UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING AND THE ENVIRONMENT

Civil, Maritime and Environmental Engineering and Science

Transportation Research Group

Engineering Doctorate

Volume 1 of 1

Developing Sustainable Supply Chains for Healthcare

by

Gavin Bailey

Thesis for the degree of Doctor of Engineering

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ABSTRACT

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DEVELOPING SUSTAINABLE SUPPLY CHAINS FOR HEALTHCARE

Gavin Stephen Bailey

The focus of this thesis is to provide hospitals and local authorities in an urban setting with a set of recommendations for sustainable methods of supply for healthcare institutions, to minimise the negative externalities of freight associated with urban hospitals.

The structure and nature of the healthcare supply chain engenders unsustainable freight patterns as a result of the poor communication and unpredictability of inventory demand from hospitals to suppliers, resulting in high freight volumes (403 freight movements recorded over a 5-day period during a November 2011 survey), and the mixing of urgent and non-urgent goods within the same supply chain. In addition to this ancillary hospital services such as hospital laboratory couriers are found to be a large traffic generator with 476 individual services booked over a 3 month period (January – March 2014).

In fulfilment of these issues three solutions are proposed to improve the economic and environmental sustainability of freight: mobile consolidation, to address the high numbers of deliveries received by hospitals; unattended locker bank delivery, to separate urgent goods from the supply chain; and, consolidation of laboratory courier services.

Assessment of the mobile consolidation centre for GOSH only operating over 1 site to 4 sites, using 93 records from the 2011 freight survey indicated savings for the week between: 10,591 VKm (1 site operation) and 12,173 VKm (4 site operation); 181.53 – 225.05 journey time hours for 2 site and 4 site operations, respectively; and, 2 – 2.33 tonnes of CO_2 equivalents between 1 site and 4 site operations. Implementation of a London-wide scenario indicated reductions of 64,204 VKm, 579 Journey Time Hours and 89 tonnes of CO_2e.

Assessment of the proposed electronic locker bank was assessed using a hill climbing model operating with a database of consignment movements; and qualitatively using staff interviews. Results indicated that a locker bank measuring 3.69m length, 1.7m height and 0.8m depth, comprising 19 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.

Current hospital and courier service providers' practices centre on collecting items as and when they arrive for outward journeys at the hospital. Using a database of 323 courier journeys at Great Ormond Street Hospital, 8 different consolidation scenarios, varying the length of time an item is delayed (ranging between 30 minutes to 10 hours). Findings indicated that consolidated approaches yielded reductions in vehicle numbers, between 120 and 255, compared to the current model of operation, but that the current model of operation is actually more environmentally efficient, generating 0.42 to 0.84 fewer metric tonnes of CO_2 than consolidated approaches.

Assessments of other hospitals such as University Hospital Southampton indicated that the three proposed solutions may be considered relevant to other hospitals. However, in the city-wide context, the benefits for each solution when implemented at a single hospital site were minimal suggesting a greater number of hospital sites would be required to deliver larger gains.

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DECLARATION OF AUTHORSHIP*

I, Gavin Bailey

declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Developing Sustainable Supply Chains for Healthcare

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Parts of this work have been published as:

Bailey, G., Cherrett, T., Waterson, B., Breen, L., and Long, R., (2014) *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)*. International Journal of Procurement Management, Special Issue on: Smart and Sustainable Healthcare Supply Chain.

Bailey, G., Cherrett, T., Waterson, B., and Long, R., (2013) *Can Locker Box Logistics Enable More Human Centric Medical Supply Chains?* International Journal of Logistics Research and Applications, Post-Conference Proceedings.

Signed: ....

Date:..

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Special thanks goes to the important contribution made by friends and colleagues, Andrew Hamilton, James Hammond and Matthew Streeter for helping to perform the freight survey at GOSH, enduring very early starts and very cold days, survived only by numerous coffee and tea runs.

Finally I would like to thank James Snowdon for his contribution as a computational programming guru.

Abbreviations

3PL(s)	Third-party Logistics Provider(s)
BCA	Benefit Cost Analysis
BCCC	Bristol City Consolidation Centre
CEP	Carbon Monoxide
CPFR	Carbon Dioxide
CNG	Courier, Express Parcels
CO	Collaborative, Planning, Forecasting and Replenishment
CO_2	Compressed Natural Gas
dB(A)	'A' weighted Decibels
DECC	Department of Energy & Climate Change
DEFRA	Department for Environment, Food & Agriculture
DSP	Delivery and Servicing Plan
DVLA	Driver and Vehicle Licensing Agency
EC	European Commission
EDI	Electronic Data Interchange
EMEA	Europe, the Middle East, Indian subcontinent and Africa
EU	European Union
EU27	EU 27 Member States
FCC	Freight Consolidation Centre
FDA	Food and Drug Administration
FTC	Freight Transhipment Centre

GHG	Green House Gas(es)
GOSH	Great Ormond Street Hospital for Children's NHS Foundation Trust
GPO(s)	Group Purchasing Organisation(s)
GPS	Global Positioning System
GVW	Gross Vehicle Weight
HGV	Heavy Goods Vehicle
ICH	Institute of Child Health
ICT	Information and Communications Technology / Technologies
IDN	Integrated Delivery Network
IMRG	Interactive Media in Retail Group
IoT	Internet of Things
IoP	Internet of People
IV	Intravenous
JIT	Just In Time
LCCC	London Construction Consolidation Centre
LEZ	Low Emissions Zone
LGV	Light Goods Vehicle
MCC	Mobile Consolidation Centre
MRP	Materials Requirement Planning
$MtCO_se$	Million Metric Tonnes of Carbon Dioxide Equivalents
NHS	National Health Service
NHS SDU	National Health Service Sustainable Development Unit

NO_x	Nitrogen Oxides
OECD	Organisation for Economic Co-operation and Development
PCU(s)	Patient Care Unit(s)
PM	Particulate Matter
PM_{10}	Particulate Matter less than or equal to 10μm
QA	Quality Assurance
QR Codes	Quick Response Codes
R&D	Receipts and Distribution
RFID	Radio Frequency Identification
SO_x	Sulphur Oxides
tCO_2	Metric Tonnes of Carbon Dioxide
TfL	Transport for London
TSP	Travelling Salesperson Problem
UCC	Urban Consolidation Centre
UCL	University College London
UDC	Urban Distribution Centre
UFT	Urban Freight Transport
UHS	University Hospital Southampton
UK	United Kingdom
UNPFA	United Nations Population Fund Agency
VKm	Vehicle Kilometres
VMI	Vendor Managed Inventory
VRP	Vehicle Routing Problem

WEDI	Workgroup for Electronic Data Interchange

Chapter 1: Introduction

In recent years the freight transportation industry has been encouraged to adopt more sustainable operating practices to help reduce its negative impacts on congestion and air quality. This has been largely due to changes in policy drivers at both the European Union (EU) and United Kingdom (UK) level, focussing on the reductions in Green House Gas (GHG) emissions by 20% by 2030; and, 60% by 2050, against the 1990 baselines; and the goal of CO_2-free city logistics by 2030 (EC 2011) set out in the 2011 EU Transport White Paper. Understanding the trends driving Urban Freight Transport (UFT) and its main generators is vital to achieving these goals.

1.1 The Urban Freight Problem

In 2010, the United Nations Population Fund Agency (UNPFA) reported that 50 per cent of the World's population lived within urban areas, with over 930 million living in urban areas within North America, Japan, Europe and Australia-New Zealand (UNPFA 2012). Such trends are creating a dichotomy between increasing demand for goods and services and limited UFT networks to provide such services (Boerkamps and Binsbergen 1999; TfL 2007; Björklund and Gustafsson 2012; Browne et al. 2012). The problem is compounded by the variety of delivery options tailored to cater for each individual consumer's needs, particularly amongst the courier, express and parcel (CEP) service providers delivering online goods. These trends require a large number of small carriers duplicating each other's routes with small and frequent deliveries across significant distances in greater numbers of vehicles with decreasing load factors (Browne et al. 2007; Häger and Rosenkvist 2012; Kaszubowski 2012).

The increase in UFT perpetuates a number of negative economic, environmental and social impacts, Figure 1.1, which compromise cities in terms of their liveability and accessibility (Boerkamps and Binsbergen 1999; TfL 2007; Malhene et al. 2012).

