The Internet of Things for Efficient Medical Logistics: A Best Practice Review

Gavin Bailey, Tom Cherrett and Ben Waterson
Transportation Research Group, University of Southampton.

Introduction

The purpose of this review is to explore how supply chain management, specifically within the NHS, can be improved through the use of emerging information and communications technologies (ICT). There are a range of technologies, such as Radio Frequency Identification (RFID) and barcodes, available to logistics providers which expedite the processing of inventory at key nodes along a supply chain. However, the evolution of 2-D coding and new applications of RFID and 'near field' technologies, pairing them with sensors and the Internet, is enabling such devices to communicate between one another at all times wherever they may be. This 'Internet of Things' is allowing for greater levels of visibility and automation within logistics, therefore increasing the potential efficiency of supply chains across all industries.

The NHS

The NHS is a public health service organisation required to deliver effective and cost efficient patient care to all residents of the United Kingdom. Procurement plays a vital role in supporting this goal through the NHS Supply Chain, which is intended to manage supply chain services such as: supplier management, inventory storage and distribution ranging from goods for theatre/ surgical services to capital equipment and catering.The NHS Supply Chain was formed from the NHS Logistics Authority and parts of the NHS Purchasing and Supply Agency (PASA). Its primary aim is to provide £1 billion of savings to the NHS by 2016.The service is operated by DHL, a third-party logistics provider (3PL) on behalf of the NHS Business Services Authority, orders and invoices are processed by electronic transaction 24-hours a day, 7-days a week, with goods distributed from seven centres to 7,500 delivery points nationwide (NHS 2010). This enables a bypass of the competitive tendering system which requires all public contracts to be advertised through the Official Journal of the European Union (OJEU), as a result of outsourcing agreements with DHL. Currently the contract saves on average 10% in suppliers' operating costs, some of which are theoretically passed on through the inventory supplied to the NHS (NHS 2010). Although the NHS Supply Chain has been a success due to a number of interlinking mechanisms/ processes within the supply chain which act to make the chain more efficient. There remain a significant number of improvements to be made as a large proportion of inventory across all hospital departments continues to be sourced directly from numerous suppliers.

A survey conducted on Great Ormond Street Hospital in London, by Steer Davis Gleave (SGD) on behalf of Transport for London, revealed that over a five-day period between the hours of 05:00 and 17:00 there are 366 deliveries made by 219 separate vehicles,operated by 145 suppliers in total (SDG 2010). Such statistics indicate that there is much to be done with regards to the consolidation of consignments in and out of the hospital. However, in order for greater levels of consolidation to occur, there needs to be increased visibility of inventory delivered to and stored within the hospital. There is a significant amount of literature to suggest that new ICT concepts such as pervasive computing and the Internet of Things can help optimise logistics processes and techniques within the NHS.

The Internet of Things (IoT)

The initial concept of the IoT was developed after Mark Weiser (1991) wrote about the potential role that ubiquitous/ pervasive computing had to play in future ICT applications, stating, "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." [pp.3]Twenty years on from this initial notion, the IoT is fast becoming a reality. The current overarching concept for the IoT is the pairing of ordinary everyday objects with the Internet to create a global network of sensors, such as RFID tags and Smart Dust (micro- and nano-scopic sensors), with the potential to sense/ detect the surrounding environment and communicate and react with other sensors, actuators and devices in any location, to the extent that "everything is alive" (Thompson 2004).

Pervasive Computing
The Internet of Things is closely related to a rising concept known as 'Pervasive Computing'. This pertains to the application of wirelessly linked devices within the living environment connected to sensors which can detect ones electronic needs. For example, if an individual was working on a presentation scheduled in their calendar for 15 minutes time, intelligent software and ICT devices could load the presentation and all related documents onto a portable computing device, having anticipated the user's needs from the schedule, and key words relating the documents to the information from the appointment e.g. project Aura (Garlan *et al.* 2002). Such technology is being tested and implemented along with IoT applications and devices in an attempt to optimise the efficiency of processes within business/ organisations, as well as an individual's personal everyday life.

Forums for the Internet of Things

Key IoT Projects and Developments
Whilst the IoT is not necessarily a new concept, it has recently become more prevalent through recent innovationsin mobile devices, particularly the smart-phone, and with it, the concept known as the 'Internet of People' (IoP)(Roussos 2009). This IoP stems from the increasing number of people carrying devices such as smart-phones capable of detecting ones location and gathering information about the surrounding environment such as light, motion and temperature. The existence and prevalence of such devices throughout the world has given birth to a global network of sensors growing in both coverage and density.Such trends make the deployment of pervasive/ ubiquitous computing throughout society easier as the perceived norm for society is for people to carry small but powerful computers around as part of everyday life.

