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Can Locker Box Logistics Enable More Human Centric Medical Supply Chains?

Abstract

The fast flow of goods into hospitals is often stalled by the external-internal supply chain interface (i.e. the receipts department). This issue is particularly pertinent regarding the delivery of urgent items for specific patients or in the event of low inventory levels.

An unattended electronic locker bank to which individual urgent items can be delivered and subsequently collected by the 'user' was proposed for Great Ormond Street Hospital in London, UK. The feasibility of this concept is quantified using a hill climbing model operating with a significant database of consignment movements; and, qualitatively using staff interviews. Results indicate that a locker bank measuring 4m length, 1.7m height and 0.8m depth, comprising 11 partitions would be required to accommodate all urgent consignments for any given day. Staff perceptions of the concept were positive suggesting the locker would potentially improve the speed and quality of healthcare delivered to patients.

Keywords: Healthcare, Supply Chain, Bullwhip Effect, Optimisation, Out-of-hours delivery.

1. Introduction

Low or exhausted inventory levels of key items within hospitals (stock-outs) present a potentially fatal issue within healthcare logistics, the risk of which is partly mitigated through the maintenance of inventory buffers (Özkil *et al.* 2009, Costantino *et al.* 2010). Despite this, stock-outs continue to occur, largely attributable to the unpredictable nature of demand and the often poor flow of information throughout the supply chain which lead to inefficiencies or errors in procurement and sub-optimal product flows (McKone-Sweet *et al.* 2005, Jarret 2006, Black and Zimmerman 2012, Azzi *et al.* 2013).

These issues have resulted in considerable research focussed on improving the efficiency of healthcare supply to optimise the cost and efficiency of hospital operations. The main theme of this research has been on hospital-supplier collaboration to achieve optimised 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.* 2008a, Kumar *et al.* 2008b, 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 enabled 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, the speed of which can be hampered by the interface (receipts room) between the external supply chain, delivering goods to the hospital gates, and the internal supply chain which ensures the distribution of products to their consignee wards / departments (Aronsson *et al.* 2011).

The objectives of this paper are to:

i) examine the nature and structure of hospital supply, in relation to the delivery of urgent medical consumables outlining the key issues and exploring some of the solutions developed in the literature, in more detail (Section 3)
ii) present a hill climbing algorithm designed to quantify the optimal specification of locker combinations given the expected stock throughput. (Section 4 and 5).
iii) test the model using 12-months of historical hospital inventory records for urgent items

2. Hospital Supply Chains

2.1. 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 (Beggin 2011). The majority of patients are referred from general practitioners and specialists.

A survey of the goods yard undertaken by the authors at GOSH (November 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 the 2010 survey conducted by Steer Davis Gleave, which indicated that 366 deliveries were made by 219 vehicles on behalf of 145 suppliers, over a 5-day period. This increase is in accordance with the 9% growth in patient numbers in 2010 from 175,000 to current levels (GOSH 2011).

GOSH is representative of a common hospital logistics operating model where many of the deliveries received are processed through a single receipts area located within a service yard. All goods are sorted into cages for delivery to their respective departments in rounds performed by materials management staff / porters. Although a common delivery structure, it has been identified as a significant issue resulting in the delay and sometimes loss of urgent items, which can contribute to repeat orders.

2.2. The Nature of Supply

Hospital logistics are typically complex, managing significant quantities of materials and data (Rivard-Royer *et al.* 2002) throughout a fragmented management structure. They comprise numerous functional silos representing separate medical services and professions, each of which require bespoke supply chains to provide for planned and un-planned emergency medical care (Aronsson *et al.* 2011). Such requirements set the healthcare industry apart from other businesses which are able to estimate or predict consumer demand and manage the supply chain accordingly (de Vries *et al.* 1999). Much of the variability experienced in healthcare is attributed to at least three different factors:

1) Clinical variability, related to the numerous different ailments, severity levels and responses to treatment;
2) Demand variability, due to the unpredictability of patient requirements (i.e. emergency medicine and referred treatment); and,
3) Variation in the approaches to care and levels of care delivered by independent clinicians and care providers (Lega *et al.* 2012).