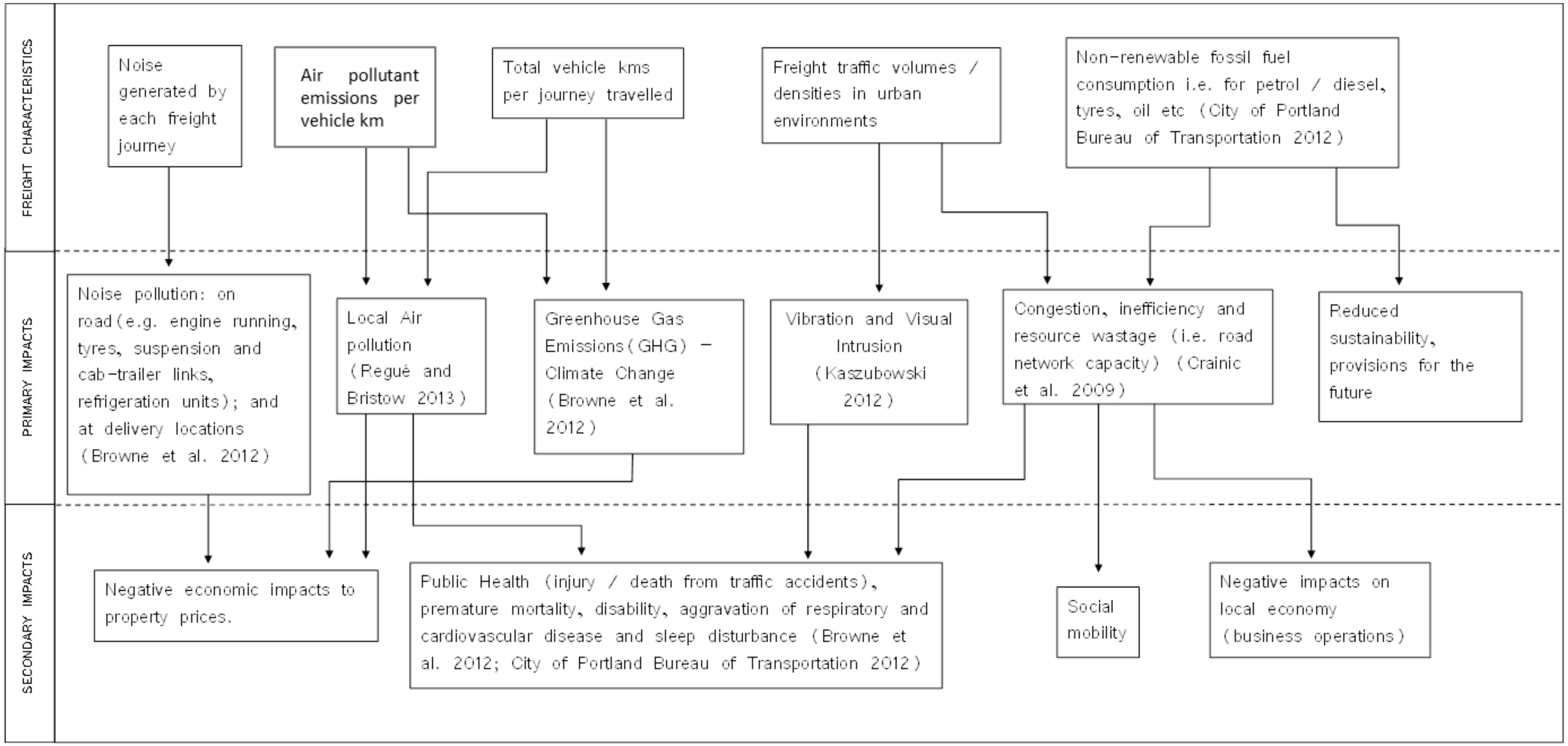


Figure 1.1 Relationships between the characteristics of freight and its primary and secondary negative impacts [Adapted from, Browne et al. (2012)]

UFT is widely considered to be the most significant contributor to GHG emissions within cities (Marcucci and Danielis 2008). Research conducted by the Organisation for Economic Co-operation and Development (OECD) found that in London, 43% of Sulphur Oxides (SO_x), 61% of Particulate Matter (PM), and 28% of Nitrogen Oxides (NO_x) were generated by freight (Crainic et al. 2009). By comparison, NO_x emissions from freight in Prague and Tokyo represent 50% and 77% of city-wide emissions, respectively (Crainic et al. 2009).

Research by Allen and Browne (2010) found that 46% of the UK's freight vehicle-kilometres (VKms) travelled can be associated with UFT from 16 urban areas (including Greater London, West Midlands, Greater Manchester, West Yorkshire, Cardiff, Bristol, Brighton and Hove, and Southampton), demonstrating the traffic impact urban freight can have on national road network infrastructure. Similarly research in France has found that UFT generates between 13% and 20% of total national traffic (Schoemaker et al. 2006).

Assessment of GHG emissions across all sectors and industries has found that public sector organisations generate a substantial amount of GHG emissions worldwide, for example the U.S. federal government was found to be the largest single emitter of GHG emissions within the U.S. (GHG-Protocol and LMI 2012). This is expected to be the case within the EU27 Member States (EU27), however global public sector emissions within the EU27 are largely un-quantified (Easton 2009). Contrary to this, assessment of GHG emissions by sector for the UK, Figure 1.2, indicates the public sector to be one of the smallest generators (10.1 $MtCO_2e$ [million metric tonnes of carbon dioxide equivalents]), with Energy Supply (202 $MtCO_2e$), Transport (118 $MtCO_2e$) and Business (86.7 $MtCO_2e$), ranking as the top 3 largest emitters of GHG (DECC 2014).

However, research into the key generators of emissions within the public sector has indicated otherwise revealing that an estimated 5% of total GHG emissions in the EU27 (209.3 $MtCO_2$ [metric tonnes carbon dioxide] per annum), can be attributed to the publically-owned healthcare sector[1] which is comparable to the 8% of GHG emissions in the U.S. attributed to healthcare (Chung and Meltzer 2009).

[1] Estimates of carbon footprint for the healthcare industry within the EU27 are derived from carbon footprint assessments based on National Health Service (NHS) England Data in Easton, M. (2009). "Promotion of Cycling and the Development of and NHS Cycling Strategy - Proposed Immediate Action and Medium Long Term Opportunities for NHS London."

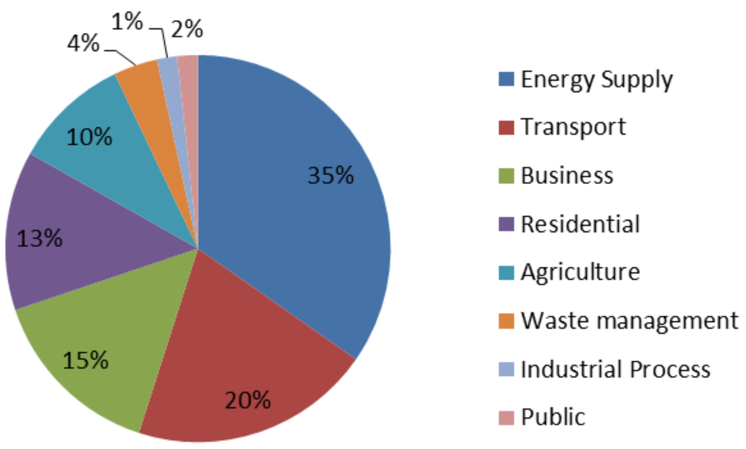


Figure 1.2 Breakdown of UK Greenhouse Gas Emissions by Industry Sector [Source: DECC (2014), pp. 9]

1.2 The Role of Healthcare in the Environment

Analysis of the UK National Health Service (NHS) in 2010, found that it was responsible for 30% of all public sector emissions and 3% of the total Carbon Dioxide (CO_2) emissions in England (European Centre for Environment & Human Health 2011). This has led to the establishment of CO_2 reduction targets for the NHS, in accordance with the 2008 Climate Change Act, which specifies a 34% reduction in carbon emissions against the 1990 baseline, by 2020 (DECC 2008). In addition, the NHS Sustainable Development Unit (NHS SDU) established the long-term goal of a 60% reduction in CO_2 against the 1990 baseline, by 2050 (NHS SDU and NHS SBS 2010).

Previous research into the generators of healthcare emissions found that the energy requirements for buildings, energy and utilities such as temperature control, ventilation and lighting were the largest contributors to hospital related carbon emissions, amounting to 162.54 $MtCO_2e$ (Million Metric Tonnes of Carbon Dioxide equivalents) per annum (Chung and Meltzer 2009). However, recent findings indicated that the procurement of goods (including embodied emissions associated with the manufacture and transportation of goods and services) represents a more significant contribution towards hospital GHG emissions (NorthShore LIJ 2013). Research conducted by the NHS SDU (2012), found that 65% (12.7 $MtCO_2e$) of the carbon footprint for hospitals can be attributed to the procurement of goods and services, 19% to building and energy use (3.8 $MtCO_2e$) and 16% (3.2 $MtCO_2e$) to travel, including the movement of patients, visitors and staff.

Further assessment of procurement activities revealed that pharmaceuticals (4.4 $MtCO_2e$), business services (1.8 $MtCO_2e$) and medical instruments / equipment (1.6 $MtCO_2e$) were the three largest economic sectors contributing to procurement related emissions (NHS SDU 2012). Assessment of wider supply chain research suggests that ancillary goods supply and services such as transportation of documentation and money, can also contribute significantly to an organisations traffic footprint (Cherrett et al. 2012). However, many such activities are largely unquantified.

Previous research suggests that a significant amount of goods related journeys and emissions are the product of an agile supply chain structure, better able to accommodate the unpredictable nature of demand within the medical supply chain (Bailey et al. 2013; Bailey et al. 2014), which encourages sub-optimal product flows, resulting in reduced vehicle load factors (McKone-Sweet et al. 2005; Jarret 2006; Costantino et al. 2010; Black and Zimmerman 2012; Azzi et al. 2013). The negative effects of such supply chain characteristics are amplified in the urban context due to high concentrations of healthcare institutions within a single area.