A number of companies/ organisations ranging from large-multinational technology giants and governmental organisations such as NASA to SME's have recognised the potential of this global network of sensors. Many of which have launched complimentary products and services in the name of the IoT.One of the leading IoT projects is HP's CeNSE (Central Nervous System for the Earth) Network.The goal of which is to create a worldwide network of nano-scale sensors capable of measuring parameters such as vibrations, rotation, sound, air flow, light, temperature and pressure (MacManus 2010a). The purpose of the CeNSE Network is to create a feedback loop for objects and people. The first commercial application of this technology involves a partnership between HP and Shell, whereby a wireless sensing system is being created to gather high-resolution seismic data. The function of which is to improve the quality of seismic imaging to improve the ease and cost-effectiveness of oil and gas exploration (HP 2010).Sensing technology developed by HP can also be implemented to monitor infrastructure such as bridges and manufacturing operations to optimise performance and improve asset utilisation.

IBM has launched a comparable project called the Smarter Planet Campaign. Like HP, it uses the central nervous system analogy using Big Blue's sensor platform, which is a collection of IBM's 1,200 smarter solutions. These solutions have been applied to a range of different tasks to improve the quality of information required to develop optimised throughout a range of industries from Healthcare to Banking and Smarter Commerce. The TrafficSense project provides a working example of the system in use. TrafficSense is a system which has been deployed to congestion management solutions, providing detailed real-time traffic information fed directly to route planners and GPS / SatNav devices so that drivers may avoid hotspots of congestion within urban environments. The information is also used in city planning and transport management systems such as traffic light cycle times and sequencing. This has yielded positive results by: reducing traffic volume during peak periods by up to 18%; reducing motor vehicle CO_2 emissions by up to 14%; and increasing public transit use by up to 7% (IBM 2011a; IBM 2011b).

In addition to networks and services provided by HP and IBM, consumer-based services such as Pachube (pronounced Patch-bay), Figure 1, are being developed. The concept here is to provide a data brokerage platform for the IoT managing a network comprising millions of sensors per day from thousands of individuals, organisations and companies worldwide (Pachube 2011).Its web-based service allows one to tag and share real time sensor data from objects, devices, buildings and environments to provide a database through which one can monitor and control (MacManus 2010b).
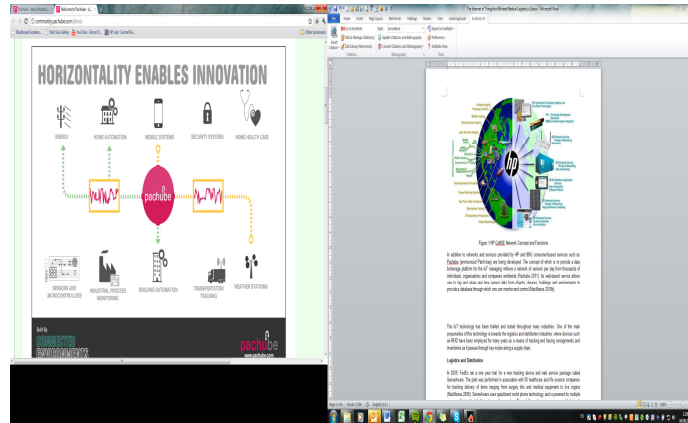
Figure 1Pachube System Concept [Source : (Pachube 2011)]

Radio Frequency Identification (RFID)

RFID represents a near-field technology using radio waves to transfer data between an electronic tag attached to an object and a reader. The purpose of the technology is for more efficient and diverse means of identifying and tracking objects within large consignments where the individual scanning of each barcode is impractical. This technology is employed throughout the logistics and distribution industries as well as within building access / identification cards and electronic transport travel cards such as the London Oyster Card.

QR (Quick Response) Codes

The profusion of smart-phone technology worldwide has led to the potential expansion of technologies such as QR (Quick Response) codes (Figure 2) into a more diverse range of applications. QR codes were initially created in the early 90s by Denso-Wave a subsidiary of Toyota. They represent an evolution of barcoding,containing data both vertically and horizontally, a property which enables them to hold considerably greater volumes of information in comparison to a bar code (Denso-Wave 2010). The main proposition behind QR Codes is to replace barcodes as a line-of-sight method of identification. A growing wave of smart-phone applications are able to read these codes which can link the user directly to an internet-based resource, free text, vCard or even a pre-filled SMS or email message (AcdntlPoet 2010).

