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Boxed up and locked up, safe and tight! Making the case for Unattended Electronic Locker Bank Logistics for an Innovative Solution to NHS Hospital Supplies (UK)

Abstract

The lack of separation between urgent and non-urgent medical goods encourages sub-optimal vehicle fleet operations owing to the time critical nature of urgent items.

An unattended electronic locker bank to which individual urgent items can be delivered, bypassing the traditional route of supply, was proposed for the Great Ormond Street Hospital in London, UK. This concept was quantified using a significant database of urgent item consignment movements to inform a 'Basic' and 'Intuitive' hill climbing optimisation model; and qualitatively using staff interviews and expert reviews.

Results from the two models indicated that a locker bank with a fixed height (1.7m) and depth (0.8m) required a length of 4m (Basic model) and 3.63m (Intuitive model), to accommodate 100% of urgent consignments for a typical week. Indicating, in this instance, that intuitive modelling approaches yield approximately 20% more optimal results than a basic approach.

Staff interviews indicated the wider extent of benefits which the concept could provide in terms of handling product returns and staff personal deliveries.

Introduction

Due to increasing financial austerity and environmental awareness, there has been a move to improve the efficiency of business operations within healthcare. In the UK, the National Health Service (NHS) has been set targets to save £20 billion through efficiency related savings by 2014-15 as part of the Quality, Innovation, Productivity and Prevention (QIPP) agenda (Department of Health 2012; Gainsbury and Stacey 2012) and reduce its overall greenhouse gas emissions by 34% by 2020, against the 1990 baseline (Sustainable Development Unit 2010).

Within many industries, such savings can be achieved with the implementation of lean supply chain management (SCM) solutions such as Just-In-Time inventory management operations to reduce the number of vehicles required to perform operations (Christopher 2011; Youn et al. 2012). However, due to the rapid response framework and unpredictability of demand within the healthcare supply chain, implementing such practices is often considered incongruous (Everard 2001). These issues are further compounded by often inefficient and costly operating practices (Costantino et al. 2010), which lead to incomplete and incoherent flows of demand information throughout the supply chain (Singh 2006).

In order to manage such operational characteristics, hospitals typically implement inventory buffers to mitigate against the potentially serious consequences of low levels ('stock-outs') of goods (Özkil et al. 2009; Costantino et al. 2010). However, in spite of this stock-outs are still experienced, resulting in orders of time-critical items passing through the same supply chain as non-urgent goods. The lack of a separate, agile supply chain can lead to the timely flow of such items becoming unreliable (Christopher 2011), particularly at the point where the external supply chain delivering goods to the hospital gates meets the internal supply chain, which moves products to their intended wards / departments (Aronsson et al. 2011).

These issues have resulted in considerable research focused on improving the efficiency of healthcare supply to optimize the cost and efficiency of back-house hospital operations. The main theme of this research has been on hospital-supplier collaboration to achieve optimized supply chains which promote transparency and communication as a means of overcoming rising costs and meeting expectations of quality within healthcare (Cardinal Health 2012; Pohl et al. 2012). Furthermore, it is held that strategic partnerships and alliances can support an overall balance of goals to maintain effective and profitable business practices. Supply chain integration initiatives such as Continuous Planning, Forecasting and Replenishment (CPFR); Vendor Managed Inventory (VMI) and Stockless Inventory are prevalent throughout this literature (Danese 2004; Landry and Philippe 2004; Kim 2005; Kumar et al. 2008; Kumar et al. 2008; Kumar et al. 2009; Mustaffa and Potter 2009; Guimarães et al. 2011). Such concepts are designed to facilitate higher visibility of inventory usage for suppliers, reducing uncertainty, lead times and the need for safety stock, resulting in more cost effective supply chain practices such as Just-In-Time and stockless inventory holdings (Mustaffa and Potter 2009; Dumoulin et al. 2012).

Conversely, self-managed and outsourced inventory practices, as an alternative to collaborative alliances within Singapore, the United States and Italy have proved successful at reducing costs without compromising the quality of healthcare (Pan and Pokharel 2007; Azzi et al. 2013). Outsourcing logistics and procurement activities to Group Procurement Offices (GPOs) by hospital clusters has yielded reduced costs through bulk-buying, and improved the scope for inter- and intra- hospital sharing, helping to avoid stock-outs (Pan and Pokharel 2007).

Another key theme within the healthcare logistics literature is that of process re-engineering with the use of emerging information and communications technologies (ICT) such as bar coding and Radio Frequency Identification Tagging (Coulson-Thomas 1997; Towill and Christopher 2005; Parnaby and Towill 2008; Parnaby and Towill 2009; Anand and Wamba 2013; Fakhimi and Probert 2013; Mans et al. 2013). The use of integrated ICTs can eliminate paper-based and some manual processes whilst improving the visibility of patients, staff, equipment and data (Anand and Wamba 2013), thereby enabling a greater understanding of demand and supply characteristics within hospitals (Towill and Christopher 2005). Enhanced visibility of hospital supply and demand allows for the potential re-design of outdated hospital processes and supply chain strategies to encourage more efficient operations such as reverse logistics (Ritchie et al. 2000; McKone-Sweet et al. 2005; Kumar et al. 2009).

As is evident from the literature, much research exists addressing the issues surrounding the general supply of medical consumables, however little has been undertaken specifically addressing urgent items within the supply chain, which often travel in conjunction with non-urgent goods (Mustaffa and Potter 2009). This paper fills a gap in the literature, exploring the potential for an alternative route of supply for time-critical items. It builds on previous research which indicates that the process of removing intermediate tiers / agents within supply chains (disintermediation) can provide a viable solution, enabling suppliers to make deliveries direct to patient care units (PCUs) as opposed to a communal goods-in facility. Such practices are employed by some drugs manufacturers to ensure quality of service and integrity of the product on delivery. This has been found to improve the speed of response in terms of goods and information flows between healthcare providers and suppliers (Shapiro and Byrnes 1992). Whilst this concept has been implemented within hospitals it has not been considered in the context of automated unattended locker bank design which aids in reducing human error within the supply chain and increasing the tracking-and-traceability of urgent items.