Healthcare supply chain literature suggests that much of the inefficiency within the healthcare supply chain may be managed through the implementation of supply chain management best practice (McKone-Sweet et al. 2005; Aronsson et al. 2011; de Vries and Huijsman 2012). However, as highlighted by Burns (2002) and McKone-Sweet et al. (2005), there are a number of obstacles such as:

- Constantly evolving technologies with short life-cycles resulting in a higher frequency of product suitability;
- Difficulty in predicting the type, nature, frequency and duration of patient ailments / illness and their product or service requirements;
- A lack of standardisation of nomenclature for healthcare products and commodities;
- A lack of visibility and monitoring of inventory within hospitals;
- A lack of capital to develop information technology supply support structures; and,
- Inadequate business and supply chain management education among key supply chain staff.

As a result, traditional inventory management approaches such as: Materials Requirement Planning (MRP) whereby exact inventory quantities are established during the process of introducing / review of product manufacturing or services; and, Just-In-Time (JIT) which are predicated on lean inventory approaches designed to reduce inventory stock holdings at any given time to reduce the associated costs and risks (e.g. inventory expiration) in holding stock, are considered to be impractical for healthcare (de Vries and Huijsman 2012; Stanger et al. 2012).

In addition to these barriers, owing to global austerity, hospitals have fewer opportunities to address the inefficiencies present within medical supply, exacerbated by the inability and / or disinclination for public and private sector businesses and organisations to invest in many environmentally sustainable supply chain solutions such as asset tracking and monitoring, and consolidation, which are often associated with high start-up and operational costs (Olsson and Woxenius 2012). Therefore, hospitals and third-party logistics providers (3PLs) are challenged with providing low cost, innovative solutions with demonstrable returns on investment from the point of inception (Lewis et al. 2010).

These issues have resulted in considerable research focussed on improving the efficiency of healthcare supply to optimise the cost and efficiency of hospital procurement and supply operations.

One of the key themes in healthcare supply chain management centres on supply chain re-design to provide greater buyer power as a means to reduce the costs of procuring medical supplies. An example of which is the Group Purchasing Organisation (GPO) structure of procurement, prevalent within the U.S. and Canadian healthcare systems. GPOs achieve significant cost savings through bulk buying and consolidation of deliveries for large numbers of healthcare institutions (Chapman et al. 1998; Nollet and Beaulieu 2005). Variants of such systems have been implemented in the form of collaborative hospital partnerships between groups of healthcare institutions in Singapore, Australia and the UK to lever greater purchasing power and greater sharing of inventory between hospitals to reduce stock wastage (Pan and Pokharel 2007; Kumar et al. 2008a; Bhakoo and Singh 2012; LPP 2013). In addition to this, attempts to reduce wastage and improve the performance of the existing supply chain structure have also been made, concentrating on the flows of demand-related information and monitoring of stock levels. To achieve this, new and emerging Information and Communication Technologies (ICT), such as Radio Frequency Identification (RFID) and 2D-coding (e.g. barcodes and Quick Response Codes, QR Codes), are used to provide intelligent storage and individual item tracking (Everard 2001; Nagy et al. 2006; MacManus 2009; MacManus 2010a; MacManus 2010b; Omnicell 2011; Varghese et al. 2012).

Many of these themes are highly prevalent across wider industry sustainable supply chain literature, such as:

- The development of ICT to enable full tracking and visibility of items throughout the supply chain thereby enabling for real-time decision making;
- Collaborative supplier partnerships to effectively utilise empty running VKms capacity reducing the overall number of vehicles required, thereby reducing supply chain costs and vehicle emissions;
- Consolidation of urban freight into low-carbon technology vehicles to move towards the goal of 'essentially CO_2-free city logistics in major urban centres by 2030' (EC 2011); and,
- Night-time freight to reduce the day time volumes of UFT within urban centres, thereby reducing congestion and emissions as a result of more efficient driving behaviours and reductions in idling time.

Each of these themes is examined in detail in Chapter 2.

1.3 Statement of the Problem

Owing to the high density of healthcare institutions (i.e. hospitals, minor injuries / walk-in centres) within urban areas, the role hospitals and other healthcare institutions play in the 'urban problem' is amplified, leading to a growing need to evaluate, understand and address the needs and requirements of hospital supply, and how it may be made more sustainable.

As demonstrated by the literature and international and national policy, supply chains represent important distribution systems for the delivery of goods within urban environments. However, the ever increasing demands from urban populations perpetuates an 'urban paradox' in which distribution networks are forced to adopt unsustainable practices to meet the demands of the consumer for bespoke on-demand services, often largely affecting the CEP sector, leading to congestion and increased GHG emissions within cities; threatening economic and environmental sustainability, as well as public health. Research has found healthcare supply to be one of the main contributors to these urban issues (Chung and Meltzer 2009; Easton 2009; NHS SDU 2012).

1.4 Research Aims and Objectives

This research was sponsored in part by Transport for London (TfL). TfL's main focus for this study was to provide hospitals and local authorities, in an urban setting with a set of recommendations for sustainable methods of supply for healthcare institutions, to minimise the negative externalities of freight associated with urban hospitals. An inner city hospital, Great Ormond Street Hospital for Children's NHS Foundation Trust, (GOSH) located in London, UK was selected by TfL as a case study to examine inward bound freight deliveries and outward bound traffic, such as laboratory courier services from the hospital, to identify the areas in which the following aims, specified by TfL, may be achieved:

1. Safeguard the existing network capacity and reduce the potential for pedestrian-vehicular conflicts through the reduction of UFT on roads;
2. Reduce congestion within the city through consolidation and the "re-moding" of freight to more sustainable means before entry into the central congested areas; and,
3. Reduce air and noise pollution within the city centre.

Each of these aims was underpinned by four main objectives:

- Reduce Freight: promote freight consolidation and business collaboration to encourage sharing of resources and reduce the number of deliveries they receive;
- Retime Freight: promote and encourage deliveries to be made out of hours when restrictions are in operation;
- Reroute Freight: facilitate amendments to the London Lorry Control Scheme night / weekend restrictions to enable 18+ tonne vehicles to be able to deliver at night;
- Re-mode Freight: promote the use of more sustainable vehicles for the movement of goods, such as rail and river.

The above aims and objectives specified by TfL are refined into the following aims and objectives tailored to healthcare.

1.4.1 **Aim**

The aim of this project is to assess the current structure of hospital supply in the context of the UK NHS, using GOSH as a case study, investigating methods to improve the operational and environmental efficiency of in-going, out-going and internal hospital logistics associated with the medical supply chain Figure 1.3, to reduce traffic volumes and the associated emissions.

This research assesses the nature of hospital demand, the organisational structure and key requirements of the medical supply chain, and the key issues with current management practices in both the context of UK NHS and worldwide to provide a set of realistic alternative recommendations to reduce supply chain impacts. The research focusses on the relationships between the management of internal goods distribution within hospitals and external supply, and how management of internal inventory processes can affect the efficiency of the external supply chain with regards to the volumes of traffic to a hospital. With this in mind, technological and operational developments within the logistics industry are examined, assessing the potential benefits they may provide within the medical sector.

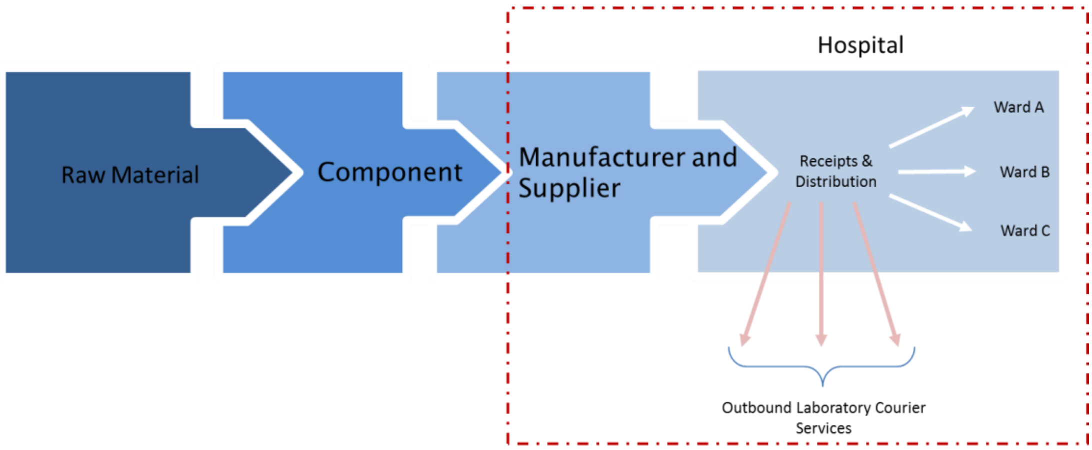


Figure 1.3 Illustration of the study area within the medical supply chain which is the focus within this research (surrounded in the red box)

A number of solutions to improve the management and efficiency of hospital supply are then developed to provide economic and environmental benefits through the improved visibility, monitoring and utilisation of inventory and the reduction in hospital-related traffic and emissions. In addition to this, the role of less than vehicle load trends associated with CEP services is assessed in the context of medical couriers to understand if and how current practices can be improved.

The thesis sets out to address the following research questions:

1. What are the various operating models used by hospitals to manage their inventory and how does this influence the most appropriate combinations that can be used?
2. What sustainable logistics solutions are available and appropriate to healthcare and what benefits can they provide?
3. To what extent can sustainable logistics provide economic and environmental transport solutions for hospital supply?

