 Implementation Strategies

According to the aforementioned guidelines of transforming the blood supply chain management, this paper can briefly provide the implementation strategies in two issues, resource management and big data and knowledge management.

5.1 Resource Management to maximize blood utilization

Applying the IoT-based healthcare applications in the blood supply chain can enhance the performances in managing blood and blood products more systematically. The tracking function can maintain and control real-time blood stock levels in the hospitals, leading to the accurate blood collection planning. It allows the RBC to replenish the blood units and fulfill demands from the local blood banks more appropriately. This contributes to blood outdated rate reduction in the system. The connection of RFID and barcode can be used to manage the unused blood units in the hospitals by tracking down the remaining shelf-lives of blood units in the inventory. This could help reducing the number of blood shortage situations in the area. These proposed IoT-based applications could lead to more efficient blood rotation policy, where any unexpired blood units can be sent back to the RBC for further transshipping to the other hospitals. Moreover, it also yields the decreasing rate of blood expiration in the system.

5.2 Big Data and Knowledge Management to support decision makings in blood supply chain

Using automatic data collection and transferring enables the blood management system to store a large amount of useful data in the blood service organizations. In developed countries, a blood-banking system which links between blood centers and hospitals can be performed automatically to communicate or make decisions on blood service operations. However, in some countries where blood services still rely on personnel judgments, it is necessary to have information stored in the blood management system to use as a knowledge tool for supporting future decision-makings in any levels such as blood allocation policy, blood inventory management, and blood crossmatching policy. The extended network system is used to connect between blood service organizations and IoT-based blood service applications in order to enhance collaborative information sharing.

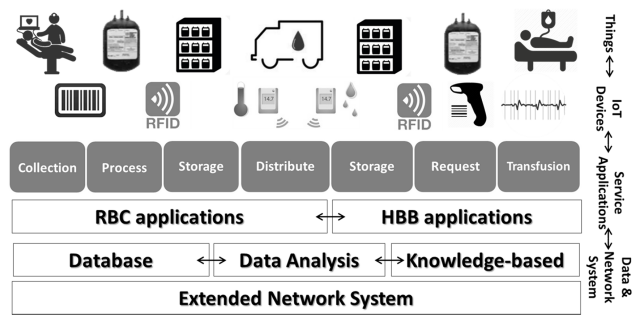


Figure 2: The IoT-based framework of the blood supply chain management

IoT-based technologies can be used to manage blood and blood products in order to minimize blood shortage and outdates rates. Blood service operations are systematically driven by the information together with the big data and knowledge management in order to support the operational decision makings in the blood supply chain management. The IoT-based framework of the blood supply chain management is presented in Figure 2.

6 Challenging Issues

The IoT-based blood supply chain management emphasizes the interactions between the blood service organizations. Blood service operations can be enhanced through the advantages of using these intelligent technologies which directly increase the blood utilization in the system. However, there are some challenging issues to take into consideration in order to transform the blood supply chain management with the IoT paradigm. These issues are briefly introduced as follows.

6.1 Barriers

Blood supply chain is a challenging system to manage. Its overall operations are complex which are associated with human, blood centers, hospitals, and patients. In theory, there are several studies that focused on the use of operations research in the blood operations problems. However, these works are too complex for application in the real context. Currently, there are advanced medical technologies that support various aspects of health services in order to improve the health outcomes of patients as well as enhance performances of care delivers, including Telemedicine, E-health, and IoT. Despite these benefits, Llewellyn et al. (2014) addressed barriers to the adoption and implementation of the advanced medical technologies. These barriers involve with the lack of encouragement from the Department of Health, change issues in new operational procedures, skills of practitioners, threats perception, leadership, infrastructure, project management, lack of knowledge toward new technologies, and costs. However, blood service operations depend largely on staff decisions which are also a main barrier in the adoption of the new advanced technologies in the healthcare context. In order to overcome these barriers, the empirical study on the advantages of the IoT application in the blood operations system is required to guarantee that such technologies are trustworthiness for investment in the real context.