This paper presents the concept of an unattended electronic locker bank as a potential tool to reduce: the delay and potential loss of items experienced at the communal goods-in facility, enabling a more direct route of supply to PCUs and improved inventory visibility throughout the supply chain. The feasibility of this concept is tested in the context of Great Ormond Street Hospital for Children (GOSH) NHS Foundation Trust in London, using a genetic hill climbing optimisation algorithm informed by 1-year of historical hospital consignment order for urgent ad-hoc deliveries.

Great Ormond Street Hospital

GOSH is a tertiary care NHS Trust, comprising 27 NHS wards and 2 private healthcare wards staffed by 3,336 clinical and non-clinical members who help to provide more than fifty different clinical specialties, treating more than 192,000 patients per annum. The majority of patients are referred from general practitioners and specialists (Beggin 2011).

A recent survey of the goods yard undertaken by the authors at GOSH (Autumn 2011) quantified the delivery and servicing activities during day-time hours of operation (07:00 – 17:00). Conducted over a 5-day period, it found that 403 deliveries were made by 223 vehicles on behalf of over 300 suppliers. This indicates a 9% growth in the number of deliveries from a comparable 2010 survey[1], which revealed 366 deliveries to be completed by 219 vehicles on behalf of 145 suppliers. This increase may be potentially attributed to a 9% growth in patient numbers in 2010 from 175,000 to current levels (GOSH 2011).

Many of the deliveries received were processed through a single receipts area located within the yard. All goods were sorted into cages for delivery to their respective departments in rounds performed by materials management staff / porters. This delivery structure has been identified as a significant issue mitigating the rapid movement of urgent items to the trust.

Characteristics of Hospital Supply Chains

Hospital logistics are characterised by a fragmented and an often discordant management structure, comprising numerous independent clinical specialties each of which have significantly different operational requirements ranging from predictable to unpredictable demand (Rivard-Royer et al. 2002; Aronsson et al. 2011). Such characteristics separate the requirements of healthcare supply from other industries such as retail, for which stock-outs represent an inconvenience, as opposed to potentially life threatening situations (Breen 2008; de Vries and Huijsman 2012; Stanger et al. 2012). Much of the variability observed within healthcare supply can be attributed to at least three different factors:

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[1] 5-day survey conducted in Autumn 2010 by Steer Davis Gleave on behalf of TfL.

1) Clinical variability, related to the numerous different ailments, severity levels and response outcomes to treatment;
2) Demand variability, relating to the type of medical treatment required(i.e. emergency medicine and referred treatment); and,
3) Variation in the approaches to care and the levels of care delivered by independent clinicians (Lega et al. 2012).

In addition to this, the nature of medical developments within the healthcare supply chain, such as: constantly evolving technologies and short product life cycles; a lack of standardised nomenclature / coding for products due to participation from numerous suppliers worldwide; and a lack of capital to build sophisticated information and communications technology infrastructure are significant barriers to the implementation of more efficient SCM solutions (McKone-Sweet et al. 2005).

In light of such characteristics it is considered unrealistic to plan inventory requirements to the exact needs of PCUs. For this reason, hospitals typically employ the use of inventory buffers (Everard 2001; Stanger et al. 2012), implementing either an 'Inventory-oriented Approach', currently practiced by GOSH and most state-managed NHS Trusts, whereby pre-established re-order levels (determined from historical orders / stock usage statistics) are agreed by hospitals and medical departments (Lapierre and Ruiz 2005); or, a 'Scheduling-oriented Approach', successfully implemented by small hospitals in Singapore with low demand and the provision of 100 beds or less (Pan and Pokharel 2007), requires accurate scheduling of purchasing operations, replenishments and supplier deliveries to ensure resource availabilities are respected and stock-outs avoided (Costantino et al. 2010). Comparison of the two approaches reveals inventory approaches to generate higher operational costs due to the requirement of more man-power and greater amounts of storage space, and scheduling approaches to require more regular reviews of stock usage to ensure all schedules are accurate and up-to-date (Pan and Pokharel 2007).

Healthcare Supply Chain Structure

The presence of an external and internal supply chain are intrinsic within the healthcare sector due to hospitals being service providers, delivering medical care to the patient (the end-consumer). Due to this role, it is typically necessary for hospitals to establish and manage the remainder of the supply chain internally, distributing medical goods and supplies to consignee PCUs. Contrary to this approach, outsourcing / sub-contracting of internal supply chains can be implemented in the form of stockless inventory / vendor managed inventory approaches, which are examined later in the paper.

Hospital supply is often based on one of three models:

1) "Conventional Model", delivery to medical departments via a central warehouse;
2) Semi-Direct, delivery via each medical departments' warehouse; and,
3) Direct delivery, daily replenishment of small medical departments' storage facilities (Aptel et al. 2001; Fry et al. 2012).

GOSH employs a conventional–semi-direct 'hybrid' model, whereby goods are received through a central receipts room, sorted and temporarily stored for delivery rounds to each PCU's dedicated storage facilities. Scheduled inventory deliveries which represent 30% of total goods procured, based on hospital spend reports, are replenished weekly for clinical departments and bi-weekly for theatre and intensive care units with the remaining inventory requirements being fulfilled by daily ad-hoc deliveries.

The activities and processes of the internal chain within hospitals are often regarded as misaligned from the overall supply chain, which has been identified as a significant issue affecting the fast and coherent flow of time sensitive and demand specific information to suppliers (Singh 2006). Research into demand variance within healthcare has found that hospital orders exhibit considerable variability (Shapiro and Byrnes 1992), affecting supplier's abilities to respond, in some cases impacting on the hospital's ability to deliver quality patient care and treatment (McKone-Sweet et al. 2005; Costantino et al. 2010). Unclear inventory demand between wards and central procurement / suppliers can create a 'bullwhip' effect (Figure 1), resulting in a lack of coordination in ordering policies at points throughout the supply chain, creating an increasing demand variance propagating up the chain (Christopher 2011). These issues also often compounded by the delay in the fast flow of goods, and the multiple procedures and information systems operating within the hospital, resulting in further costs and inefficiencies (Poulin 2003; Dembirίska-Cyran 2005).