1.4.2 **Research Objectives**

Each of these questions is addressed by the following core objectives:

- Understand the requirements of hospitals and the impacts they have on the operation of the healthcare supply chain.
- Investigate current and future developments in healthcare and logistics technologies, how they will affect the ways in which people receive medical care and how it may affect the movement and provision of inventory to hospitals.
- Evaluate the range of sustainable urban logistics solutions, how they may be implemented in the context of healthcare, and potential barriers to their implementation.
- Develop solutions intended to address the main travel generators for hospitals whilst maintaining or improving the current levels of service for medical supply to hospitals.
- Understand the potential benefits of each solution by: quantitatively assessing their impacts using computer-based modelling and analysis methods, informed by real-world data gathered at GOSH; and, qualitatively scrutinising the practicality of each solution using feedback from healthcare practitioners, representatives of local authorities, healthcare suppliers and logistics providers.

1.5 Scope of the research

This research will primarily focus on the UK NHS, presented in the context of international healthcare systems and networks, with a particular focus on inner-city hospitals within London, UK, in accordance with the wishes of the industry sponsor, TfL.

1.6 Potential Implications

This research aims to fill a gap in healthcare logistics knowledge. It aims to identify the main traffic generators within hospitals, specifically those responsible for high volumes of emissions. Further to this it evaluates the factors affecting the implementation of traditional sustainable urban delivery solutions within the sector and aims to overcome them, whilst also improving the levels of service for the supply of inventory to hospitals, and the distribution of goods internally.

1.7 Dissemination of Research Findings

A number of contributions to the academic record have been produced during the period of candidature.

The following peer reviewed journal articles have been produced:

Bailey, G., T. Cherrett, B. Waterson, L. Breen and R. Long (2015). *Boxed Up and Locked Up, Safe and Tight! Making the Case for Unattended Electronic Locker Bank Logistics for an Innovative Logistics Solution for NHS Hospital Supplies (UK).* International Journal for Procurement Management 8(1-2): 104 – 125.

Bailey, G., T. Cherrett, B. Waterson and R. Long (2013). *Can Locker Box Logistics Enable more Human-centric medical supply chains?* International Journal of Logistics: Research and Applications 16(6): 447-460.

Xie, Y., Breen, L., Cherrett, T. and Bailey, G. An exploratory study of the NHS medical device Reverse Exchange system. Is it working effectively and can innovative ICT improve it? Submitted to Supply Chain Management: An International Journal. Pending review.

The following peer reviewed conference papers have been produced:

Bailey, G., Cherrett, T., and Waterson, B., (2014) *A Simulated Annealing Approach to Explore Temporal Consolidation of Healthcare Courier Services to Reduce Carbon Emissions*. Conference on Service Operations and Logistics, and Informatics (2014). IEEE International. October 08 – 10, Qingdao, Shandong, China

Bailey, G., Cherrett, T., and Waterson, B., (2014) *Does Mobile Consolidation Solve the Traditional Consolidation Centre Conundrum? A Feasibility Study in the Context of UK Healthcare.* . Logistics Research Network Conference (2014). The Chartered Institute of Logistics and Transport (UK).

Bailey, G., Cherrett, T., and Waterson, B., (2012) *Can Locker Box Logistics Enable More Human Centric Supply Chains*. Logistics Research Network Conference (2012). The Chartered Institute of Logistics and Transport (UK).

Bailey, G., Cherrett, T., Waterson, B., and Long, R., (2012) *The Hidden Life Saver? – Unattended Locker Box Logistics for Faster and More Efficient Hospital Supply*. Transportation Research Board 92nd Annual Meeting.

Bailey, G., Cherrett, T., and Waterson, B., (2011) *The Internet of Things for Efficient Medical Logistics*. Logistics Research Network Conference (2011). The Chartered Institute of Logistics and Transport (UK).

1.8 Thesis Outline

This thesis is divided into eight further chapters, Figure 1.4. *Chapter 2* examines the previous and current research regarding healthcare supply chains, identifying the main characteristics which contribute to traffic generation for healthcare institutions. In addition to this, it assesses the range of sustainable supply chain management and freight logistics measures which have been implemented to achieve more sustainable forms of supply; and, the main barriers to their success.

Chapter 3 outlines Great Ormond Street Hospital as the test case hospital for this research. In addition to this it provides a site-wide assessment of the main hospital travel generators, highlighting the key healthcare supply chain issues at the Trust, such as high frequencies and quantities of vehicles delivering to the hospital each week, comprising largely CEP service deliveries.

Chapter 4 details the central computational methodologies used to assess each of the three main research themes.

Chapter 5 details a new mobile consolidation centre concept intended to resolve the high volumes of delivery traffic to Great Ormond Street Hospital, whilst also attempting to address the main barriers common to the implementation of traditional freight consolidation concepts. This chapter includes the feasibility testing of the concept, using both quantitative and qualitative methods.

Chapter 6 tests the feasibility of an unattended delivery concept for the provision of urgent goods deliveries to Great Ormond Street Hospital. The focus of work is the proposed implementation of an electronic locker bank delivery unit, to which all time-critical items can be delivered, for collection by the end-consumer, i.e. physician delivering medical treatment to a patient.

Chapter 7 examines the role of laboratory courier services at Great Ormond Street Hospital, focussing on their carbon footprint. It expands on the findings of this analysis by exploring the scope for more sustainable practices and means of transporting laboratory samples and results between GOSH laboratories and customers.

Chapter 8 provides a discussion of sustainable hospital supply in a wider context, considering the findings from Chapters 4, 5 and 6 with respect to University Hospital Southampton (UHS), a peri-urban hospital Trust.

Chapter 9 provides a summary of the findings and concludes the key findings of the research. This chapter closes with an outline of future research.

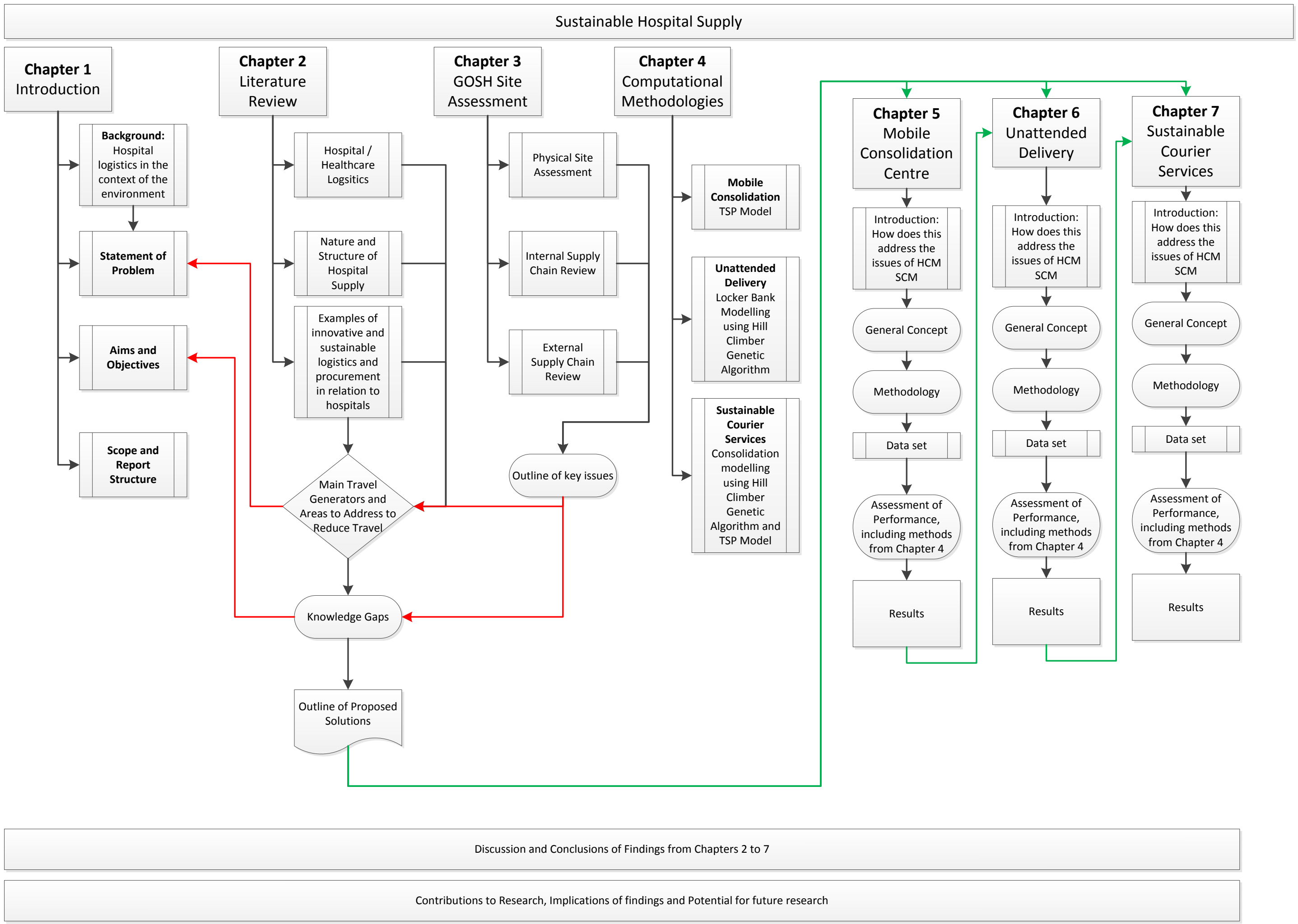


Figure 1.4 Illustration of the organisational structure of this thesis and the relationships between chapters and research themes

Chapter 2: Literature Review

2.1 Introduction

A supply chain represents a set of connected nodes (organisations, people, activities, information and resources) through which a product moves from a raw material state to a useable commodity at the end of the chain where it is consumed (Christopher 2011), Figure 2.1.

