THE HIDDEN LIFE SAVER? – UNATTENDED LOCKER BOX LOGISTICS FOR FASTER AND MORE EFFICIENT HOSPITAL SUPPLY

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ABSTRACT

The efficient flow of goods into hospitals is disrupted by the presence of time critical (urgent) items in the chain encouraging sub-optimal vehicle fleet operations. Furthermore, the fast delivery of such items can often become stalled by the transition between the external and internal supply chains, leading to duplicate ordering. These issues result in increased volumes of hospital-related traffic and a delay in the delivery of care to patients.

An unattended electronic locker bank, comprising individual lockable boxes to which different urgent items can be delivered is proposed as a potential solution with the aims of: separating urgent and non-urgent goods in the chain, thereby enabling consolidation of non-urgent consignments; and, bypassing the traditional route of supply.

The feasibility of this concept was tested in the context of Great Ormond Street Hospital for Children in London using a database of consignment movements to assess physical requirements of the locker bank, using a hill climbing optimization technique; and, qualitatively using interviews with key members of staff.

Results of the quantitative analysis indicated that a locker bank measuring 3.33m (10.93ft.) in length, 1.7m (5.58ft.) height and 0.8m (2.62ft.) depth, comprising of 11 partitions would be required to accommodate 100% of all urgent consignments passing into the hospital during a typical week. Staff perceptions of the locker bank concept were largely positive suggesting the locker box could improve the speed and quality of healthcare delivered to patients.

Key Words: Supply Chain, Bullwhip effect, Optimization, Out-of-hours delivery

INTRODUCTION

The convergence of increasingly larger numbers of people and resources within cities is generating significant pressures on urban freight networks which are widely considered to be a vital part of urban economies *(1)*. Previous research into traffic generators, within the UK, found that 5% of all traffic can be attributed to the healthcare industry *(2)*. Much of which can be linked to inefficient operating practices (such as the provision of large inventories) developed in response to the unpredictable nature of hospital demand to prevent exhaustion of hospital goods (stock-outs) *(3)*. In spite of these practices, stock-outs are still experienced due to unusual demand*(4)*, disparities in inventory requirements between hospitals and suppliers, and faulty goods, which can result in increased numbers of ad-hoc deliveries to meet requirements. The presence of such time critical items within the chain can also contribute to sub-optimal vehicle load factors (fill-rates) due to the higher frequency of deliveries required to supply urgent stocked-out items.

In addition to this, the fast flow of goods into hospitals is often hampered by the interface between the external supply chain delivering goods to the hospital gates, and the internal supply chain ensuring the distribution of products to patient care units (PCUs) for patient treatment *(5)*. This delay can result in duplicate orders of inventory and additional trips to neighboring hospitals to procure the required goods.

This paper presents an unattended locker bank as a potential solution to these issues to enable for the separation of urgent and non-urgent goods in the supply chain, thereby allowing for suppliers / distributors to consolidate consignments to increase vehicle fill-rates; thereby reducing traffic by increasing fleet efficiency. The locker bank is also intended as a means with which to remove nodes in the supply chain (dis-intermediation) and enable direct delivery of items to the consignee, bypassing the communal ‘goods-in’ facility. This concept is tested in the context of Great Ormond Street Hospital for Children (GOSH) National Health Service (NHS) Foundation Trust in London, using data on consignment deliveries to assess the feasibility of a locker bank according to the required physical dimensions of a unit capable of accepting urgent goods demand.

Great Ormond Street Hospital

GOSH is a tertiary care NHS Trust comprising of 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 *(6)*. The majority of patients are referred from general practitioners and specialists.

A recent 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 revealed 366 deliveries to be completed 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*(7)*.

Analysis of vehicle fill-rates recorded during the survey revealed an average fill-rate of 40% for all vehicles, indicating sub-optimal freight traffic to the hospital. This can be linked to the presence of urgent items in the chain (requiring delivery within 48-hours) which accounted for approximately 1.9% of deliveries during the survey.

In addition to this, 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 resulting in the delay or loss of urgent items, which can contribute to duplicate orders.