Given these uncertainties in demand, industrial and manufacturing techniques such as Just-In-Time (JIT) are deemed unsuitable for hospital supply considering the high potential consequences of stock-out situations (de Vries and Huijsman 2012, Stanger *et al.* 2012). Consequently, healthcare supply chains maintain inventory buffers to mitigate against excessive patient demand and stock-outs (Stanger *et al.* 2012). These are typically managed by employing either an 'Inventory-oriented Approach', currently practiced by GOSH and most state-managed NHS Trusts, whereby pre-established re-order levels are agreed by hospitals and medical departments (Lapierre and Ruiz 2005); or, a 'Scheduling-oriented Approach', for which purchasing operations, replenishments and supplier deliveries are accurately scheduled to ensure resource availabilities are respected and stock-outs avoided (Costantino *et al.* 2010). A study of Singapore hospitals conducted by Pan and Pokharel (2007) found this approach has been successfully implemented by small hospitals in Singapore, with low demand and the provision of 100 beds or less. Inventory approaches typically require more manpower and greater amounts of inventory storage space and therefore higher operational costs, however scheduling approaches require regular reviews of stock usage to ensure all schedules are accurate and up-to-date (Pan and Pokharel 2007).

The materials services within hospitals are responsible for generating large quantities of time-sensitive data (Singh 2006), much of which is indicative of hospital demand. Research into demand variance in healthcare supply chains has found that hospital orders exhibit considerable variability due to inaccurate and incomprehensive information (Shapiro and Byrnes 1992). This has been found to affect 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). Within GOSH, whilst most orders are procured via an electronic ordering system, a lack of visibility of information pertaining to current- / processed- / back- orders between the staff requesting, approving and receiving orders has been noted. This can result in situations where consignments which have not been checked-in to the receipts area go un-noticed for some time after their actual delivery, stalling the supply process and affecting the timely delivery of medical treatment to patients. Such issues create a lack of clarity in inventory demand between wards which can result in a 'bullwhip' effect, 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).

2.3. Structure of Hospital Supply

A key feature of healthcare logistics is the presence of an external and internal supply chain. The issue with this structure is the management of the external-internal chain interface, which is often complicated by multiple procedural and information systems, resulting in increasing costs and inefficiencies (Poulin 2003, Dembiríska-Cyran 2005).

Hospital supply is often based on one of three basic 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 and Pourjalali 2001)*.

GOSH employs a conventional – semi-direct hybrid delivery system with weekly replenishment for each medical department or bi-weekly for theatre departments and intensive care units, with daily deliveries of ad-hoc orders. All goods are received to the hospital through a single point via a goods-in yard where items are logged into an electronic record system and placed into designated cages ready for collection and delivery to their respective wards. This task is performed by materials management staff.

The direct delivery model removes the need for an external and internal supply chain. This approach was implemented within the U.S. and Canada from the 1970s to the 1990s in the form of the 'Stockless Inventory Approach'(Kowalski 1991) and operated on the principle of consolidating the hospitals' suppliers, and outsourcing the management of supplies to the remaining suppliers. This approach differs from the VMI, as suppliers take on all responsibilities of re-stocking, including the internal supply chain. This enabled sufficiently high levels of inventory visibility and transparency for suppliers to respond to demand, resulting in a higher frequency of supplier deliveries, greater mean vehicle fill-rates and a greater turnover of inventory, requiring fewer materials management and clinical staff to monitor and manage stock (Nicholson *et al.* 2004). However, a significant imbalance in the benefits between the hospital and the distributors, such as larger inventories stocked by suppliers leading to higher costs and additional work to prepare for orders, rendered stockless methods unattractive to suppliers (Rivard-Royer *et al.* 2002). Furthermore, owing to the specialist nature of many of the products supplied to hospitals such as GOSH, rationalization of suppliers becomes impracticable.