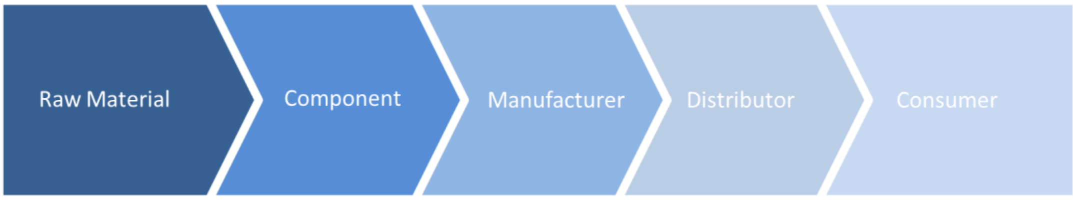


Figure 2.1 Illustration of the basic model for supply chains

The structure and operation of a supply chain is typically organised to cater for the nature of the end-customer's demand and their market strategies (Porter 1998), typically addressed through the implementation of one of three approaches: supply chain agility, which focusses on a chain's ability to adapt to rapid alterations in the volume of demand, and product characteristics; lean supply, which focusses on efficiency, i.e. reducing the size of inventory holdings to closely match consumption thereby reducing the financial costs and risks associated with holding large inventories; and, a hybrid model combining the two concepts, whereby parallel lean and agile supply chains operate simultaneously. A supply chain is therefore a vital component of a business according to the services and levels of performance it can achieve.

In healthcare, supply chains are widely regarded as one of the most important non-clinical support services, owing to the potentially serious consequences of low and exhausted levels ('stock-outs') of key inventory items within hospitals (Özkil et al. 2009; Costantino et al. 2010). Due to such risks lean supply chain strategies are seldom employed within healthcare, and large inventories (typically 2-week's provisions) are stocked to avoid stock-outs. However, in spite of this stock-outs continue to occur due to the unpredictable nature of demand and characteristically poor flow of information throughout the supply chain (McKone-Sweet et al. 2005; Pan and Pokharel 2007). Such characteristics of supply mean that the use of inventories in parallel with agile supply strategies is prevalent, resulting in sub-optimal product flows yielding low vehicle load factors (McKone-Sweet et al. 2005; Jarret 2006; Black and Zimmerman 2012; Azzi et al. 2013).

Recognition of the shortcomings in healthcare supply chains has led to a large compendium of healthcare supply chain management literature, exploring methods to improve the reliability of medical provisions to hospitals. The first part of this chapter explores the nature of hospital demand and the structure of healthcare supply chains, examining previous and current models of supply designed to create more sustainable and efficient supply. Following this, a review of the advances in healthcare supply chain management and ICT concepts for healthcare is performed. This chapter closes with a review of sustainable supply chain and logistics practices employed throughout a wide range of other industries, drawing on the characteristics and requirements of hospitals to examine how they may be implemented within the context of healthcare, thereby identifying the research gaps and opportunities.

2.2 Healthcare Supply Chains

Hospital logistics is typically complex, involving the management of significant quantities of materials and data (Rivard-Royer et al. 2002) across an often fragmented management structure (Glickman et al. 2007). The process has to cover 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, such as supermarkets, in terms of its logistics requirements which are largely able to estimate or predict consumer demand and manage the supply chain accordingly (de Vries et al. 1999; de Vries and Huijsman 2012). Much of the supply chain variability experienced in healthcare is attributed to at least three different factors:

1. Clinical variability, related to numerous different ailments, severity levels and potential response outcomes;
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 approaches to goods supply such as JIT, based on lean operations wherein all goods are provided as and when they are required (holding minimal inventory) are deemed unsuitable for hospital supply owing to the potentially dangerous 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, unusual / unforeseen 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 in the UK, whereby pre-established re-order levels are agreed by hospital and medical departments (Lapierre and Ruiz 2005); or, a 'Scheduling-oriented approach', for which purchasing operations and supplier deliveries are accurately scheduled to ensure resources are available and stock-outs avoided (Costantino et al. 2010). Previous research has found this approach to be effective within small hospitals (100 beds or less) with low demand (Pan and Pokharel 2007). Inventory approaches typically require more staff and greater amounts of inventory storage space yielding higher operational costs whereas, scheduling approaches require increases in staff time to accommodate regular reviews of stock usage to ensure all schedules are accurate and up-to-date (Pan and Pokharel 2007).

2.2.1 Healthcare Supply Chains: Demand Information

The materials services within hospitals are responsible for generating large quantities of time-sensitive data, much of which is indicative of hospital demand (Lee et al. 2011). Research into demand variance in healthcare supply chains has found that hospital orders exhibit considerable variability, commonly regarded, in supply chain literature, to be due to inaccurate and incomprehensive information (Shapiro and Byrnes 1992). Such issues create a lack of clarity in inventory demand between wards which can result in a 'bullwhip effect', Figure 2.2, creating an increasing demand variance propagating up the chain, as a result of poor coordination in ordering policies at points throughout the supply chain (Christopher 2011).

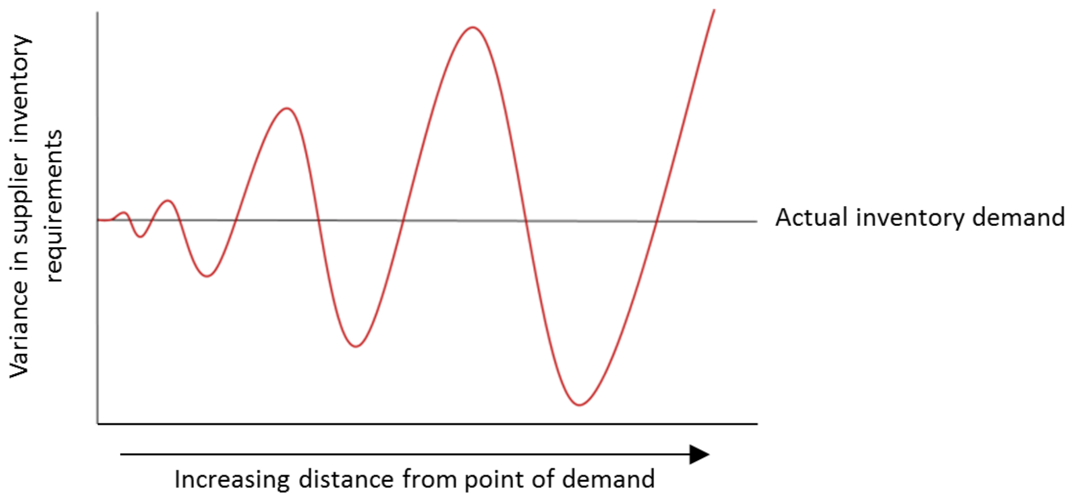


Figure 2.2 Illustration of the Bullwhip Effect, the relationship between the distance from the point of demand generation and variance in demand predictions

2.2.2 **Structure of Healthcare Supply Chains**

Healthcare supply chains are characterised by having internal and external components. As demonstrated by the bullwhip effect, the structure, operation and flow of information and products through the hospital (internal supply chain) can dramatically alter the structure and performance of the external supply chain, which transports goods to the hospital.

Previous research has identified that the accurate and timely flow of information and goods through the external-internal chain interface, Figure 2.3, is often complicated by multiple procedural and information systems resulting in increasing costs and inefficiencies (Poulin 2003; Dembiríska-Cyran 2005). In order to accommodate such complications posed by the internal and external structure of hospital supply chains, they are typically managed according to one of three models: i) conventional; ii) semi-direct delivery approaches, typically implemented within hospitals such as GOSH; and, iii) the direct delivery approach (Rivard-Royer et al. 2002).