HOSPITAL SUPPLY CHAINS

Hospital logistics are typically complex, managing significant quantities of materials and data *(8)* throughout a fragmented management structure. They comprise numerous functional silos each of which represent separate medical services and professions, which require bespoke supply chains to provide for planned and un-planned emergency medical care *(5)*. 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 *(9)*. Much of the variability observed 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 *(10)*.

Given these uncertainties in demand, industrial and manufacturing supply concepts such as Just-In-Time (JIT) are deemed unsuitable for hospital supply considering the high cost of stock-out situations such as patient illness or death *(11, 12)*. Consequently, healthcare supply chains maintain inventory buffers to mitigate against long queues of patient demand and stock-outs *(11)*. These are 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 *(13)*; 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 *(14)*. The scheduling-oriented approach has been successfully implemented by small hospitals in Singapore, with low demand and the provision of 100 beds or less *(15)*. 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 *(15)*.

The materials services within hospitals are responsible for generating large quantities of time-sensitive data *(16)*, 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 *(17)*, affecting supplier's abilities to respond, in some cases impacting on the hospital's ability to deliver quality patient care and treatment*(14, 18)*. Unclear inventory demand between wards can also create 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 *(19)*.Such issues contribute to inefficient vehicle load factors and a higher frequency of deliveries in order to accommodate such variability in demand.

THE STRUCTURE OF HOSPITAL SUPPLY

A key feature of healthcare supply is the presence an external and internal chain. The issue with this structure is the management of the external-internal chain interface, which is often complicated by multiple procedures and information systems operating within the hospital, resulting in increasing costs and inefficiencies *(20, 21)*.

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*(22)*.

GOSH employs a semi-direct 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 via a goods-in yard where items are sorted and then forwarded to their respective ward / department store. Due to the nature of this model and the average size of ward stores (86.5 m^2 (931 ft^2)) no more than two weeks provision for each item is stocked. However, low-use, high-cost items (e.g. OxyTip sensors, used to monitor blood oxygen saturation levels) are ordered in bulk to achieve the necessary discounts from the supplier and, are kept within dedicated stores.

The direct delivery model attempts to remove the need for an external and internal supply chain, present within the first two models. This approach was implemented within the U.S. and Canada from the 1970s to the 1990s in the form of the 'Stockless Inventory Approach'*(23)*. It operated on the principle of consolidating the hospitals' suppliers to a minimum, and outsourcing the management of supplies to the remaining suppliers. This enabled sufficiently high levels of visibility and transparency of inventory usage for suppliers to respond to demand. This yielded a higher frequency of supplier deliveries, with greater vehicle fill-rates and a higher turnover of inventory, resulting in fewer materials management and clinical staff required to monitor / manage stock *(24)*. However, a significant imbalance in the benefits between the hospital and the distributors rendered stockless methods unattractive to suppliers *(8)*. 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 *(17)*. However, dis-intermediation has also been found to inhibit a company's ability to respond to demand variability *(25)*. By applying this concept in the context of a hospital supply chain, an electronic locker box system could be a potentially viable solution to separate urgent items from non-urgent consignments within the chain, allowing for consolidation of non-urgent orders into fewer vehicles. This would also dis-intermediate the chain at the point of the external-internal supply chain interface within hospitals improving the flow of supply and information between suppliers and PCUs.

THE UNATTENDED LOCKER BOX CONCEPT

Unattended locker banks are an alternative delivery solution developed in response to failed deliveries from online retailers, estimated to cost UK retailers, carriers and consumers between £790 million (over $1.2 billion) and £1 billion (approximately $1.5 billion) per annum *(26)*. The concept provides individuals / companies with a locker bank as an alternative delivery address *(27)*. 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 *(28-31)*. 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 *(28)*; whereas,
2) Amazon and DHL Packstation customers register with the service which allows them to provide a locker bank as the direct delivery address *(29, 30)*.

Studies by Edwards et al *(27, 32)* and Song et al *(33)* have demonstrated the significant savings in operating costs and carbon emissions achievable with these unattended collection-delivery point facilities 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 between 3.8 and 8.7 tonnes (4.18 to 8.59 tons) of CO_2 as carbon *(33)*. Such savings have created take-up of the concept within the field services sector, where field service engineers across numerous industries such as internet service providers and home appliances / utilities can order specialist parts to be delivered over night for the next-day *(34)*.