Adaptations to the conventional and semi-direct hospital supply models have previously been made to achieve a direct delivery structure (stockless inventory approach). Implemented within the U.S. and Canada from the 1970s to the 1990s, it operated on the principle of consolidating the hospitals' suppliers to a minimum, and outsourcing the management of goods to the remaining suppliers (Kowalski 1991). This allowed greater visibility of inventory use, enabling faster and more accurate response to demand (Nicholson et al. 2004).

Unfortunately significant imbalances in the benefits gained by the hospitals and the distributors rendered stockless methods unattractive to suppliers (Rivard-Royer et al. 2002). Whilst some contracts with suppliers are based on a direct order / delivery system as opposed to 3rd party wholesalers, owing to the nature of many products supplied to specialist trusts such as GOSH, rationalisation of all suppliers to the trust becomes impracticable.

More recent studies including those of the stockless inventory approach have demonstrated that for organisations with unpredictable demand, supply chains operate better without intermediate tiers (Shapiro and Byrnes 1992). However, disintermediation has also been found to inhibit a company's ability to respond to demand variability (Zhang and Zhang 2007).

Unattended Locker Box Concept

Unattended locker banks are an alternative delivery solution developed in response to the demands of the field services sector and the large proportion of failed home deliveries experienced within the UK costing between £790 million (0ver $1.2 billion) and £1 billion (approximately $1.5 billion) to retailers, carriers and consumers per annum (IMRG 2010). The concept provides individuals / companies with a locker bank as an alternative delivery address (Edwards et al. 2010). Each locker bank: comprises numerous secure boxes, equipped with wireless communications (3G) to send notification of confirmed deliveries to recipients. They are typically owned, operated and maintained by the locker box provider and are often situated in central locations within a town or city (Amazon 2012; ByBox 2012; DHL 2012; DX-Business-Direct 2012). The process of parcel delivery varies according to the locker box supplier, for example:

1) ByBox users are required to instruct delivery of orders via the ByBox central warehouse, from which a dedicated network of ByBox night-time couriers deliver the parcel to the requested locker bank (ByBox 2012); whereas,
2) Amazon and DHL Packstation customers register with the service which allows them to provide a locker bank as the direct delivery address (Amazon 2012; DHL 2012).

Studies by Edwards et al. (2009); Edwards et al. (2010) and Song et al. (2009) have demonstrated the significant savings in operating costs and carbon emissions can be achieved with unattended collection-delivery points in the context of home deliveries. Results from these studies indicated annual savings of between £2,778 ($4,123) and £6,459 ($9,585) in carrier's transportation costs and reductions in emissions of between 3.8 and 8.7 tonnes (4.18 to 8.59 tons) of CO_2 as carbon (Song et al. 2009). The concept has been widely adopted within the field services sector, where engineers can order specialist parts to be delivered overnight into the lockers for the next-day's servicing activity (Rowlands 2007).

It is important to note that the concept of locker banks differs significantly from intelligent medicine cabinet storage systems which are designed to create and maintain leaner supply chain operations by automatically reordering stock to replenish items removed for use (Shieh 2008; Medeiros et al. 2011). Unattended locker boxes serve only as a means for temporary stock holding (1-day maximum), informing a member of staff that a single specialist order / consignment is ready to collect.

The proposed locker box concept is based on the traditional system operated in the field services sector, (Figure 2), and is designed to provide a fast- and direct- route for urgent deliveries from entry to the hospital to the point of use. The aim is to provide a separate supply chain for urgent items, enabling consolidation of individual consignments to increase vehicle load factors. In this paper, it is assumed that the system would function accordingly:

1) A clinician places an order for items designated for an emergency patient to be transferred the next day;
2) The order is processed through procurement who request delivery of the item to the ByBox warehouse;
3) The supplier prints a unique label sent with the order for the item, which allows scanning of the item at the locker bank for deposit;
4) Once the barcode attached to the item is scanned and a unique code is entered, a locker box opens within the locker bank. The door is closed and the delivery is confirmed;
5) Upon closing the door, the locker box sends a message to the hospital switch board which forwards the message, along with the necessary security codes for accessing the locker box, via the hospital ward phone system to the recipient. Once a partition has been closed it is only possible to open the door of the partition by entering the security code generated by the locker bank unit.

This system is designed to facilitate night-time delivery of items and expedite the delivery of urgent supplies to their consignee ward. In addition to this, it will also reduce day-time traffic thereby offering more efficient fuel consumption.

Methodology

This study uses quantitative (modeling) and qualitative (staff interview) methods to establish the feasibility and practicality of the locker box concept within the hospital environment at GOSH. The main aims of the assessment were to: test the feasibility of the proposed concept; quantify the optimal dimensions of a locker bank according to the potential demand for urgent goods-in; and, compare the benefits of the basic modeling method and a more intuitive approach.

The models were informed by the November 2011 survey data which captured ad-hoc deliveries [n=403] and identified the product description, supplier / manufacturer name and consignee department for recorded deliveries. These product listings were presented to the Head Nurse[2], who identified 38 product lines considered to be urgent goods, signified by the unique functions they perform e.g. tubing packs, customized items and equipment packs predominantly for theatre departments. For example, Perfusionist Theatres use cardiopulmonary bypass machines for surgery, therefore stock-outs of items such as tubing packs would prevent bypass operations being performed.

The urgent orders identified from the survey data were transposed onto a 1-year historical record of consignment orders for the 2011/12 financial year (April – March). The actual delivery package dimensions for 63% of the 1,098 separate urgent product orders contained within 425 separate consignments were obtained from the suppliers. An assumed package size was generated for the remaining 37% according to the weighted average of all the acquired box sizes. This process revealed that orders were delivered within standardized packaging, returning only 8 different actual box sizes and 1 generated box size.