Figure 2 QR Code [Source: (ISO/IEC 2000)]

From these the user may obtain a means to access endless amounts of information about the item the QR code pertains to. Such applications are resulting in a vastly increased growth of items attached to the Internet as any individual is now able to generate their own unique QR code attached to any URL they so wish. QR codes have been successfully implemented within logistics enabling businesses to track-and-trace both physical and virtual resources throughout a supply chain using scanning devices (Lynn 2010). IoT technology has also been trialled and tested throughout many industriesfor more focussed applications.

Healthcare

The application of pervasive computing and the IoT has been extensively tested within a healthcare setting, with the intention of increasing and optimising patient treatment and care whilst affording a greater range of flexibility and freedom for both the patient and clinicians.The Elderly Care homes run by Elite Care (www.elitecare.com) provide examples of pervasive computing within a care environment. The Elite Care Information Technology Group installed a system of portable and wearable devices wirelessly networked, to create an intelligent and responsive environment for the elderly in a residential setting. In the scheme, infrared and RFID sensors were used to detect the presence of an individual throughout the Elite Care environment. Embedded weight sensors in each bed collect accurate daily weight readings and analyse sleep activity for each resident to provide early indication of illness through loss of weight and/ or wakefulness potentially due to pain or stress (Stanford 2002). This system has ultimately led to greater levels of monitoring and therefore improved and more accurate care for the residents, whilst providing increased levels of autonomy for those being cared for.

Another use of pervasive computing and the application of IoTwithin healthcare is that of "Smart Pills" implanted with broadcasting sensors. Trials of the concept have been designed by Novartis, which are currently going through regulatory approval for testing.The chips attached to the medicines are activated by stomach acid. Once active they gather and broadcast information regarding dosage and timing to a small patch worn on the patient's skin or alternatively an implant placed under the skin. The patch/ implant in turn transmits the data via a smartphone or over the Internet to a doctor, communicating information from the detector on the chip such as date- and time- stamps, drug type, dose and place of manufacturer, as well as physiologic parameters such as heart-rate activity, and respiratory rate (Hopkins 2010). Detector data can also be combined with other telemetered parameters such as blood pressure, weight, blood glucose, and patient-generated feedback to provide a higher and more comprehensive level of medical care for each individual patient (Hopkins 2010). Such technologies enable more accurate diagnoses and a higher quality of patient care with the medication of more appropriate drugs should the data indicate the current course of treatment is ineffective. Such data can then be used to make advanced orders of prescription drugs.

An early manifestation of pervasive computing applications in medicine which has strong implications for the use of the technology in hospital logistics is that of 'The Magic Medicine Cabinet'. This employs technologies such as smart labels, face recognition, health monitoring devices, flat panel displays and the Internet to support both the informational and physical aspects of consumer healthcare (Floerkemeier and Lampe 2004). It provides 'patients' with a situated portal enabling one to: perform routine physical care such as taking the correct medicineand tracking vital signs with blood pressure monitors; access up-to-date personalised health information; and contact physicians, pharmacists and other professional care providers online (Wan 1999). The system was designed to ensure better personal 'at-home' care and improve the accessibility to healthcare professionals, with the result of this technology having similar uses and implications to that of "Smart Pills".

Logistics and Distribution

In 2009, FedEx ran a one year trial for a new tracking device and web service package called SenseAware. The pilot was performed in association with 50 healthcare and life science companies for tracking delivery of items ranging from surgery kits and medical equipment to live organs (MacManus 2009). SenseAware uses quad-band world phone technology, and is powered by multiple sensors able to detect light, motion and temperature. Through the web service, users are able to track and trace the location of a package, and set up triggers/ alerts and notifications using a geo sensor to inform one when a package arrives at a destination.

Such ICTsystems enable real-time decision making which can reduce/mitigate the wastage of goods. For example, if the shelf life of a perishable goods package on a long-haul journey suddenly diminishes, i.e. due to a change in the temperature controlled environment it is travelling in, the package can be diverted to another closer location where the product will arrive before it expires. The success of this system has led to the launch of a portfolio of temperature-sensitive solutions for the healthcare industry, named FedEx HealthCare Solutions deployed across Europe, the Middle East, Indian Subcontinent and Africa (EMEA). The primary aim of these solutions is to help healthcare supply chains manage expansion into new markets (Eye-for-Transport 2011b). The associated website also provides a resource through which customers gain a high degree of visibility with 24-

hour monitoring and end-to-end solutions to handle storage, fulfilment and distribution of inventory (Eye-for-Transport 2011a).

IBM is also currently designing a comparable systemusing QC Codes (similar to QR Codes they differ only by the error correction algorithm to ensure data reliability) and tiny GPS Sensors, coupled with the addition of automated response. The system is designed to moderate the temperature and humidity of shipping containers to optimise the conditions under which temperature sensitive products such as prescription medications are transported(McLeod 2011). This is hoped to improve the quality of drugs worldwide and also provide a means with which to track each individual bottle/ box of drugs across an entire supply chain. IBM (2011a) believes that increased visibility will allow greater traceability enabling faster response to recall scenarios, thus minimising potential repercussions whilst also creating greater security throughout the supply chain.