More recent studies including those of the stockless inventory approach have demonstrated that for organizations with unpredictable demand, supply chains operate better without intermediate tiers, a process known as disintermediation (Shapiro and Byrnes 1992). Considering the structure of the internal supply chain, disintermediation involves the removal of staff processes within the chain. In this context, an electronic locker bank system could be a potentially viable solution to disintermediate the chain at the point of the external-internal supply interface within hospitals, improving the flow of supply and information between suppliers and Patient Care Units (PCUs).

3. The unattended locker box concept

Unattended locker banks are an alternative delivery solution developed in response to the large proportion of failed deliveries attributed to online retail, estimated to cost UK retailers, carriers and consumers between £790 million (over $1.2 billion) and £1 billion (approximately $1.5 billion) per annum (IMRG 2010). The concept provides individuals / companies with a locker bank as an alternative delivery address (Rowlands 2007). Each locker bank comprises numerous secure box partitions, equipped with wireless communications (3G) to send notifications 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 request 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 that significant savings in operating costs and carbon emissions are achievable using unattended collection-delivery point facilities in the context of home-deliveries. In a study of failed delivery attempts, assuming 200 household drops per day, 60 failed first-time deliveries, and a further 30 failed second delivery attempts annual savings of: between £2,778 ($4,123) and £6,459 ($9,585) in carriers' transport costs and reductions in emissions of between 3.8 and 8.7 tonnes (4.18 to 8.59 tons) of CO_2 as carbon were estimated (Song *et al.* 2009). Such savings have created take-up of the concept within the field services sector, where field service engineers can order specialist parts to be delivered over night for the next-day (Rowlands 2007).

The proposed locker box concept is based on the traditional system operated in the field services sector, (Figure 1), 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 enable a more human-centric supply chain by informing the recipients of the arrival of urgent orders so that they may either personally collect the item or instruct an available staff member (clinician / support staff) to collect the item for immediate use. In this paper, it is assumed that the system would function according to a leading UK-based unattended delivery system (ByBox 2012):

1) A clinical practitioner places a request for an order with the Ward Sister, who is in control of the stocking of items for his / her ward, for items for a specific patient due to be transferred to the hospital for surgery the next-day, marking it as "urgent";
2) The order is processed through procurement who request delivery of the item to the locker bank operators 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 item barcode is scanned in by the courier 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 recipient ward's central phone informing the clinical practitioner of the items arrival. The item is collected either by the clinical practitioner / a nurse / materials management staff / porters, available to perform the task.