The qualitative assessment was conducted using one-to-one interviews with key members of staff: Head Nurse; Head of Corporate Facilities; 2 members of Supply Chain management; and, 4 Ward Sisters /Lead Nurses to assess the contextual and operational value of the concept. During the interviews, staff were presented with the concept and its basic functionality. They were then asked to provide feedback regarding perceived uses and applications.

Locker Box Modelling

Locker Box Partitions and Demand

Partitions for unattended locker bank facilities are typically determined according to the statistical distribution of package sizes dropped off at the facilities with a significant proportion of deliveries being a shoe box or smaller in size (Turner 2011). In consideration of this, two modelling approaches were adopted to quantify the value of various locker partition formulations. Both methods involved the hard-coding of 4 partition sizes for the allocation of the demand, differing according to how the size of locker partitions were determined.

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[2] Formally, “Head Nurse, Clinical Equipment, Products and Practices”

Basic Partition Allocation

The first, 'Basic' method, which is more akin to the locker partition sizes for current locker banks (Turner 2011), comprises partition sizes measuring full-height, half-height, quarter-height and eighth-height boxes, for the locker bank, as follows:

A) 170cm x 80cm x 80cm;
B) 85cm x 80cm x 80cm;
C) 425cm x 80cm x 80cm; and,
D) 21.2cm x 80cm x 80cm.

The full-height of the locker bank is determined in accordance with the approximate height provided by the Health and Safety Executive guidelines (HSE 2012). The depth of the locker partitions has been fixed at 80cms, based on the minimum width to which the selected spaces in within GOSH may be reduced, established during consultation with estates and facilities staff. The width of the locker partition represents the maximum practical width for the door of a partition, this restriction is also a result of consultation with staff at GOSH.

Intuitive Partition Allocation

The second 'Intuitive' method comprises partition sizes determined according to the total order population, which was condensed into consignment types of the same volume, generating 36 different consignment types, each of which contains a single package size. The number of packages and their dimensions for each consignment size were fed into a linear model which identified the minimum length required for each of the following four locker box partitions, with the same restrictions for the 'Basic' partition allocation imposed on their height and depth. This is necessary to test the optimization of the critical dimension i.e. the length of the partition sizes, which consequently affects the length of the overall locker bank:

A) 170cm (66.9in) x 80cm (39.3in) x 80cm;
B) 80cm x 80cm x 80cm;
C) 40cm (15.7in) x 80cm x 80cm; and,
D) 20cm (7.9in) x 80cm x 80cm.

The calculations (Equation 1) assume each package is stored upright, restricting its rotation by 90º on the x-axis. The package is rotated so that the longest horizontal length is positioned against the depth to minimize the required length of the locker. The algorithm determines how many packages in the consignment can fit within a single 2-D vertical footprint for each partition (as defined above). The overall length of the partition (L_{pi}) is determined by the length of the packages (l_{bi}) being deposited within each 2-D footprint multiplied by the total number of footprints required to accommodate all the boxes within the consignment (nV).

$$L_{pi} = nV \times l_{bi} \qquad [1]$$

This process returned a required length for the four locker partitions for each consignment. The consignments were assigned to a partition size based on the 'best-fit' according to the shortest required length and minimum residual space. If the required length for two or more partitions was the same for a consignment, it was assigned to the smallest of the partitions. Furthermore, if the required length of a locker partition exceeded 80cm, the consignment was divided into equal parts (i.e. halves or thirds) for practical reasons pertaining to the opening of the locker doors within hospital corridors. These allocations were superimposed onto the annual population to generate a demand for the locker bank.

The required length of the four partitions was defined according to the maximum length required to accommodate the largest consignment assigned to the partition. This process generated the following lengths for each partition:

A) 74cm (29.1in)
B) 37cm (14.6in)
C) 30cm (11.8in)
D) 37cm (14.6in)

Locker Box Unit Model

The locker box model takes the listing of consignments received on each day, sub-divided into the pre-sized partitions A, B, C and D. The aim of the model is to establish the optimal combinations of partitions that allow a maximum number of orders to be stored within the smallest space possible.

A genetic hill climbing optimization methodology is selected over the full genetic algorithm to find optimal combinations of box partitions. Hill climbing algorithms present a more straightforward, iterative approach to a heuristic problem. They begin with a random solution to a problem and attempt to find a better solution by incrementally changing a single element of the solution. If the change produces a superior result all subsequent changes are made to the new solution, repeating the solution until it can no longer be improved (Russell and Norvig 2010); whereas, full genetic algorithms attempt to emulate the process of natural evolution through the pairing of solutions (parents) and the reproduction of new solutions (children) derived from the constituents of the starting pair. This process is repeated with the children, selecting the superior candidates for "reproduction" until no further improvements can be achieved (Russell and Norvig 2010).

The rationalization for the selection of the hill climbing algorithm is due to the relative small size and smoothness of the 'search space' (variation of and total number of possible solutions / combinations) being optimized, therefore minimizing the possibility of the algorithm becoming finding a local optima instead of a global optimum (Russell and Norvig 2010). In addition to this, research indicates that hill climbing algorithms can achieve similar or the same optima as other "efficient" genetic algorithms, with greater speed (Rojas 1996). The genome for a candidate is a sequence of locker box partition allocations of varying sizes, as defined above, such as "A-A-B-B-C-C-D-D". Each gene allele (possible locker bank partition) is selected at random from the available partition sizes which is hard-coded to 4 different variations A, B, C and D. The initial candidate pool (population of randomly generated locker banks with differing locker partition combinations) is tested for fitness and survival in order to determine the best candidate. The term survival references a locker bank's ability to accommodate all items from each order. This is determined by the following process: each day is tested and if an order cannot be fitted within the partition combination then the coverage value (percentage of consignments accommodated within the locker bank) is reduced. If the coverage falls below the minimum coverage value (i.e.

the specified minimum % of consignments accommodated by the locker bank) then the genome is discarded. Surviving genomes are then tested for fitness.