Internet-connected technological solutions have also been successfully implemented within unattended electronic locker-box delivery systems, which is an increasingly more popular sector of the logistics industry. ByBox, the UK leader in electronic locker-box logistics, have employed the use of RFID and end-to-end wireless technology to maximise stock visibility and minimise customer stock holding. They have achieved this through innovations such as: Thinventory^{TM} whereby such technological solutions enable the management of each key stage of the supply chain process; VanVentory^{TM} which ensures continued visibility and management of stock whilst mobile; and, a'Virtual Warehousing' option called ByBox2Box, whereby RFID technology can detect the presence of an item in a box allowing for stock exchanges and transfers using centralised box-bank systems as opposed to large warehousing/ distribution centres (ByBox 2011). This technology and its application carries great potential for the future of more efficient low-cost supply chain management.

"Servitisation"
Applications of technologies such as RFID tagging have led a paradigm shift within the photocopier and aeronautics industries. The ability for an RFID tag to be tracked and log information with the addition of embedded sensors has led to products such as photocopiers and airplane engines becoming a service, whereby ownership of the product is retained by the manufacturer whilst the functionality of the unit is leased out to the customer (Michael et al. 2010). This process is known as Servitisation. Charges for use of the services are made according to the usage of the item. For example, revenue from the rental of a photocopier is made according to utilisation levels i.e. paper and toner consumption; similarly, Rolls-Royce "Power-by-the-Hour"TotalCare® service rents engines out to airlines on the basis of charges accrued according to the number of hours of operation logged and tracked using RFID technology(Rolls-Royce 2011). An additional function of this application is the continuous monitoring of product wear and tear which makes proactive maintenance possible therefore reducing unplanned downtime. Such capabilities can potentially help to improve the management/ usage planning and maintenance of hospital equipment and facilities which are leased out to hospitals either on a regular scheduled basis or on-demand.

IoT in the NHS
The healthcare industry is widely considered to be more complex than many businesses/ organisations, given the greater number of departmental silos within a single hospital entity (Bertolini et al. 2011). It therefore requires a significant amount of management informed by large amounts of data gathered from the monitoring and analysis of day-to-day operations. This information is used to coordinate the procurement and distribution of operations while respecting inventory capacities, focussed on scheduling decisions such as when to buy a product, when to deliver to each care unit, when each employee should work and what they should do (Lapierre and Ruiz 2005). Under these requirements, IoT applications developed to detect, monitor, track-and-trace and in some cases respond to the surrounding environment/ information present a number of potential beneficial functions within the healthcare setting. The extensive network of sensors and detectors available through the IoT present a valuable asset in the acquisition of significant quantities of increasingly more accurate and detailed information. Such information can then be used to make more appropriate decisions and judgements within the healthcare arena.

Visibility
The increased visibility of product and vehicle movements throughout the supply chain, afforded by technologies such as FedEx's SenseAware and IBM's Big Blue Sensor platform would enable more effective delivery and scheduling to be planned to hospital sites. This could be used to mitigateagainst

stock-outs of required drugs and / or medical equipment which can lead to appointment cancellations. Consequently this results in the wastage of intangible resources such as a physician's time to see patients.

An additional functionality is provided using RFID technology paired with the Internet. Compliance with drug-pedigree mandates associates significant amounts of track-and-trace information with each drug item, which far exceeds the storage capacity of any tag available on the market (Roussos *et al.* 2009). However, pairing tags attached to products with the Internet enables the data about the product to be stored in a private-network or publically online.

With all the information being available electronically, Electronic Data Interchange (EDI), involving computer-to-computer exchange of inter- and intra-company and hospital data (both business and technical), based upon the use of agreed standards would provide added potential for collaboration between logistics and distribution providers (Hammant 1995). Such systems have been implemented by the Pharmacy Business Technology Group working closely with the National Procurement eEnablement Programme yielding positive results (Finesilver 2002). Mutual consolidation of consignments would actively reduce the amount of cargo related traffic on the road. This may consequently directly address issues at hospitals regarding high numbers of deliveries being made by a high number of individual couriers/ distribution companies.