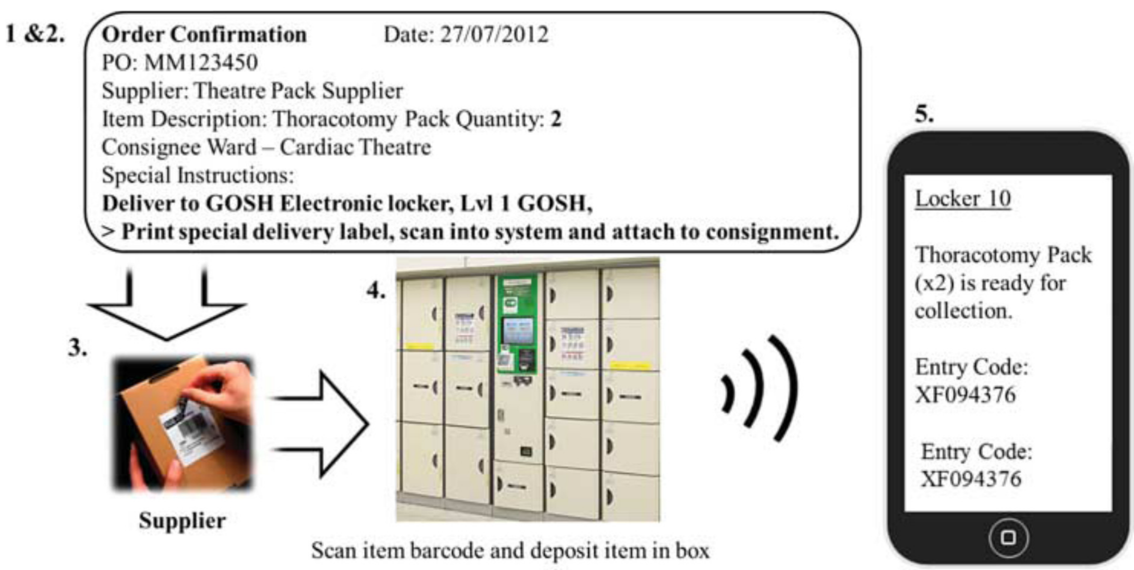

Figure 1. Locker bank process of operation

The locker bank concept differs significantly from intelligent medicine cabinet storage systems which represent an automatic inventory management system, re-ordering stock when levels diminish. Their aim is to aid the creation and maintenance of leaner supply chain operations and increase the levels and quality of inventory management, automatically reordering stock to replenish items removed for use (Amazon 2012, DHL 2012). Unattended locker banks provide a different service, serving only as a means for flexible, temporary stock holding (1-day maximum), informing a member of staff that a single specialist order / consignment is ready for collection.

4. Methodology

This study used quantitative (modelling) and qualitative (staff interviews) 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 concept; and, quantify the optimal dimensions of a locker bank according to the potential demand for urgent goods-in.

The model was 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[1], 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 actual delivery package dimensions for 63% of the 1,098 separate urgent product orders contained within 426 separate consignments from 2011/12 financial year (April to March) 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. These results revealed that orders were delivered within standardized packaging, returning 8 actual box sizes and 1 generated box size, Table 1

Table 1. Box sizes and frequencies.

ID	Box dimensions ($L \times W \times H$) (cm)	Quantity	% of population
1	22.5 × 15.2 × 2.7	33	8
2	27 × 14 × 130	10	2
3	28 × 42 × 94	13	3
4	30 × 37 × 17	20	5
5	32 × 16.5 × 6.3	9	2
6	37 × 30 × 17	126	30
7	38 × 27 × 19.8	15	4
8	57 × 37 × 25.5	57	13
9	44.7 × 32.4 × 28.9 [generated]	143	34

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 unattended locker bank concept outlined in the previous section. They were then asked to provide feedback on the following subjects: the perceived uses / benefits for the locker bank with regards to: next-day delivery; faulty / incomplete item scenarios; the deposit and collection of lab samples; inter-departmental transfers; out-of-hours deliveries; stock-critical items, such as small, high value / controlled items; the reduction in staff time for managing urgent items; and, the improved recording of urgent items.

[1] Formally, "Head Nurse, Clinical Equipment, Products and Practices"

4.1 Locker Box Modelling

4.1.1. 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. For example, ByBox determines the requirements for many of their locker banks on the basis that an undisclosed proportion of deliveries made are approximately the size of a shoe box or smaller (Turner 2011). In consideration of this, the total order population was assigned to one of 4 hard-coded locker partitions, representative of: full-, half-, quarter- and an eighth- the approximate height provided by the UK Health and Safety Executive height restriction (170cm) safely lifting items (HSE 2012):

A) 170cm x 80cm x 80cm;
B) 87.5cm x 80cm x 80cm;
C) 58.3cm x 80cm x 80cm; and,
D) 21.9cm x 80cm x 80cm.

The locker width and depth were restricted to 80cm on account of practically reducing the usable width of hospital circulation spaces. A 5th partition "E" was allocated with zero dimensions to allow the model to achieve optimal results when testing lower coverage scenarios. Each consignment was assigned to the smallest feasible locker partition and all subsequently larger partitions in order to achieve full optimization of the available lockers. If a consignment did not fit within the largest available partition size, it was divided into equal parts (i.e. halves or thirds) until it did.