The fitness function uses a First Fit Decreasing Height strip packing algorithm *(Lodi et al. 2002)* where the returned fitness value is the length of the bounding box for all the locker partitions packed into the required number of strips. Therefore, given a scenario of two locker bank configurations which accommodate 100% of all consignments, the configuration which yields the shortest overall locker bank length will be selected. Once this process has been completed the fittest individual is selected, from which a new population of locker banks (children) comprising new locker box partition combinations are generated. Each child is then mutated to create new individuals which are then tested for survival and fitness.

Results

Both tests were performed with varying degrees of minimum coverage, ranging from 100% of all deliveries to 80% (Table 1 and Figures 3 and 4), with a population of 11 automatically generated partitions, necessary to accommodate all consignments delivered on the 'busiest day'. This was necessary to accommodate the full variance of consignment numbers throughout the year.

Basic Model Results

The results for the Basic Model (Table 1) indicate that a locker bank of 4m in length will accommodate between 98% and 100% of all consignments for the year. Between 403 and 412 consignments will fit within a locker bank measuring 3.2m. Similarly there is no variation exhibited in the required length of the locker bank to achieve between 80% and 90% coverage of all consignments.

Intuitive Model Results

Results from the Intuitive Model indicate more optimal locker bank configurations are achieved for each coverage value, yielding a smaller maximum required length of 3.63m to accommodate 100% of consignments, as opposed to the 4m specified by the Basic Model. This is reflected in all stages of the modelling process (Figure 5).

Direct comparison of the results from the two models in Table 1 shows that the Intuitive Model returns required locker bank lengths ranging from 10% (100% coverage) to 116% (80% coverage) more optimal than those specified by the Basic Model. The results in Figure 5, provide a tool with which GOSH will be able to determine the coverage which can be achieved by any given amount of space which they have available to allocate for a locker bank. Graphical analysis of the results plotted in Log10-x, Figure 5, indicates that more detailed modelling methods such as that of the intuitive model, provide a higher utilisation of space, therefore achieving greater coverage values within the same amount of space as the current more basic method of locker bank specification.

However, analysis of the visual results for the locker partitions indicates that more optimal partition allocations and configurations are achieved with the Basic Model. This is due to the nature of the box sizing specification, being that all partitions are of equal width; and, that larger partitions are equally divisible by all smaller partitions. Conversely, the unallocated space present in the Intuitive model results suggest that further optimisation of the 'search space' can be achieved, with potentially higher coverage values. These results suggest that there is value in adopting more detailed methods to allocate space for locker banks.

Discussion

Interviews with clinical and non-clinical members of staff provided insight into the operational and contextual uses for a locker box system, including its wider implications within GOSH.

Operational Use

As demonstrated by the review of the literature unattended locker bank unit may enable faster flow of goods into the hospital, and enable out-of-hours deliveries to be made over-night providing next-day delivery of items. Non-clinical management and support staff considered that adoption of faster lead-times for all goods for PCUs was unattractive. However, support staff considered that adoption of faster lead-times for all goods for PCUs was unattractive. Whilst enabling faster delivery times is largely feasible for many manufacturers, a lead time of 24-48 hours is agreed by the hospital to encourage staff to anticipate demand and order products in advance to maintain 'safe' inventory buffers and prevent life threatening stock-out scenarios.

Contextual Scenarios

Faulty / Incomplete / Critically Urgent Items
Staff identified that on rare occasions, supplies received by the hospital arrived with faults/ incomplete contents/ breaches of containment, rendering them unfit for purpose. In such circumstances, materials management staff would source critically urgent items from local NHS Trusts which could generate considerable courier activity. In such scenarios, a locker box would provide a point of consolidation for all goods which are being sourced, providing greater levels of track-and-trace for items and faster delivery to the final point of use.

The reverse logistics system within the NHS is not designed to accommodate the consolidated processing of returns. Damaged or faulty stock is normally returned to source i.e. sent to the receipt and distribution store or pharmacy store and given to the courier to return to the company when the next delivery arrives. Studies have been undertaken within the NHS focussing on order consolidation to reduce the frequency and quantity of inbound deliveries (Breen 2004; DHL Excel Supply Chain 2012). Innovation in the form of the locker box could facilitate a more sophisticated model of reverse logistics and delivery consolidation being designed and executed. This same model could be applied in a customised form to deliveries / retrievals of stock from community pharmacies in the NHS and NHS clinics. Research conducted by Xie and Breen (2012) indicated a need for further 'Greening' (promotion of activities to proactively encourage the reduction / return of waste) of the pharmaceutical supply chain by adopting a cross-boundary approach. This approach involves all stakeholders e.g. practitioners, GPs, Patients, pharmacists etc, to design and facilitate an effective reverse logistics system. The locker box could be a crucial element in the facilitation of this, especially in providing an easy drop-off point for unwanted medicines.

Deliveries and Collection of Laboratory Samples
Interviewees identified the additional function the locker bank may provide in the deposit and collection of samples sent to the on-site laboratories at local NHS Trusts. Currently, samples are collected either through the receipts area or direct from the departments. A dedicated locker box would provide a separate location from which the samples could be left for collection. Should a sample require a refrigerated environment for storage, it may be possible for a dedicated temperature controlled container to be provided. In addition to this, the locker bank may also be used for the overnight delivery and collection of important mechanical / medical components required for testing.