A further impact of this technology would be to improve the reverse supply chain. This could potentially act to back-load vehicles with non-hazardous waste materials for transport off site to the appropriate disposal facility; and to other hospital sites along the vehicles delivery route. This would provide further means of reducing traffic in and out of hospital sites. Greater levels of visibility would also provide enhanced contextual awareness. Comprehensive track-and-trace capabilities of inventory within supply chains and therefore potentially within hospitals would enable greater utilisation of resources between departmental silo's and even hospitals. By employing a larger scale system of the Magical Medical Cabinet, which logs the items removed from a store and the individual/ department which requested them, departments / nearby hospitals could potentially fully utilise medical inventory from numerous store locations whilst maintaining an accurate log of each department's usage. Such scenarios have been modelled within a virtual simulated world to test their effectiveness, see (Thompson and Hagstrom 2008).

Another benefit of improved visibility would be to allow greater collaboration between hospitals and suppliers. By tracking and tracing the usage of medical consumables within a hospital a more accurate log of stock-take can be generated, as well as more detailed profile of product demand. Such information can be passed on to suppliers to improve their ability to meet product orders. The information may also be used as a broad indicator of the illnesses/ ailments which are likely being treated by each department (Bailey 2011).

Detailed Monitoring
The large amounts of information gathered from the sensors networked through the IoT can be used to monitor and report on the surrounding environment and the 'agents' operating within it. As demonstrated by the Elite Care elderly homes environment, Magical Medicine Cabinet and Novartis 'Smart Pill' technology, IoT technology can be used to improve the delivery and accuracy of medical care. Such applications can provide significant benefits to the distribution of drugs on the ward, where most errors occur (Gobbi 2011), and management of inventory within hospitals. The 'Smart Pill' and to some extent the Magical Medicine Cabinet technologies pose the most significant impact on hospital inventory management. In a scenario where the sensor from either technology indicates a different course of treatment is required due to a patient being unresponsive to the current medication. The necessary procedures can be initiated in preparation for the most appropriate treatment in anticipation of the patient's arrival or indeed before the patient requires it. Up-to-the-second knowledge of such information would allow for more accurate predictions of inventory stored inter- / intra-hospital, therefore allowing for better utilisation. Furthermore, if a system similar to the Magical Medicine Cabinet were to be implemented in the drugs trolleys on the wards, the potential for the accidental administering of the incorrect medication to patients could be reduced or even eliminated, further improving inventory management through the monitoring of misconsignments.

Another benefit afforded by detailed monitoring is sensor-driven analytics. By monitoring a patient's behaviour and symptoms in real-time and at relatively low cost, physicians are able to make better

diagnoses and prescribed tailored treatments. For example, Chui *et al* (2010) reported that healthcare trials of patients with chronic illnesses such as congestive heart failure outfitted with sensors continuously monitoring weight, blood pressure and heart rate and rhythm as they go about their daily lives provided practitioners with early warnings of conditions which would otherwise lead to unplanned hospitalisations and expensive emergency care. Care of conditions such as congestive heart failure are predicted to save a billion dollars annually in the U.S. as a result of reduced hospitalisation, treatment and the related logistics (Chui *et al.* 2010).

A final benefit of improved inventory monitoring technologies is the potential reduction of unnecessary wastage of medical products. With the tagging of medical consumables, as tested in the Magical Medicine Cabinet trials, sensors would be able to confirm the size, specification and properties of items removed from the store. This would mitigate against the issue of staff selecting the incorrect size of high value medical treatment items such as catheters, which can be worth around £1000 each.

Servitisation in Healthcare

Within the NHS there is a range of high value, low-use equipment including diagnostic equipment leased out to hospitals upon request, ranging from Magnetic Resonance Imaging (MRI) machines and Computerised Axial Tomography (CAT) scanners(Bailey 2011). The requirement for such machines creates a direct and transferrable application for RFID technology and the associated sensors employed within the office photocopying and airplane engine services. The information gained for such sensors for medical equipment would provide an accurate log pertaining to the location and purpose of the equipment's use. Consequently, it would be possible to create a demand profile for the requirement of the machines and also provide an accurate log of the illnesses and ailments being investigated. This would have significant implications regarding generating useful statistics for the types of illnesses and ailments occurring within particular areas of the country. Such information could then be used in the research of illnesses, and governmental/ organisational healthcare plans and strategies.

eLogistics

The use of IoT applications within the NHS would provide steps towards adhering to the EU Freight Logistics Action Plan, the primary aim of which is to promote innovation by encouraging the use of ICT in freight (Zunder *et al.* 2010). The concept of ICT in the process of transport, demand and supply chains is known as eLogistics, however across the literature it is also referred to as e-commerce, e-fulfilment, e-procurement and e-tailing see:(Rushton *et al.* 2009; Christopher 2011). eLogistics includes data flows and processes such as ordering, inventory management, transporting, co-packaging and co-distribution. These processes can be incorporated into a single concept known as continuous planning, forecasting and replenishment (CPFR).