4.1.2. Locker Box Unit Model

A genetic optimization algorithm is used to search for the optimal locker partition combination. 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 maximally optimal combinations of partitions that allow a maximum number of orders to be stored within the smallest space possible. A genetic hill climbing optimization algorithm is selected over the full genetic algorithm to find optimal combinations of box partitions. This methodology represents a heuristic approach to the issue of finding the optimal combination of box partitions without the necessity of analysing a significant number of permutations. The algorithm performs a search for the optimal locker box partition arrangement, adjusting the arrangement for each iteration and then determining whether the change improves the fitness (proportion of consignments that can be accommodated). Once an improvement can no longer be found, the remaining combination is considered optimal. For a more detailed description refer to, (Russell and Norvig 2010). The rationalization for using a hill climbing algorithm is due to: the relative small size and smoothness of the 'search space' being optimized, therefore minimizing the possibility of the algorithm becoming 'trapped' within local optima (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 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 is tested for fitness and survival in order to determine the best candidate (Figure 2). Survival is determined by the ability of the selected genome to accommodate all items from each order. This is examined by testing the consignments from each day, 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 then the genome is discarded. Surviving genomes are then tested for fitness.

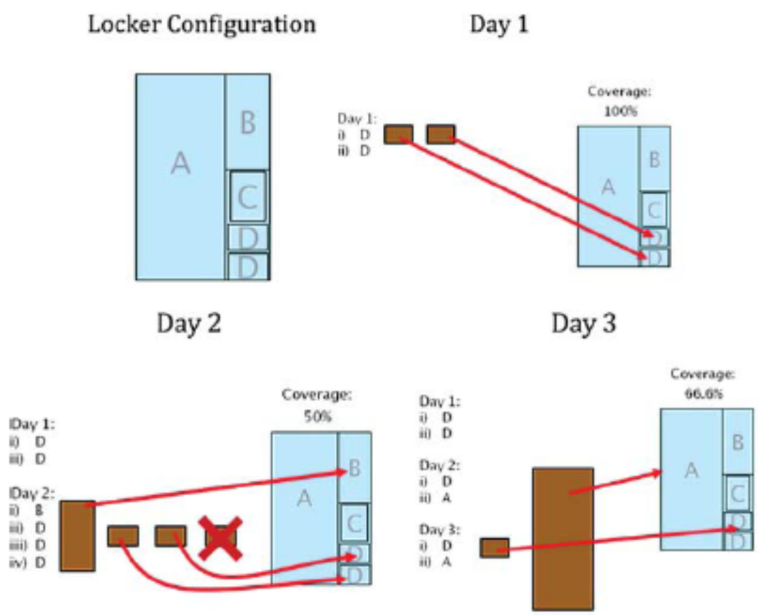

Figure 2. Process for test for coverage.

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. When a step is performed the fittest individual is selected and all candidates' genomes are overwritten with its sequence. Each child is then mutated to create new individuals which are then tested for survival and fitness. The candidates are reordered and the packing diagram is updated.

5. Results

The model was tested with varying degrees of minimum coverage, ranging from 100% of all deliveries to 80% (Table 2 and Figure 3), 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. The addition of partition "E" with zero dimensions allowed the algorithm to achieve optimal partition combinations for lower coverage scenarios enabling the omission of instances for the 'busiest day' consignment numbers.

Table 2. Locker bank model results.

Coverage (%)	Number of consignments accommodated ($n = 425$)	Basic model: Required length (m)	Basic model: Partition combination
100	425	4.0	A,A,A,B,B,C,C,D,D,D,D
99	420	4.0	A,A,A,B,B,C,C,C,D,D,E
98	416	4.0	A,A,A,B,B,C,D,D,D,E,E
97	412	3.2	A,A,A,C,C,D,D,D,E,E,E
96	408	3.2	A,A,A,C,D,D,D,D,E,E,E
95	403	3.2	A,A,A,C,D,D,D,E,E,E,E
90	382	2.4	A,A,C,C,D,D,D,E,E,E,E
80 (81%)[a]	340	2.4	A,B,B,C,D,E,E,E,E,E,E

[a]81% minimum coverage was returned for the 'stated' minimum coverage of 80%.