Wider Implications

Out-of-Hours Deliveries
Potentially one of the greatest benefits the unattended locker bank system offers is out-of-hours deliveries of critically urgent items, providing improved: staff utilization, operational efficiencies, and transport, associated with reduced CO_2 emissions. Studies by Brom et al (Brom et al. 2011) and Holguín-Veras et al (Holguín-Veras et al. 2011) found that pilots of off-hour delivery programs provided reductions in costs and improvements in delivery conditions and staff utilization as a result of increased reliability in delivery times. A pilot of off-hours deliveries in Manhattan comprising 33 companies, receiving deliveries between the hours of 19:00 and 06:00, indicated economic benefits in the order of $147 to $193 million per annum as a result of travel time savings, reductions in CO_2 emissions for regular-hour traffic and increased freight productivity (Holguín-Veras et al. 2011).

In hospitals, on-call pharmacy staff normally respond to queries regarding stock availability at unsociable hours. An emergency stockpile (cupboard) is available for either security staff or the on-call pharmacist to access and dispense medication to patients. The locker bank could be used to stock critical stock items in non-pharmacy locations to make stock more accessible to staff. Stock would be secure and the recording of all stock movements through the system would enable more effective stock reconciliation.

Personal Deliveries
Personal deliveries, such as staff member's non-work related, private post, can represent a significant burden on a business' post-room. Studies by Song et al (Song et al. 2009) and Edwards et al (Edwards et al. 2009; Edwards et al. 2010) provide strong evidence to suggest that implementation of locker bank facilities at work locations would provide significant cost savings to carriers and customers in terms of reducing the travel associated with failed first-time delivery attempts and the collection of items from couriers depots.

There are currently an un-quantified number of personal deliveries ordered by staff received through the receipts department at GOSH. However, an analysis of the deliveries and servicing activities for the Transport for London, Palestra building in London, which employs 2,500 staff, found that 26% of 121 deliveries received over a 5-day period were attributed to personal staff orders (TfL 2011). With respect to GOSH, the delivery of personal orders may add significantly to hospital-related traffic; and, the sorting and delivery of such items can contribute to overloading of the receipts departments' human resources and storage capacity. As a result personal deliveries are regarded as undesirable by members of the supply chain teams and corporate facilities.

Using the proposed locker bank for receipt of such items was presented to clinical and non-clinical members of staff as a solution to this issue. The idea received negative responses from supply chain and corporate facilities staff who perceived that such a facility may act to encourage staff to request personal orders to be delivered to the locker bank, therefore reducing its available capacity and its ability to perform its primary function of accepting urgent medical items.

Reduction of Stock Shrinkage
The locker box could also be used for standard stock replenishment as well as the proposed urgent stock scenario presented above. This principle could also be applied to stock taken to the wards by hospital porters but not stored at the point of delivery. Stock could be locked away by porters for later retrieval by ward staff which has positive implications for inventory accountability. This is particularly pertinent where high value products are being delivered and where controlled drug theft from pharmacy is prevalent (Healthcare Risk Management 2010; Pharmaceutical Journal Online 2012) or when it needs to be held securely in a high security environment (Franklin et al. 2010; Pharmaceutical Journal Online 2012).

Conclusion

The flow of goods-in to GOSH has been found to operate at sub-optimal levels with poor vehicle load factors and the slow movement of urgent items between the external and internal supply chains, via a central receipts department.

An unattended electronic locker bank to which urgent items can be delivered to bypass the traditional route of supply, and enabling separation of urgent and non-urgent goods was proposed. The feasibility of a unit was tested using a ‘Basic’ and ‘Intuitive’ hill-climbing optimisation model. The results for which indicate a locker bank with a limited height (1.7m) and depth (0.8m) measuring 4m and 3.63m in length for the Basic and Intuitive models, respectively is required to accommodate 100% of all urgent consignments passing into the hospital during a typical week. The difference in the results between the two models indicates that there is some value in adopting a more detailed modelling approach for locker bank partition allocation, yielding a 10% space saving.

The expected benefits of the proposed system are the removal of an average of 8 urgent deliveries from the daily average number of ad-hoc deliveries [n=81], thereby allowing for consolidation of the remaining non-urgent deliveries.

Staff perceptions of the locker box concept were predominantly positive suggesting the locker bank would potentially improve the speed and quality of healthcare delivered to patients. Interviews also identified the wider extent of benefits which the concept can provide such as the returns of goods and personal staff deliveries.

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Table 1, Locker Bank Model Results

Coverage (%)	Number of Consignments Accommodated (n=425)	Basic Model		Intuitive Model		Efficiency Savings (%)
		Required Length [m (ft)]	**Partition Combination**	**Required Length [m (ft)]**	**Partition Combination**	
100	425	4.0 (13.17)	A,A,A,B,B,C,C,D,D,D,D	3.63 (11.92)	A,A,A,A,B,C,C,C,C,C,C	10
99	420	4.0 (13.17)	A,A,A,B,B,C,C,C,D,D	3.33 (11)	A,A,A,A,C,C,D,D,D,D	20
98	416	4.0 (13.17)	A,A,A,B,B,C,D,D,D	2.96 (9.75)	A,A,A,B,B,B,D,D,D,D	35
97	412	3.2 (10.5)	A,A,A,C,C,D,D,D	2.22 (7.33)	A,A,B,C,C,C,D,D,D,D,D	44
96	408	3.2 (10.5)	A,A,A,C,D,D,D,D	2.15 (7.08)	A,A,B,B,C,C,C,C	48
95	403	3.2 (10.5)	A,A,A,C,D,D,D	2.15 (7.08)	A,A,B,B,C,C,C	48
90	382	2.4 (7.91)	A,A,C,C,D,D,D	1.41 (4.67)	A,C,C,C,C,C,D,D,D,D	70
80(81%)	340	2.4 (7.91)	A,B,B,C,D	1.11 (3.67)	B,B,B,C,C,C,C,D,D	116

*81% minimum coverage was returned for the ‘stated’ minimum coverage of 80%
Coverage values are rounded down to the nearest whole percentage.