Such tools may be used to maximise the sharing within and between sites and/ or minimise the volume of inventory within hospital. This can be used to insure against demand for particular drugs/ treatments/ medical equipment. Stocking of large inventories is commonly an expensive practice and carries risks related to items within the inventory exceeding the end of the products life (Lee and Billington 1992). CPFR can mitigate against such scenarios. Using Internet connectivity accurate stock information afforded by IoT technologies and applications can be shared between supply chain partners and the surrounding hospital network to coordinate operations. This would ensure greater usage of inventory already stocked within hospitals and reduce redundant deliveries and duplicate inventories (Bowersox *et al.* 2000) which are currently one of the issues within hospital supply management.

Clinical Education

Previous research studies (Weal *et al.* 2009) have shown that IoT applications such as QR Codes and RFID tagging can provide some of the more significant benefits within the clinical education environment. QR Codes affixed to medical inventory, products, machinery and tools can provide a fast and efficient means for clinical staff to scan the item and potentially obtain a guidance video providing information about an item, its applications, its supply chain and how to use it/dispose of it under such applications. This would eliminate the need for medical staff to refresh their knowledge by revisiting large text books on the wards, a practice which is common within medicine as a result of the ever growing numbers of procedures and new medical studies. The benefits of such a system would be to: improve cleanliness as product codes could be scanned by a handheld device or smart phone;

reduce the growing issue of staff such as nurses experiencing sensory overload with all the information posted around hospitals; and most importantly, the speed and effectiveness at which information can be obtained and assimilated by an individual.This can potentially improve the track-and-trace of inventory as it could be scanned at-point-of-use and reduce wastage as a result of improper use of medical products.

Such applications of IoT technologies also have a purpose for rehabilitation of the elderly; infirm; and, those with degenerative brain disorders or who have suffered a brain trauma. In a similar way to the codes being attached to medical equipment and inventory, they can be applied to everyday items around the house such as kettles and toaster(Gobbi 2011). The codes can then be scanned which consequently links the scanning device to a visual or audio demonstration of how to use the item. Such uses of this technology would help to rehabilitate individuals back into a semi- or fully-autonomous state of living. The end result of which is the alleviation of pressure on hospitals to care for individuals who are otherwise unable to be discharged from a 24-hour care environment. This would enable more effective management of outpatients and much like the smart pill enable ordering of appropriate inventory and equipment in preparation of a patient requiring care.

Issues with IoT
Although the number of new innovative intelligent, IoT technologies are fast becoming more abundant. Some of the technologies and principles which underpin them are flawed and present significant barriers to implementation.RFID represents one of the main technologies used throughout the IoT trials and applications. The value proposition behind the technology is as a replacement for the barcode as a non-line-of-sight identification method. However, the true potential of the technology has been realised by many companies such as FedEx and IBM who use it to grant a user with an omnipresent view of operations, coined by Michael *et al* (2010) to be 'Uberveillance'. However, there are three significant barriers to the wide-scale implementation of RFID technology:

The first of these is that RFID technology requires specialist technical skills to manage the variety of devices and tags operating on varying frequencies and under different capacities; the second pertains to the rapid developments in RFID technology and their fluctuating reading reliability such as: when a tag that is present is not detected, not in range of the reader, detuned, misaligned, and/ or obscured by metal or water in the vicinity of the RFID system(Floerkemeier and Lampe 2004); the final issue is related to the cost of RFID devices and tags as well as the necessary middleware and software components which create a perception that RFID systems and the actuators are too expensive to invest in for the value proposition which they offer (Michael *et al.* 2010). However, there have been advances in the field of IoT with the use of QR codes as a replacement for RFID technology. This technology presents a cheaper alternative to near-field technologies, with the world-wide potential for its use owing largely to the popularity of smart-phone devices expanding the capabilities of the 'Internet of People'.

IoT Principles
One of the most significant barriers to the global implementation of IoT applications is legislative control. Many of the IoT technologies and concepts proposed may be considered to be a breach of ones' right to privacy. In particular this issue refers to the tracking, tracing and monitoring of items which may be retained on a person in the form of a tagged package/ parcel or indeed their smart-phone. Another issue regarding legislation is that of legal liability. Liability frameworks for the bad decisions of automated systems will have to be established by governments, organisations, companies, and actuaries for insurers (Chui *et al.* 2010) before they can be implemented within sectors such as Healthcare. In addition to this, the cost and reliability of sensors and the related technological add-ons such as actuators will have to fall to create widespread use of the technologies.