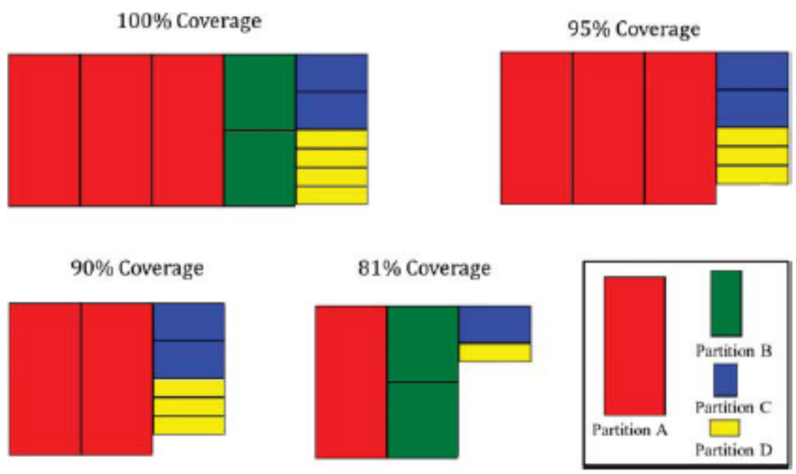

Figure 3. Visual configuration of results.

Analysis of the results indicated that a locker bank measuring 4m in length would accommodate between 98% and 100% of all consignments for the year. Between 403 and 412 of the total consignments would fit within a locker bank measuring 3.20m. The stepped decrease in length can be directly related to the number of partition "E" allocated to the locker bank.

Surplus space within the imaginary limits of the specified locker bank suggested that additional optimization of the available space may be achievable.

5.1 Operational Use

Delivery Notification and Collection of Items

The most optimal process for notifying of an items arrival was determined from consultations with key staff. Given that hospital bleepers and mobiles are only provided to support staff, the central phone systems for each ward would be the most appropriate form of communication. Notification of an items delivery would be best sent via the switchboard / help-desk, who would then forward the message and necessary security information to open the locker partition onto the intended recipient for collection. This process represents the same one used for emergency contact of personnel throughout the hospital. It is expected that the additional traffic through the switchboard (on average 8 notifications daily) would not cause any adverse effects on its daily operation.

Interviews with clinical members of staff also indicated that given the inherent urgency of an item being delivered via the locker box, collection of an item would be performed by any member of staff who was available at that time. This would include all members of the clinical and non-clinical teams, i.e. nurses, doctors, materials management and porters. Furthermore, owing to the greater traceability of items through the locker bank system, a reduction in the amount of time spent locating missing items is expected, in addition to better overall time management. Such time savings would outweigh the time required for staff to perform individual collections from the locker bank unit.

Due to the optimal configuration of the locker bank, a 'fail-safe' mechanism would be required to ensure that, should an item not be collected before 08:00 the next day, materials management staff would collect it and deliver to the recipient PCU. This mechanism represents the current system in-place, and therefore carries the same issues for an items correct / intended use as an item may be collected and sent to the ward / department store without specific linkage to the intended patient.

Next-Day Delivery

Results from clinical staff interviews identified the extended lead-time between the day of order and time of goods receipt was a common issue affecting the timely delivery of care to patients. Whilst it has been identified that this lead-time can be artificially extended due to bottle-necks at the receipts area, staff suggested that a reduction in the agreed 48-hour lead-time would improve the delivery of treatment to patients.

An unattended locker bank unit would facilitate this, enabling out-of-hours deliveries to be made over night for next-day delivery collection. Non-clinical management and support staff perceived this to be of use predominantly to laboratories and in the event of unpredictable patient demand. However, adoption of faster lead-times for all goods for PCUs is regarded as unattractive. Whilst achieving faster delivery time on goods 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 of requiring them to maintain a 'safe' inventory buffer and prevent potentially life threatening stock-out scenarios.