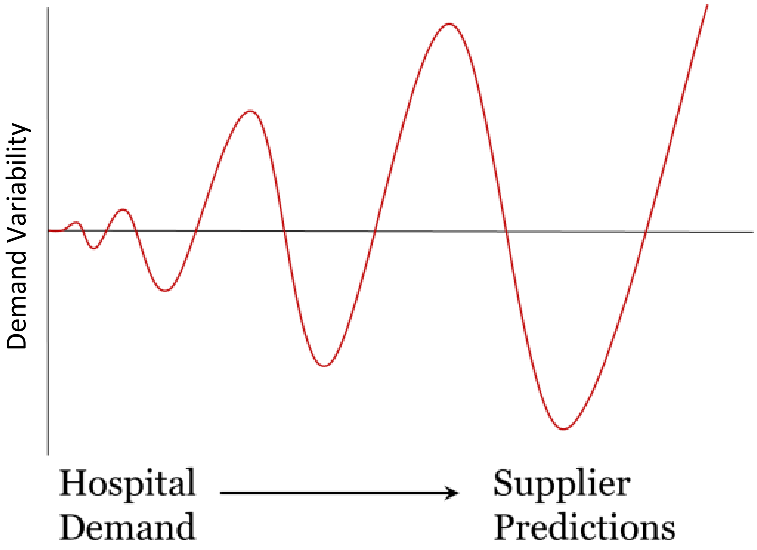
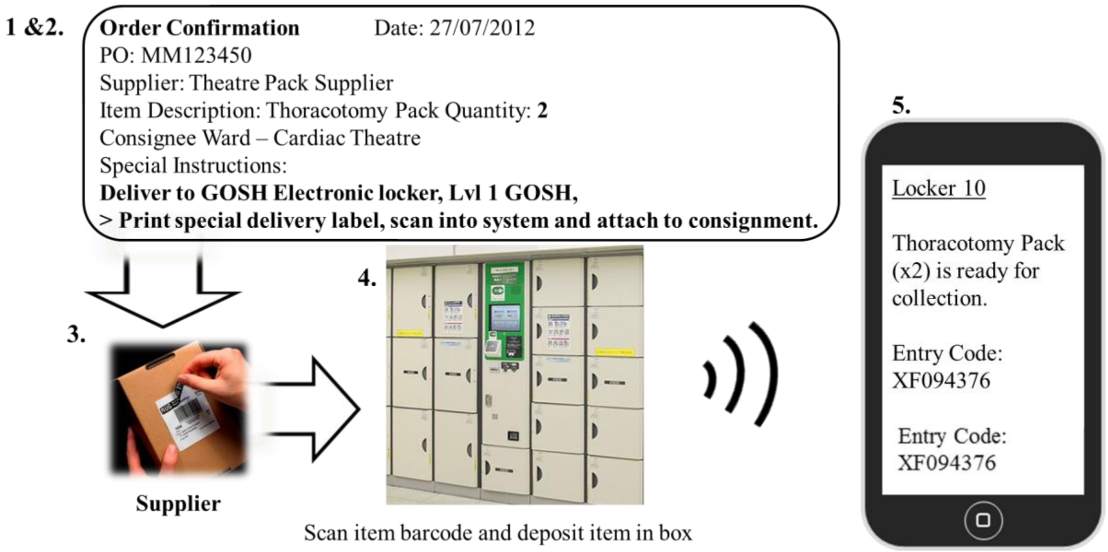


Figure 1, The Bullwhip Effect Trend



Order Confirmation Date: 27/07/2012
PO: MM123450
Supplier: Theatre Pack Supplier
Item Description: Thoracotomy Pack Quantity: **2**
Consignee Ward – Cardiac Theatre
Special Instructions:
Deliver to GOSH Electronic locker, Lvl 1 GOSH,
> Print special delivery label, scan into system and attach to consignment.

Locker 10

Thoracotomy Pack (x2) is ready for collection.