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 provide a separate supply chain for urgent items enabling consolidation of individual consignments to increase vehicle load factors; and, enable a more human-centric supply chain by linking key personnel in hospitals who can act quickly when specific stock items announce their arrival via the locker box system. In this paper, it is assumed that the system would function according to the leading UK-based unattended delivery system, to facilitate night-time delivery of items thereby reducing day-time traffic, increasing the speed of delivery and offering more efficient fuel consumption:

1) A clinical practitioner places an order of items for an emergency patient 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 locker bank operator receives the item, labels it with a unique barcode and / or Radio Frequency Identification tags and ships to GOSH overnight, delivering the item to the locker bank;
4) Once the item barcode 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 recipients' phone informing them of the items arrival.

It is recognized that this method does increase the number of vehicle-kms attributed to deliveries, however it is necessary to achieve the full range of benefits. Adaptation of the concept may be made to enable direct night-time delivery, thereby avoiding additional vehicle kilometers.

The locker bank concept 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 *(35, 36)*. 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.

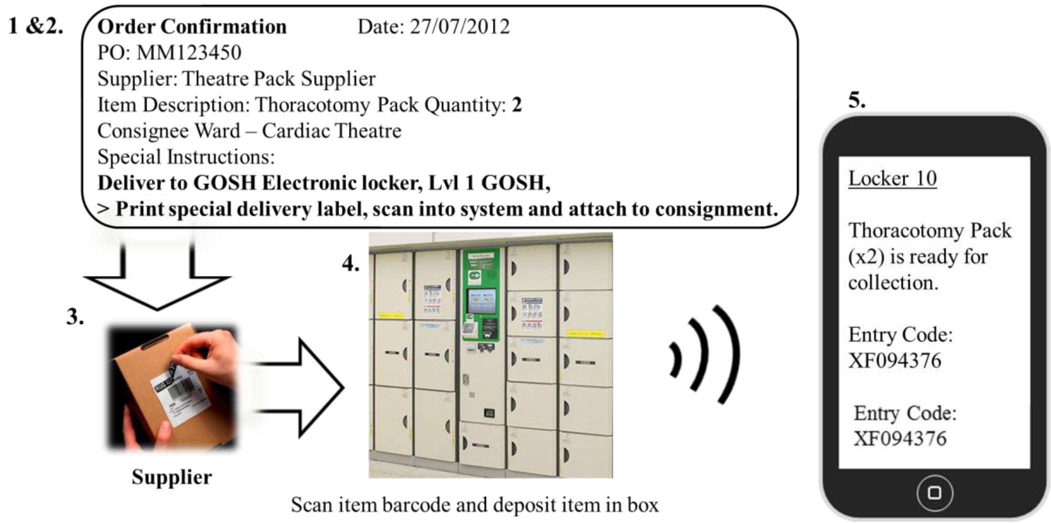

FIGURE 1 Locker Bank Process of Operation.

METHODOLOGY

This study uses quantitative (modeling) 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 of urgent goods-in.

The model was informed by the November 2011 survey data which captured ad-hoc deliveries and identified the product description, supplier / manufacturer name and consignee department for recorded deliveries. These product listings were presented to the Head Nurse, Clinical Equipment, Products and Practices, 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 425 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 only 8 different actual box sizes and 1 generated box size.

The qualitative assessment was conducted using one-to-one interviews with 5 key members of staff: 'Head Nurse, Clinical Equipment, Products and Practices'; Head of Corporate Facilities; Supply Chain management; and, a Ward Sister 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 Modeling

Locker Box Partitions and Demand

The total order population 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 identifies the minimum length required for each of the following four locker box partitions, with restrictions imposed on their height and depth:

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

$$L_{pi} = nV \times l_{bi}$$

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 two, 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. The rationalization for this is due to the relative small size of the 'search space' being optimized *(37)*. 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. Survival is determined by the ability of the selected genome to accommodate all items from each order. 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 then the genome is discarded. Surviving genomes are then tested for fitness.

The fitness function uses a First Fit Decreasing Height strip packing algorithm *(38)* 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.

RESULTS

The model was tested with varying degrees of minimum coverage, ranging from 100% of all deliveries to 80% (Table 1 and Figure 2), 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. Tests of minimum coverage of 80% and less generated the same results, suggesting that optimal configuration of 11 partitions will accommodate at least 80% of deliveries.