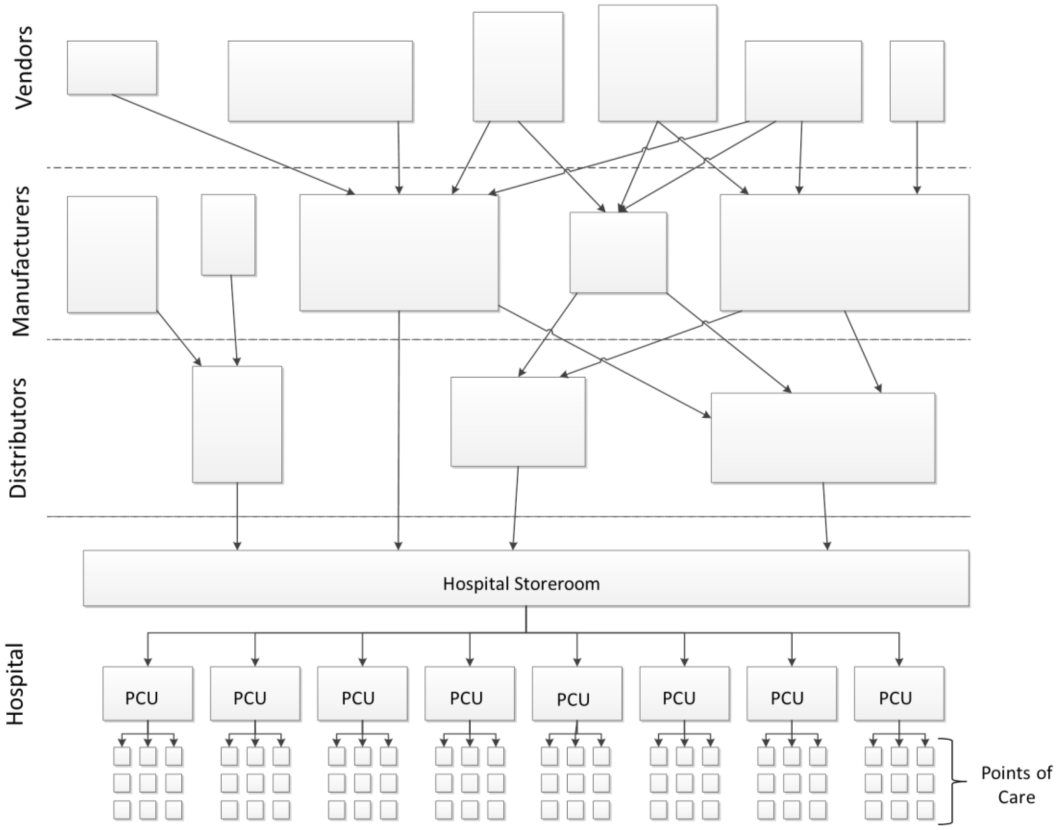


Figure 2.3 Illustration of the external-internal hospital supply chains, the key supply chain nodes and elements (PCU = Patient Care Unit) [Adapted from: Lindsey (2012) [pp.38] in (Rivard-Royer et al. 2002) [pp.414]]

Conventional Healthcare Supply Chain Model

The conventional model, Figure 2.4, focuses on a central procurement department ordering large quantities of inventories for use in all patient care units (PCUs) throughout the hospital, to be stored within a central store room. Under this model, goods are delivered through the external supply chain to the hospital, at which point they are transferred to the central store to be held until a stock request is made to replenish ward level inventory. Whilst this model enables bulk buying discounts to be achieved, it is typically associated with higher inventory costs due to the space required to hold goods (Aptel and Pourjalali 2001).

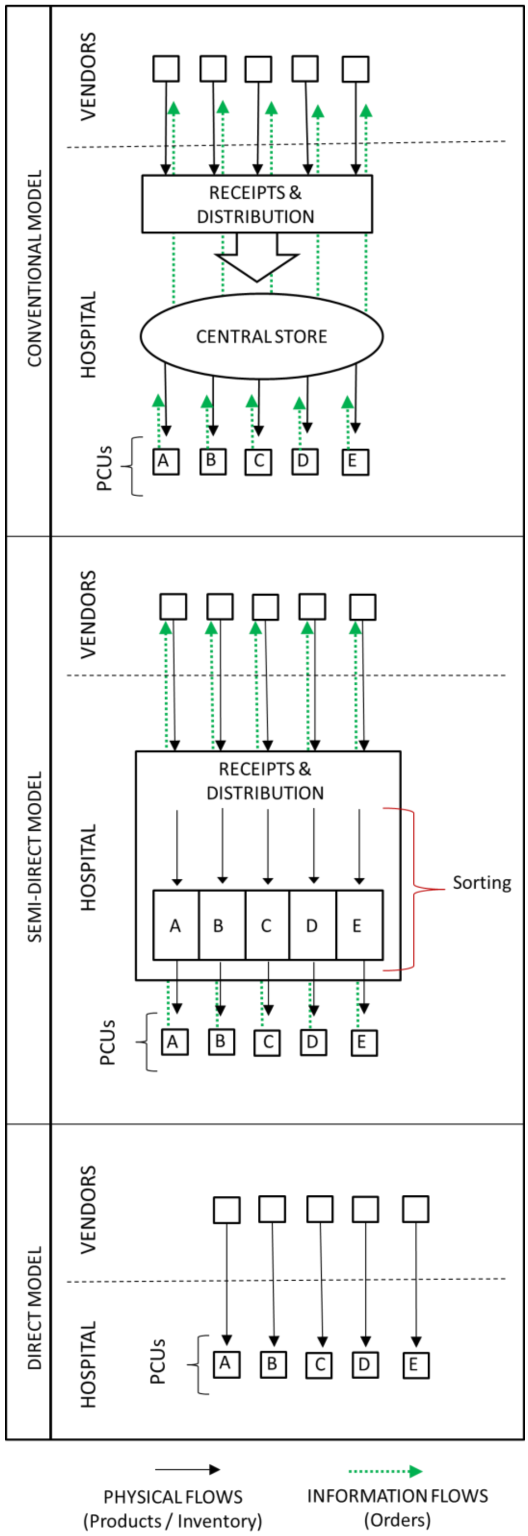


Figure 2.4 Illustration of the three models of hospital supply chains demonstrating the differences in the number of nodes / agents required for each operating model. (Direct model does not contain information flows since inventory is managed by suppliers, eliminating backwards communication.

Semi-Direct Healthcare Supply Chain Model

The semi-direct model, Figure 2.4, sees individual PCUs placing separate orders direct with suppliers. Upon receipt of goods into the hospital via a central receipts and distribution location, goods are sorted and distributed internally direct to each ward store. This method reduces the level of inventory held within the hospital due to the smaller size of individual stores at the ward level, and increases the speed with which items are delivered to medical departments owing to their direct delivery from receipts and distribution (Aptel and Pourjalali 2001).

Direct Delivery Healthcare Supply Chain Model

The direct delivery model, Figure 2.4, is representative of the stockless inventory approach which was implemented predominantly within the U.S. and Canada from the 1970s to the 1990s (Kowalski 1991). This was developed to resolve the poor generation and communication of accurate and time-sensitive data, indicative of hospital demand for suppliers (Lee et al. 2011), within hospitals and throughout the internal and external supply chains (Poulin 2003; Dembiríska-Cyran 2005), the result of which leads to a bullwhip effect.

The stockless inventory approach, Figure 2.4, operates on the principle of consolidating supply by reducing the number of suppliers providing goods to the hospital, and outsourcing the management of supplies to the remaining suppliers. This approach builds on the Vendor Managed Inventory (VMI) approach for which full responsibilities of maintaining agreed inventory levels within the buyer’s stores are passed to the suppliers, imparting greater responsibilities for managing the internal supply of goods to hospital stores. Central to the concept of the stockless inventory approach is the removal of intermediate tiers / agents within the internal supply chain.

This process, known as disintermediation, has been found to improve the performance of supply chains with unpredictable demand (Shapiro and Byrnes 1992). Such findings have been corroborated by stockless approaches which enable sufficiently high levels of inventory to be kept whilst requiring fewer materials management and clinical staff to monitor and manage stock (Nicholson et al. 2004). For example, implementation of the stockless approach at St Luke’s Episcopal Hospital (Houston, Texas, U.S.) delivered savings of $350,000 by reducing staff and $162,500 by reducing inventory (Freudenheim 1991). However, higher inventory costs and increased workloads accrued by suppliers as a result of increased inventory management rendered stockless methods unattractive to suppliers (Rivard-Royer et al. 2002). Furthermore, owing to the specialist nature of many of the products supplied to specialist hospital trusts, such as GOSH, which may only be sourced exclusively from specific suppliers the rationalisation of suppliers during the supply consolidation process becomes impracticable.

Research to optimise the cost and efficiency of back-of-house hospital operations has continued in a similar vein to that of the stockless inventory approach, building upon the theory of disintermediated supply chains for improved communication of demand (Kumar et al. 2008a). The main theme of this research focusses on hospital-supplier collaboration to achieve optimised supply chains which promote transparency and communication as a means of overcoming rising costs and meeting the expectations of quality within healthcare (Cardinal Health 2012; Pohl et al. 2012). Supply chain integration initiatives such as Collaborative Planning, Forecasting and Replenishment (CPFR) and VMI are central to this research.

CPFR and VMI are predicated on the alignment of the chain through the communication and visibility of data pertaining to demand, inventory and freight shipments throughout a supply chain, to enable: reductions in inventory holdings and more efficient planned logistics, such as higher vehicle fill rates, to be achieved (Kumar et al. 2008b; Langabeer 2008). Whilst CPFR and VMI are designed to achieve the same goals, they do so using different approaches.

CPFR is modelled on a pull supply chain structures whereby the supplier receives orders from the customer, checks the availability of products and delivers them, as opposed to a push supply chain wherein suppliers dictate the quantity and frequency of products delivered to the customer (Kumar et al. 2008b). However, it seeks to implement common technologies between all supply chain partners enabling more comprehensive communication of demand and supply information throughout the chain so that greater synchronisation of manufacturing and production throughout the chain may be achieved, to ensure demand requirements are met (Langabeer 2008).

VMI seeks to re-organise the responsibilities between suppliers and customers in the supply chain by passing the monitoring, replenishment, shipping and timing of demand to suppliers (Danese 2004). Under VMI principles deliveries are determined to ensure stock levels at the customer’s facility are maintained within a co-agreed range (Danese 2004; Mustaffa and Potter 2009). By doing so, reductions in hospital administration, inventory levels and the uncertainty of customer demand may be achieved (Mustaffa and Potter 2009). Examples of VMI have demonstrated fewer stock-outs to occur, and greater flexibility in production planning and distribution (Mustaffa and Potter 2009; Guimarães et al. 2011).