Entry Code:
XF094376

Entry Code:
XF094376

Figure 2, Locker Bank Process of Operation

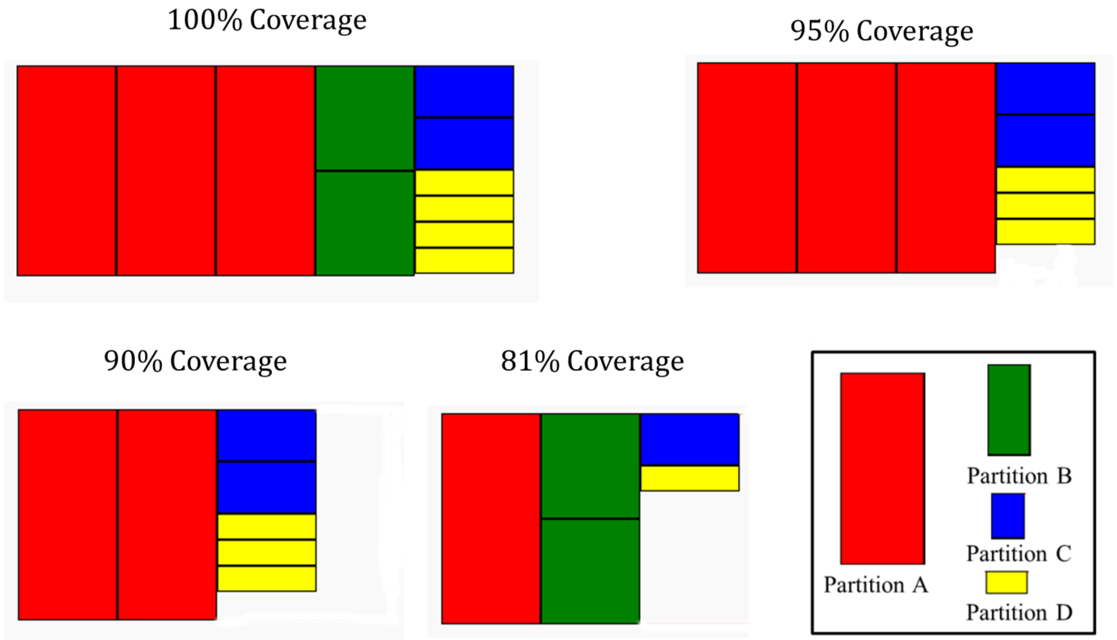


Figure 3, Basic Model Visual Results

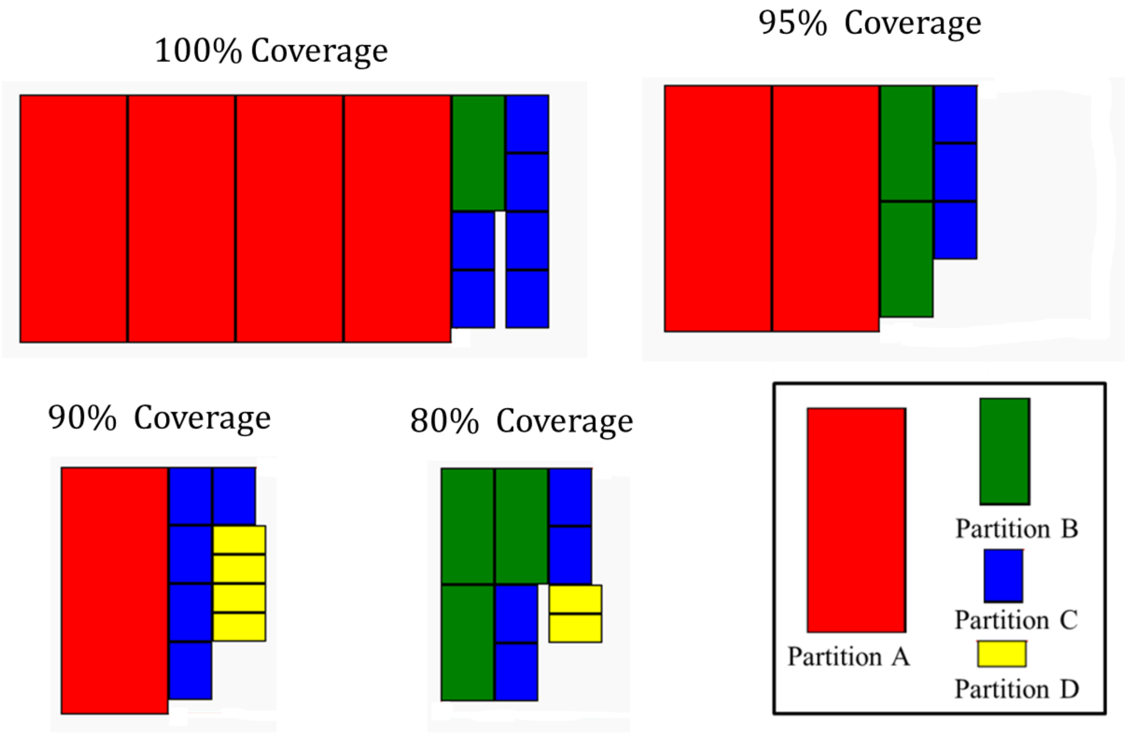


Figure 4, Intuitive Model Visual Results

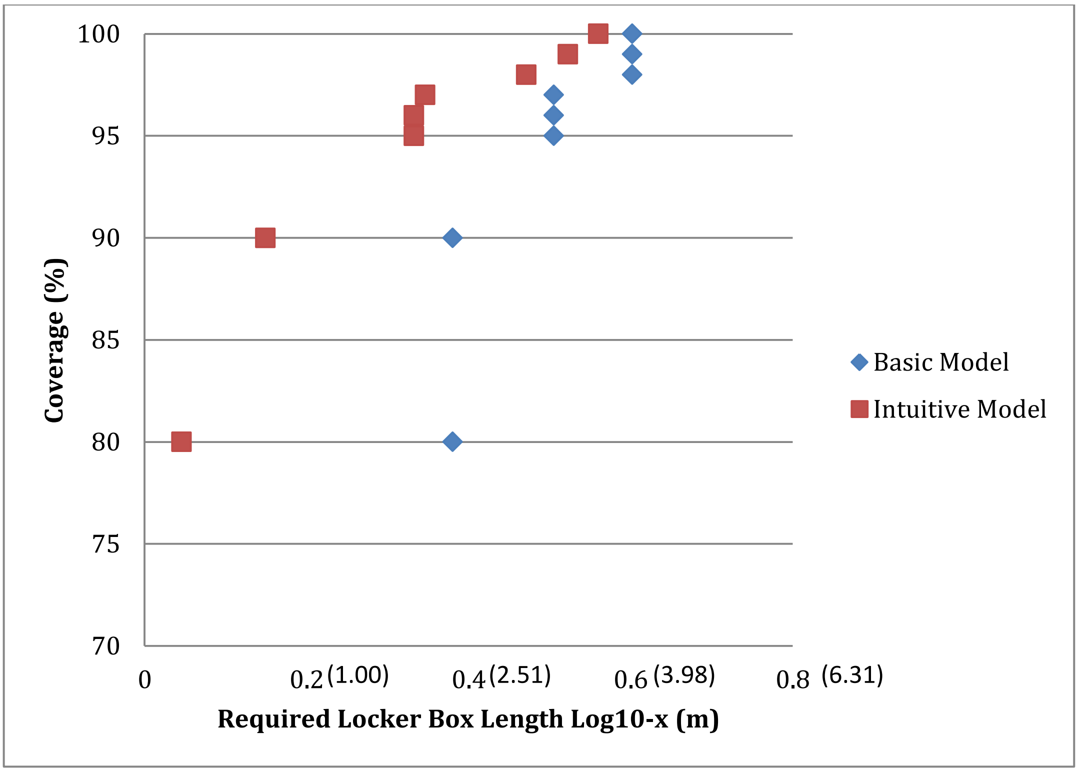


Figure 5, Graphical Analysis of Results

Keywords:

- Supply Chain
- Bullwhip effect
- Optimisation
- Out-of-hours delivery
- Healthcare
- Hospital logistics
- Unattended Locker Boxes
- Stockless inventory