TABLE 1 Locker Bank Model Results

Coverage (%)	Number of Consignments Accommodated (n=425)	Required Length [m (ft)]	Partition Combination
100	425	3.33 (10.92)	A,A,A,A,C,D,D,D,D,D,D
99	420	3.33 (10.92)	A,A,A,A,C,D,D,D,D,D,D
98	416	2.96 (9.71)	A,A,A,B,B,C,D,D,D,D,D
97	412	2.22 (7.28)	A,A,B,C,C,C,C,D,D,D,D
96	408	2.22 (7.28)	A,A,B,C,C,C,C,D,D,D,D
95	403	2.22 (7.28)	A,A,B,C,C,C,D,D,D,D,D
90	382	1.41 (4.62)	A,C,C,C,C,D,D,D,D,D,D
80	340	1.04 (3.41)	B,B,C,C,C,C,D,D,D,D,D

The results in Table 1 indicate that a locker bank 3.33m (10.93ft.) in length will accommodate between 99% and 100% of all consignments for the year. Between 403 and 416 of the total consignments will fit within a locker bank measuring between 2.22m (7.28ft.) and 2.96m (9.71ft.).

Analysis of partition combinations shows a rapid decrease in the required number of partition A with a gradual decrease in the percentage of minimum coverage. Analysis of the demand data according to the 'best-fit' partitions for each consignment indicates that only 11% of deliveries require a partition A, a further 11% partition B, 0.5% partition C, and 78% partition D. This relationship is reflected in the combinations of partitions provided for each of the minimum coverage scenarios.

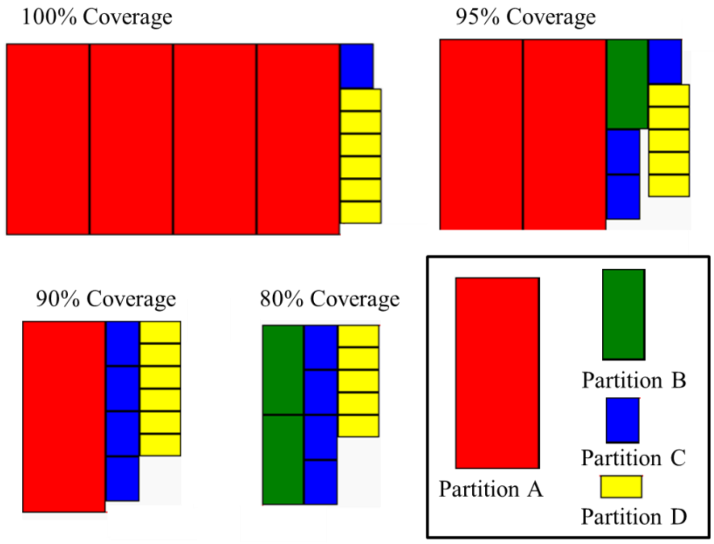

FIGURE 2 Locker Bank Model: Visual Output.

Assessment of the results in Table 1 represented in the Log-y transform of the required length (Figure 3) indicates a stepped increase and an exponential increase in the relationship between the minimum coverage and required length. These relationships explain the occurrence of gaps within the locker box diagrams (Figure 2), which allow for additional capacity to be provided without requiring an increase in the overall length of the locker bank.