5.2 Contextual Scenarios

Faulty / Incomplete Items / Critically Urgent Items

Staff identified that on rare occasions, supplies received by the hospital may arrive with faults / incomplete contents or breaches of containment, rendering them unfit for purpose; or, supplies may be required for a same-day transfer. In such an event, when an item is in immediate demand without replacement items available, materials management staff contact local NHS Trusts to locate the required item. In such circumstances, items may be sourced from numerous Trusts within separate geographical locations, collected by separate couriers. Use of a locker box would provide a point of consolidation for such goods, providing greater levels of track-and-trace for items and faster delivery to the final point of use.

Deliveries and Collection of Laboratory Samples and "Long-life" Transplants

Non-clinical members of staff suggested that the on-site laboratories which occasionally require further testing to be conducted at local NHS Trusts off-site may benefit from use of the system.

Currently, samples are collected either through the receipts area or direct from the department. A dedicated temperature controlled locker box partition would provide a separate location from which the samples could be left, allowing for a faster, more efficient collection process. Such provisions would also allow for the deposit of "Long-life" / slow perishing transplants such as Cornea, which can upon occasion be left within theatre areas unattended and unchecked.

Inter-Departmental Transfers

Interviews with clinical members of staff indicated that on average, 60 person-to-person inter-departmental transfers occur per week. Such transfers are necessary to manage the stock-out situations on wards which in-turn create difficulties in the management of inventories and individual ward budgets. Using the locker bank for inter-departmental transfers received negative responses from interviewees. The perceived benefits of improved inventory management afforded by the use of locker banks for inter-departmental transfers were outweighed by the speed at which a person-to-person transfer can be completed.

6. FURTHER CONSIDERATIONS

6.1 Locker Box Location

An analysis of the top 5 departments receiving non-stock orders for the duration of the 2011/12 financial year, indicated that situation of the unit within close proximity to Theatre departments, Interventional Radiology (189 orders), Perfusionist (57 orders) and Cardiac theatres (49 orders), would be most appropriate.

The main issue to consider in implementing a locker bank is the physical space required to accommodate a system within a secure and convenient location, easily accessible to those delivering and collecting items i.e. close to areas of use and within clean / sterile areas of the hospital so staff are not required to change their clothing to make collections.

In addition to this, whilst the locker box units are secure, situation within an area to ensure security during delivery and collection, when items are most exposed to theft and tampering must be considered.

Recognition of such requirements may require adaptation of the locker bank concept to enable dual-entry for delivery of items from one side and collection by staff within a clean hospital environment from the other. Consideration of the availability and potential interference of wireless communications within selected locations due to signal disruption from the built environment is also required to accommodate electronic locker banks.

Potential issues regarding more detailed workflow arrangements and mobile communications availabilities are recognized but are however beyond the scope of this paper.

6.2 Wider Implications

Out-of-Hours Deliveries

Potentially, one of the greatest benefits the unattended locker bank system offers in facilitating consolidation is out-of-hours deliveries of critically urgent items, providing potential savings on staff utilization, operational efficiencies, and transport associated CO_2 emissions. Studies by Brom *et al.* (2011) and 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).

7. CONCLUSION

With the use of a hill climbing optimization algorithm and staff interviews, the feasibility of implementing an unattended electronic locker bank to which urgent items can be delivered in order to separate urgent and non-urgent goods within the medical supply chain has been tested. Results from the model indicate that a locker bank measuring 4m in length, 1.7m height and 0.8m depth, comprising of 11 partitions would be required to accommodate all urgent consignments passing into the hospital during a typical week. The expected benefits of this are the removal of 8 urgent deliveries from the average daily number (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: greater levels of accountability for small high value items, and a secure location for "long-life" transplants, which can upon occasion be left within the theatres area unattended, to be deposited.

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