However, both concepts may be implemented in tandem as well as in isolation. For example Glaxosmithkline, used Electronic Data Interchange to enhance horizontal and vertical communication of demand through a centralised data system for all supply chain members (Danese 2004). Assessment of GSK's Italian manufacturing plant found that implementation of VMI and CPFR approaches maintained inventory levels within the agreed VMI range 83.3% of the time, with an over-production of inventory recorded for the remainder (Danese 2004).

Examples of VMI practices implemented within hospitals in Singapore, the U.S. and Italy have demonstrated that self-managed and outsourced inventory practices can successfully reduce the costs of healthcare within both public and private healthcare sectors, in some cases delivering estimated annual savings of 22.7 per cent yielded through outsourced inventory practices (Azzi et al. 2013).

2.2.3 **Current Models of Healthcare Supply**

As previously established, the structure of a supply chain is governed by the requirement to meet the demands of the end-consumer. Owing to the high variability and unpredictability of demand for individual medical products and services in hospitals, the parallel chain model of supply is ubiquitous within the industry, Figure 2.5. Parallel supply chains typically comprise of a primary multi-echelon supply chain, wherein suppliers ship goods to a central warehouse operating as a forward stock location for large inventories to be distributed to numerous Trusts with reduced lead times and consolidated deliveries. At the same time a secondary single-echelon supply chain, through which urgent and special orders for goods are made and shipped direct from the supplier to the hospital, in individual dedicated delivery vehicles operates. Similar models of supply are widely implemented across many industries in which unpredictable demand exists, such as high-street clothing retailers (Fisher 1997; Indu and Govind 2008; Christopher 2011).

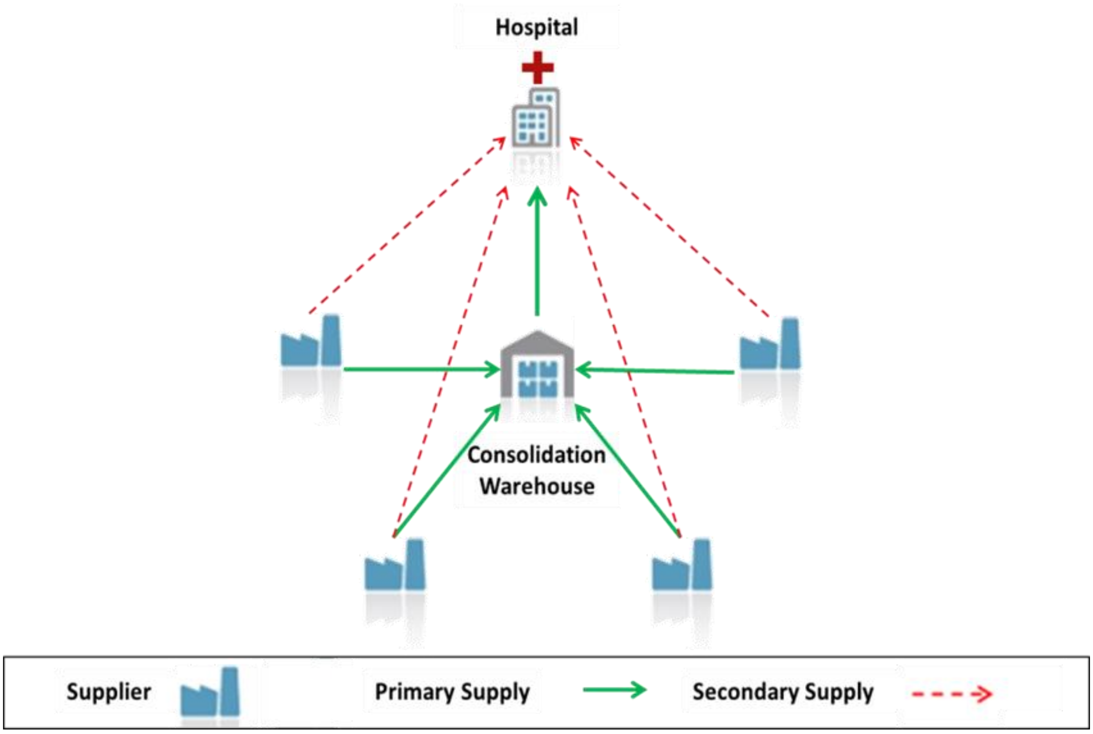


Figure 2.5 Illustration of the parallel healthcare supply chain structure, primary supply represents a multi-echelon supply route; and secondary supply represents a single-echelon route of supply

Structure of Public Sector Healthcare Supply

Inventory management within the UK NHS is presented using GOSH as a case study. The system and processes employed throughout the NHS are considered to be largely homogenous, with specific procurement and supply agreements being tailored for specialist Trusts. However, the ordering volumes, frequencies and composition of inventory is hospital specific and therefore inventory usage statistics may not be representative of an NHS-wide view.

The NHS model of supply is typically based on a semi-direct, parallel healthcare supply chain, whereby goods enter into a central receipts and distribution area where they are sorted for distribution to individual ward stores. The supply chain model is predicated on a multi-echelon supply route for consolidation (NHS Supply Chain) and a single-echelon route for deliveries direct from suppliers to hospitals, Figure 2.5. As part of this research, analysis of annual hospital spend reports at UK NHS healthcare institutions, GOSH and University Hospital Southampton (UHS), indicated that between 30-37 per cent of inventory was procured via the primary route of supply (NHS Supply Chain) with the remainder being procured direct from suppliers. Furthermore, according to stock order volumes at GOSH for the 2011/12 financial year, goods procured through the multi-echelon consolidated supply route represented approximately 20% (130,923 product lines ordered) of all goods-in to the hospital.

NHS Supply Chain

The NHS Supply Chain is operated by a 3PL providing end-to-end supply chain services, such as procurement, logistics, customer and supplier support, to all NHS England Trusts through a network for regional distribution centres for: catering, dental, theatres, orthopaedics, infection prevention, audiology, pathology and ophthalmology (NHS 2012). Each depot serves a number of NHS Trusts within a specific region.

The NHS Supply Chain operates an inventory-oriented approach maintaining pre-established thresholds of goods for each ward ensuring at provisions for 2-weeks of inventory, updating replenishment schedules annually. NHS Supply Chain stock is managed with readings of inventory once / twice a week (depending on the needs of the department) with deliveries of inventory being made 48 hours (i.e. two working days) after ordering. Deliveries typically consist of large orders of bulk items such as medical aprons, gloves and pulp goods (e.g. disposable bed pans and bowls) consolidated in vehicles, with a minimum load factor of 90% (Pipe-Wolferstan 2013). In the case of GOSH, NHS Supply Chain deliveries are made to the Trust at night, with medical inventory being delivered to a secure overnight storage location within the loading bay.

Poor utilisation of the primary consolidated route of supply has been found to generate a high number of ad-hoc deliveries to hospitals resulting in more expensive ordering practices from fewer bulk buying discounts, leading to high volumes and frequencies of delivery vehicles to Trusts (Poulin 2003; McKone-Sweet et al. 2005; Pan and Pokharel 2007; Costantino et al. 2010). Also of major concern is the potential for loss of- urgent items amongst non-urgent goods within the same supply chain leading to product re-orders (Bailey et al. 2013; Bailey et al. 2014).

Structure of Private Sector Healthcare Supply

Examination of the U.S. privatised healthcare system reveals a greater utilisation of the conventional parallel supply chain model (Figure 2.5), with more stringent use of the direct route for urgent orders. Owing to the privatised nature of the U.S. healthcare system, 60% of privately-owned hospitals are responsible for generating their own income(Aptel and Pourjalali 2001), providing their own specialised set of services, and therefore negotiating rates and deals with suppliers giving rise to Group Purchasing Organisations (GPOs).

GPOs represent a single purchasing entity (either: for profit, run by a third-party independent of the hospital system; not-for-profit as an Integrated Delivery Network (IDN) whereby participating hospitals are part owners; and, a hybrid of the first two), often for multiple hospitals, whose primary function is to negotiate contracts with suppliers, utilising aggregated purchasing volumes to lever significant purchasing power and discounts with manufacturers, distributors and other vendors (Burns 2002; Nollet and Beaulieu 2005; Varghese et al. 2012). However, the role of GPOs often extends to the warehousing, consolidation and delivery of goods to their member Trusts thereby acting to reduce the overall number of deliveries to each hospital site. Within this system, urgent or special orders of products, typically pharmaceuticals, are ordered direct from supplier for delivery to the hospital, bypassing the GPO (Varghese et al. 2012; Toronto Atomospheric Fund et al. 2013). Owing to the financial benefits provided by GPOs, an estimated 4,800 to 5,000 healthcare facilities in the U.S. subscribe to one or more GPOs, with two GPOs acting as the supply contracting company for a combined 4,000 hospitals (Panero et al. 2011).