For successful implementation of IoT technologies into a healthcare setting, all of these issues need to be addressed. Further to this, the practicality of some of the benefits of the system would also need addressing. For example, many of the technologies offer greater amounts of highly detailed information which may be applied to creating a demand profile for particular medical consumables. However, in reality the demand for medical consumables within a hospital is wholly reliant upon the illnesses and ailments treated by the medical staff and the course of action those medical staff choose to employ. Therefore, predicting demand for medical consumables within an intensely complex system which operates predominantly under human influence may be considered impracticable.

Conclusions

The Internet of Things and its associated technologies offer great potential for the improved operation within hospitals for both the delivery and use of medical inventory; and, the delivery of medical care to patients. However, it is clear that much of the technology such as RFID sensors and automation and "Smart Pills" have a long way to go before the wide-scale implementation of such devices. Despite this, IoT applications such as QR Codes have a more immediate and equally significant role within the industry, offering similar benefits to the more expensive and 'futuristic' technologies. This function is created as a result of the growing popularity of smart-phone, which is linking more and more individuals to the Internet making concepts such as the Internet of Things and Internet of People denser and increasingly extensive.

The wider implication of these technologies using the tracking of each device, via each unique Internet Protocol (IP) address assigned to phones when paired with the Internet, and the items it scans is complete visibility and monitoring for all products bought and consumed by customers and patients worldwide. Such capabilities would enable many of the solutions discussed in this paper to become a reality within the context of healthcare and a hospital environment.

References

1. AcdntlPoet (2010). "Some "Rational" fun with QR Codes." from: https://www.ibm.com/developerworks/mydeveloperworks/blogs/nfrsblog/entry/some_rational_fun_with_qr_codes6?lang=en_us. [Accessed on 14/03/11].
2. Bailey, D. (2011). Interview with Dr Daniel Bailey (Consultant Physician at King's College Hospital, London) regarding the potential benefits for the Internet of Things within Medicine. London.
3. Bertolini, M., M. Bevilacqua, F. E. Ciarapica and G. Giacchetta (2011). "Business process re-engineering in healthcare management: a case study." Business Process Management Journal Vol 17(Issue 1): pp 42-66.
4. Bowersox, D. J., D. J. Closs and T. P. Stank (2000). "Ten Mega-Trends That Will Revolutionize Supply Chain Logistics." Journal of Business Logistics Vol 21(Issue 2): pp 1-16.
5. ByBox (2011). "ByBox." from: www.bybox.com. [Accessed on 04/06/11].
6. Christopher, M. (2011). Logistics and Supply Chain Management. Harlow, Pearson Educational Limited.
7. Chui, M., M. Löflet and R. Roberts (2010). "The Internet of Things." McKinsey Quarterly (Issue 2): pp10
8. Denso-Wave (2010). "QR Code.com: About 2D Code, Bar code to 2D Code." from: http://www.denso-wave.com/qrcode/aboutqr-e.html. [Accessed on 04/06/11].
9. Eye-for-Transport (2011a). "FedEx launches enhanced resource for healthcare industry." from: http://www.eyefortransport.com/content/fedex-launches-enhanced-resource-healthcare-industry. [Accessed on 27/05/11].
10. Eye-for-Transport (2011b). "FedEx launches suite of healthcare solutions in EMEA." from: http://www.eyefortransport.com/content/fedex-launches-suite-healthcare-solutions-emea. [Accessed on 27/05/11].
11. Finesilver, J. (2002). Electronic Data Interface - EDI What's in it for pharmacy? "from: www.cmu.nhs.uk/eBusiness/.../edi%20benefits_jf_overview_june2002.doc. [Accessed on 04/06/11].
12. Floerkemeier, C. and M. Lampe (2004). "Issues with RFID Usage in Ubiquitous Computing Applications." Applications', in Ferscha, A. and Mattern, F. (Eds.): Pervasive Computing: Second International Conference, Vienna, pp 188-193.
13. Garlan, D., D. P. Siewiorek, A. Smailagic and P. Steenkiste (2002). "Project Aura: toward distraction-free pervasive computing." Pervasive Computing, IEEE Vol 1 (Issue 2): pp 22-31.
14. Gobbi, M. (2011). Interview with Dr Mary Gobbi regarding areas within the NHS where the Internet of Things and related technologies would provide the most significant benefits.
15. Hammant, J. (1995). "Information technology trends in logistics." Logistics Information Management Vol 8(Issue 6): pp 32-37.
16. Hopkins, C. (2010). "The (Near) Future of Medicine: Take Two Computers and IM Me in the Morning." from: http://www.readwriteweb.com/archives/the_near_future_of_medicine_take_two_computers_and.php. [Accessed on 31/05/11].