6.2 Stakeholders' Complexities

Although the structures of the blood supply chain networks of different countries are not the same. But the main stakeholders commonly consist of regional blood center (RBC) and hospital blood banks (HBBs). Practically, the RBC is responsible for the blood collection, processing, production, and inventory management in order to allocate blood units to the HBBs. Each HBB has to manage its blood bank in order to provide blood units for the patients' treatments. The complexities among all stakeholders are involved with inter-organizational collaboration of the associated blood service operations from the human to the patient. The regulations and procedures in each stakeholder are different which make the IoT-based technologies difficult to implement in the entire system. System components, deployed technologies, and service applications should be well developed in order to connect among the stakeholders with the restrictions of privacy information in each organization.

Moreover, data sharing among the stakeholders is one of the most complexity issues in the blood supply chain system. In practical, the information systems among the stakeholders are not fully linked, because of the regulations and procedures in each organization. This problem causes the data transmission to be discontinuous among the networks. However, the HBBs have to provide actual demand data to the RBC so that the RBC in order to manage blood collection properly. The proposed IoT-based applications will allow the data transmission among the stakeholders to be real-time and more automatic. The visibility of blood information will reduce the uncertainty in blood service operations as well as improve blood management throughout the network.

The IoT-based applications can be applied to connect between the RBC and the HBBs for real-time data sharing in order to support the decision making in the blood service operations. Moreover, the IoT technologies can be used to manage blood inventory more systematically. The IoT-based system will automatically transmit the necessary information in order to mitigate the uncertainties in blood operations management as well. Thus, the consolidation of the blood service organizations is a key success towards the implementation of IoT-based applications in the blood supply chain management.

6.3 Architecture

The generic IoT-based system architecture consists of four layers which are sensing, network, service, and interface. There are brief details of its components to be addressed (Li, Xu and Zhao, 2015) as well as the issues in developing the architecture of the IoT-based applications in managing the blood supply chain. Sensing layer is able to track the environment and exchange information among devices by using tags or sensors. In the sensing layer, there are necessary issues to be concerned such as cost, size, resource, energy, deployment, heterogeneity, network communication, and protocol. Network layer is aimed to aggregate data from information technology infrastructures to transmit data in the environment. Also, there are primary issues to be addressed such as network management technologies, energy efficiency, quality of service, data and signal processing, and security. Moreover, all of the service activities are performed at the service layer such as information exchanging, data management, database, searching, and communication. There are main components to take into considerations, including service discovery and composition, trustworthiness management, and application programming interfaces. In interface layer, many devices are involved

in the IoT-based applications. The compatibility issue of the various things should be addressed for the connected interactions in the environment.

6.4 Standardization

Standardizations are primary key to the success in the implementation of the IoT-based technologies in the system, including the blood supply chain. The standardizations must deliver interoperability, compatibility, reliability, and effectiveness of the operations in the environment. The RBC and the HBBs have to closely collaborate in determining policies and system architecture, ensuring the privacy, acceptability, security of networks, and developing joint standards in the IoT-based blood supply chain management system.

6.5 Security and Privacy

The architecture of the IoT system has an impact on the security and privacy of the stakeholders. The security requirements in the IoT system are addressed (Fabian and Gunther, 2007), including resilience to attacks, data authentication, access control, and information privacy. Moreover, information privacy is one of the most sensitive topics in the IoT area. Privacy Enhancing Technologies have been developed to provide information privacy such as Virtual Private Networks, Transport Layer Security, and Domain Name System Security Extensions. Stakeholders should contain these security and privacy requirements in their implementation plans for managing the blood supply chain with the IoT-based technologies.

7 Conclusions

IoT-based healthcare applications paradigm consists of four main functions, tracking, identification and authentication, automatic data collection, and sensing. This study has incorporated the IoT paradigm to provide the guidelines to transform the blood supply chain management in order to improve blood service operations. Tracking is used to monitor blood inventory counting and storage location. Identification and authentication is the function aimed to ensure that the blood transfusion standard is followed. Automatic data collection is used as a mechanism to drive the information flows in blood logistics operations. The

use of sensing can improve the quality of blood during transportation as well as monitor the patient for irregularities during postoperative blood transfusion.

Furthermore, the implementation strategies are provided to point out the issues that blood utilization and blood operational decision makings can be improved. The IoT-based framework of the blood supply chain management is proposed to conceptualize the interactions between blood products, donors, patients, practitioners, processes, and service operation applications through the network connection. The challenging issues are discussed to provide further details in related aspects. The consolidation of the blood service organizations is a key success towards the implementation of IoT-based applications in the blood supply chain management in the real context.

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