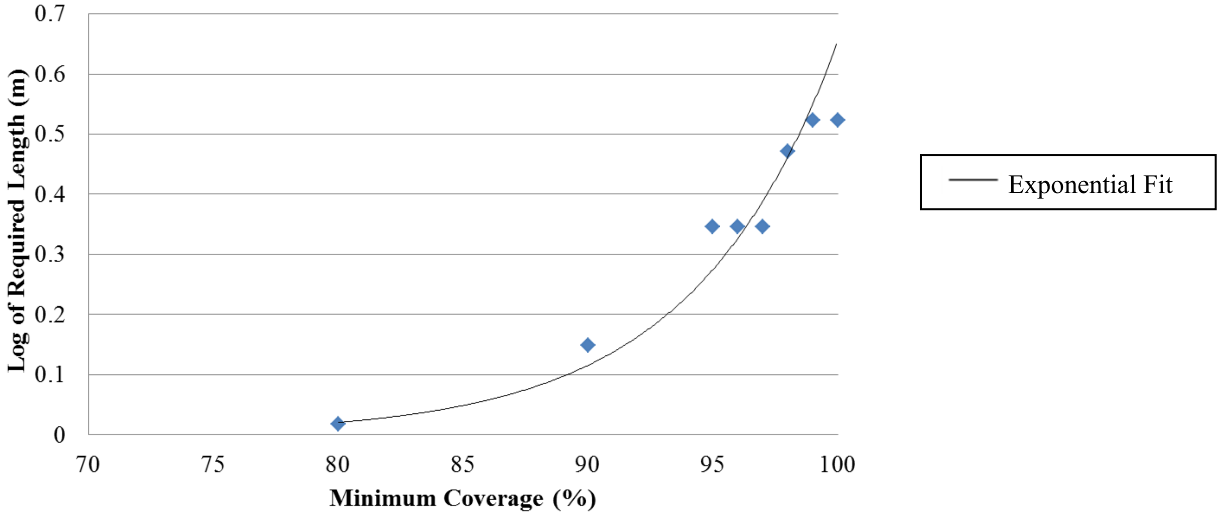

FIGURE 3 Required Locker Bank Length Against Minimum Coverage.

DISCUSSION

The locker box concept has been presented as a method for separation of urgent and non-urgent inventories and dis-intermediation of the internal hospital supply chain for orders of urgent items, which under 'normal' operations can become delayed within the receipts area. The main aims of this system are to: provide an alternate route of supply for urgent items to PCUs to enable consolidation of non-urgent consignments; and, increase the speed, visibility and monitoring of urgent items entering the hospital. Interviews with clinical and non-clinical members of staff provided insight into the contextual uses for a locker box within GOSH.

Operational Use

Delivery Notification and Collection of Items

Non-clinical members of staff were questioned regarding the process for notification of an items delivery. The original concept proposed to staff entailed confirmation messages being sent to the consignee's mobile phone / email address. However, interviewees identified that clinical members of staff are issued with hospital bleepers, and ward access to emails is intermittent and inconsistent. Therefore it was established that notification of an items delivery would be sent via the switchboard / help-desk, who may then forward the message and necessary security information to open the locker partition onto the intended recipient for collection.

Interviews with clinical members of staff also indicated that given an item being delivered via the locker box chain is urgent, collection of an item would be performed by any member of staff who is available at that time. This would include all members of the clinical team from junior to senior roles.

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 the item and deliver it to the recipient PCU. This mechanism however presents issues of an items correct / intended use as an item may be collected and sent to the ward / department store without specific identification of the patient it is intended for.

Next-Day Delivery

Results from clinical staff interviews identified the lead-time between the day of order and time receiving deliveries being a common issue. Whilst it has been identified that this lead-time can be artificially extended due to bottlenecks 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 providing next-day delivery of items. 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 enabling 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 life threatening stock-out scenarios.

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 / 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
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.

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 the required size 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.

FURTHER CONSIDERATIONS

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 XMR (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 is also required to accommodate electronic locker banks.

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 *(39)* and Holguín-Veras et al *(40)* 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 *(40)*.

Personal Deliveries

Studies by Song et al *(33)* and Edwards et al *(27, 32)* 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 *(39)*. 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.

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. These issues are particularly pertinent with the high frequency of ad-hoc deliveries and the provision of urgent items to the hospital for specific patient requirements.

An unattended electronic locker bank to which urgent items can be delivered in order to separate urgent and non-urgent goods, and bypass the traditional route of supply was proposed. The locker bank comprised numerous separate partitions (individual lockable boxes), each of which can accommodate various different consignments intended for different consignees. The practical feasibility of a unit according to the demand of urgent goods-in was tested using a hill climbing optimization technique and, staff interviews. Results of the quantitative analysis indicate that a locker bank measuring 3.33m (10.93ft.) in length, 1.7m (5.58ft.) height and 0.8m (2.62ft.) depth, comprising of 11 partitions would be required to accommodate 100% of all urgent consignments passing into the hospital during a typical week. The expected benefits of this are the removal of an average of 8 urgent deliveries from the daily average number of adhoc 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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