17. HP (2010). "Shell and HP to Develop Ultrahigh-resolutionn Seismic Sensing Solution." from: http://www.hp.com/hpinfo/newsroom/press/2010/100215xa.html. [Accessed on 04/05/11].
18. IBM (2011a). "A Smarter Planet." from: http://www.ibm.com/smarterplanet/us/en/?ca=v_smarterplanet. [Accessed on 31/05/11].
19. IBM (2011b). "TrafficSense System." from: http://www-304.ibm.com/partnerworld/gsd/solutiondetails.do?solution=39758&expand=true&lc=en. [Accessed on 04/05/11].
20. ISO/IEC (2000). International Standard: Information technology - Automatic identification and data capture techniques - Bar code symbology - QR Code, ISO/IEC. 18004.
21. Lapierre, S. D. and A. B. Ruiz (2005). "Sheduling logistic activities to improve hospital supply systems." Computers and Operations Research Vol 34: pp 624-642.
22. Lee, H. L. and C. Billington (1992). "Managin Supply Chain Inventory: Pitfalls and Opportunities." Sloan Management Review(Spring).
23. Lynn, A. (2010, 17th November 2010). "IBM Uses QR Codes...But What's in It for Me?". from: http://scanlutions.com/uncategorized/ibm-uses-qr-code-what-is-in-it-for-me/. [Accessed on 14/03/11].
24. MacManus, R. (2009, 4th December 2009). "FedEx Joins the Internet of Things With SenseAware." from: http://www.readwriteweb.com/archives/fedex_joins_the_internet_of_things_with_senseaware.php . [Accessed on 11/03/11].
25. MacManus, R. (2010a, 3rd March 2010). "McKinsey: Get Ready For Sensor-Driven Business Models." from: http://www.readwriteweb.com/archives/mckinsey_internet_of_things.php. [Accessed on 11/03/11].
26. MacManus, R. (2010b, 15th December 2010). "Top 10 Internet of Things Developments of 2010." from: http://www.readwriteweb.com/archives/top_10_internet_of_things_developments_of_2010.php. [Accessed on 11/03/11].
27. McLeod, S. (2011). "Internet of Things: Prescription Medicine." from: http://www.minddump.org/internet-of-things-prescription-medicine. [Accessed on 31/05/11].
28. Michael, K., G. Roussos, G. Q. Huang, A. Chattopadhayay, R. Gadh, B. S. Prabhu and P. Chu (2010). "Planetary-Scale RFID Services in an Age of Uberveillance." Proceedings of the IEEE Vol 98 (Issue 9): pp 1663-1672.
29. NHS (2010). "Logistics." from: http://www.supplychain.nhs.uk/portal/page/portal/Suppliers/Our%20Services/Logistics. [Accessed on 31/05/11].
30. Pachube (2011). "Pachube's scalable infrastructure." from: http://www.pachube.com/. [Accessed on 04/06/11].
31. Rolls-Royce (2011). "TotalCare." from: http://www.rolls-royce.com/civil/services/totalcare/index.jsp. [Accessed on 04/06/11].
32. Roussos, G. (2009). "Sensor and Actuator Networks and the Internet of Things". from: http://www.dcs.bbk.ac.uk/~gr/pdf/iot_wuxi_web.pdf [Accessed on 14/07/11].
33. Roussos, G., S. S. Duri and C. W. Thompson (2009). "RFID Meets the Internet." Internet Computing, IEEE Vol 13 (Issue 1): pp 11-14.
34. Rushton, A., P. Croucher and P. Baker (2009). The Handbook of Logistics and Distribution Management. London.
35. SDG (2010). Great Ormond Street Hospital Delivery Survey. London.
36. Stanford, V. (2002). "Using pervasive computing to deliver elder care." Pervasive Computing, IEEE Vol 1 (Issue 1): pp 10-13.
37. Thompson, C. (2004). "Everything is alive." Internet Computing, IEEE Vol 8 (Issue 1): pp 83-86.
38. Thompson, C. W. and F. Hagstrom (2008). "Modeling Healthcare Logistics in a Virtual World." IEEE Internet Computing Vol 12 (Issue 5): pp 100-104.
39. Wan, W. (1999). Magic Medicine Cabinet: A Situated Portal for Consumer Healthcare. International Symposium on Handheld and Ubiquitous Computing.
40. Weal, M. J., D. T. Michaelides, K. R. Page, D. C. De Roure, M. Gobbi, E. Monger and F. Martinez (2009). Location based semantic annotation for ward analysis. 3rd International Conference on Pervasive Computing Technologies for Healthcare.
41. Weiser, M. (1991). "The Computer for the 21st Century." Mobile Computing and Communciations Review Vol 3 (Issue 3).
42. Zunder, T., I. Zunder and M. Z. Dewan (2010). ELogistics Systems Application For Service Users And Providers. TRB 2011 Annual Meeting. Washington.