Similar systems to the GPO IDN structure have been implemented in Singapore, wherein outsourcing logistics procurement activities of GPOs by hospital clusters within the public health sector has enabled reduced costs to be achieved through bulk-buying, and improved sharing of inventories between hospitals, helping to avoid stock-outs (Chapman et al. 1998; Pan and Pokharel 2007; Kumar et al. 2008a). Similarly in Toronto, 6 hospitals (Toronto General, Princess Margaret, Mount Sinai, Toronto Rehab, SickKids Hospital and Toronto Western) assessed the impacts of off-site and on-site goods consolidation through a single company as a means to remove more than 40 trucks per day within downtown Toronto and reduce hospital loading dock requirements (Toronto Atomospheric Fund et al. 2013). Findings from the analysis of off-site and on-site options for the study indicated increases in total VKm travelled and annual tCO_2 (tonnes of carbon dioxide equivalents) emissions for off-site consolidation; and reductions of 7-10 deliveries per hospital each day and reductions of 5-6 tCO_2 per year for on-site consolidation

(Toronto Atomospheric Fund et al. 2013). However, off-site consolidation was found to positively address the loading bay congestion issues at hospitals, whereas, on-site consolidation exacerbated the capacity issues at the host hospital (Toronto Atomospheric Fund et al. 2013).

As demonstrated, previous healthcare supply chain research focussed on improving the visibility and monitoring of products within hospitals, and generating accurate and up-to-date demand information to be conveyed up the chain. However, whilst such practices yield operational benefits within hospitals, the additional economic and environmental costs rendered approaches unfeasible.

2.3 Advances in Healthcare Supply Chain Management

A more recent theme within healthcare supply literature focusses on process re-engineering within hospitals using emerging Information Communication Technologies (ICTs) such as bar-coding and Radio Frequency Identification Data (RFID) (Coulson-Thomas 1997; Towill and Christopher 2005; Parnaby and Towill 2008; Parnaby and Towill 2009; 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 equipment and the communication of patient details such as medical condition and received treatments 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 utilising empty VKms on return journeys (Ritchie et al. 2000; McKone-Sweet et al. 2005; Kumar et al. 2009). Such ICT applications are underpinned by the concept of the 'Internet of Things'.

The Internet of Things (IoT) developed by Weiser (1991) refers to the pairing of ordinary everyday objects with the Internet to create a global network of sensors, such as RFID tags and Smart Dust (micro- and nano- scopic) sensors, with the potential to sense and detect the surrounding environment and communicate with other sensors, actuators and devices in any location, to the extent that 'everything is alive' (Thompson 2004). With the opportunities created by 'smart phones', greater levels of pervasive computing are permeating everyday life, creating a global network of sensors known as the Internet of People (IoP). This network is growing in both coverage and density with the potential to detect light, motion, sound and location (Roussos 2009). Such trends are enabling easier deployment of pervasive ubiquitous computing and software applications throughout society, thereby enabling for novel and innovative applications of ICT throughout healthcare and the wider logistics industry to facilitate greater visibility and automation.

2.3.1 Intelligent Storage for Improved Management of Hospital Inventory

Studies in 2003-2004 revealed that $11 billion (£6.79 billion) was spent due to inefficiencies in hospital spending and unbilled, unaccounted inventory within hospitals in the U.S. largely due to the storage of items on open shelves (Nagy et al. 2006), a practice commonly implemented though-out UK NHS Trusts. Intelligent storage solutions are designed to accurately manage stock usage within hospitals using various technologies, ranging from manual button counting systems to 2D coding and RFID applications, to measure the consumption and re-stocking of items within a store. These technologies enable the automatic reordering of stock to replenish items removed for use and provide more accurate measures of demand (Everard 2001; Varghese et al. 2012). Intelligent storage solutions, Figure 2.6, implemented within pharmacy and blood supply areas in hospitals have been found to deliver recurring cost savings of between 10% and 12%, with potential reductions in inventory levels (averaging 45%) as a result of improved scheduling and a reduction in duplicate inventories (Omnicell 2011). Application of such storage systems within operating rooms at Billings Clinic, Montana, U.S has enabled for more accurate patient charging, identifying $1 million (£616,000) per annum in previously lost charges, labour savings of 5,000 to 7,000 hours per year, a reduction in missing inventory valued between $300,000 (£184,000) and $400,000 (£246,000) per year to almost zero, and a reduction in annual inventory adjustment from 5 – 6% to 1% (Omnicell 2011).

Figure 2.6 Example of an intelligent storage solution for the management of hospital inventory [(Source: (Omnicell 2011)]

Implementation of comparable systems into surgical theatre supply rooms within two major London NHS Trusts delivered varying results, with one system providing significantly improved inventory management, and the other presenting few benefits from the current form of storage. The cause of which was identified as a lack of policing for the “correct and proper” usage of the system, (i.e. the removal of only what had been authorised by the computer system managing the cabinet) at the Trust where few benefits were observed (Fry et al. 2012). This finding highlights one of the key flaws with the current design of intelligent storage systems, whereby staff are required to prevent accidental and intentional misuse of cabinets thereby enhancing positive behavioural and attitudinal change.

2.3.2 **Unattended Delivery for Secure Delivery of E-Commerce Items**

Unattended delivery solutions such as electronic locker banks which enable a secure location to which items can be deposited by couriers and collected by the recipient at their convenience, implement similar technologies, such as 2D coding and RFID tags. However, they differ significantly in operation. Whereas intelligent storage solutions 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 banks serve only as a means for temporary stock holding (1-day maximum), informing the customer when their order is ready for collection.

Unattended locker banks, Figure 2.7, were developed in response to the large proportion of failed deliveries within the UK forecast to cost £771 million in 2014 (IMRG 2014). The concept's main aim is to provide individuals and companies with space within a locker bank, comprising numerous secure locker box partitions equipped with wireless communications (3G) to send delivery confirmation notices to recipients, as an alternative delivery address (Edwards et al. 2010). They are typically owned, operated and maintained by the locker bank provider and are often situated in central locations within a town or city (Amazon 2012; ByBox 2012; DHL 2012; DX-Business-Direct 2012).

Figure 2.7 Example of unattended electronic locker bank, situated in a petrol station forecourt [Source: (Bailey 2014)]

The process of parcel delivery for unattended delivery may vary with either: parcels being directed through the locker bank operator's warehouse, from which items are forwarded to a locker bank via a night-time distribution service (ByBox 2012); or, customers registering with locker bank operators allowing them to provide a local locker bank as the direct delivery address (Amazon 2012; DHL 2012). Previous research has demonstrated that significant economic and environmental benefits can be achieved with unattended collection and delivery points for the home-deliveries market (Edwards et al. 2009; Song et al. 2009; Edwards et al. 2010).

Song et al. (2009) demonstrated estimated savings of £2,778 to £6,459 ($4,100 - $9,500) in carrier transport costs and reductions of 3.8 to 8.7 tonnes of CO_2 emissions may be achieved by the same-day transfer of an item to the customer's nearest collection and delivery point (situated within local supermarkets, Post Offices and Railway stations) in the event of a failed first-time delivery, where:

- a single carrier serving the county (in this case, West Sussex, UK), performs 62,400 deliveries (over a 12 month period) accruing £69,453 in first-time delivery and re-delivery costs; and,
- 50% of customers who experience failed first-time deliveries opt to collect failed deliveries from the carrier's depot to retrieve items, generating £65,330 in travelling costs and handling charges.

Despite such benefits, the initial manifestation of unattended delivery within the UK failed as a result of a lack of awareness of the concept from consumers, and concerns regarding the insurance of products deposited within the lockers (Turner 2011). However, the concept was successfully implemented within the field services sector, where field service engineers working for a range of companies ordered specialist parts to be delivered over night for the next-day (Rowlands 2007).

Examples of the concept within the business to consumer market have since become more prevalent being successfully established worldwide, including the UK, Germany, France and the U.S. (Amazon 2012; ByBox 2012; DHL 2012), with more recent manifestations of the concept being implemented by online supermarket ordering services, whereby frozen, refrigerated and ambient temperature products may be delivered to locker banks situated in train stations (Waitrose 2014).

A trial of an unattended electronic locker bank was implemented within a hospital for the collection of online purchases by members of the public (McKinnon and Tallam 2003). Owing to the focus of such technologies within the online consumer and business-to-business service sectors, and a lack of awareness as to the services such technology can provide in the context of healthcare, there has been little research to demonstrate their potential in the field. However, parallels may be drawn between the field engineering services sector and healthcare owing to the similar requirements for specific time critical items for a single client (Bailey et al. 2013). In addition to this, owing to the additional traceability and security afforded by unattended electronic locker banks, they may also be used as temporary short-term storage of critical pharmaceutical items within secure locations throughout hospitals to increase the accessibility of emergency stockpiles of medication on wards (Bailey et al. 2014). Such applications of unattended delivery solutions would ensure that stock is secure and the movement of stock is recorded, enabling more effective stock reconciliation.

Whilst it is recognised that attended delivery solutions are well established within the logistics industry providing “shop drop” points whereby staff at local shops are granted legal powers by internet consumers to receive their goods for collection later by the recipient (Collect+ 2011; UPS 2013). It may be considered that attended delivery solutions provide very few benefits in the context of hospitals as the majority operate a dedicated receipts and distribution (R&D) department to receive all deliveries.

The applications and practices afforded by technologies such as intelligent storage and unattended electronic delivery solutions improve the visibility and monitoring of stock from hospital to ward level, addressing the poor levels of demand specific data highlighted in previous healthcare supply literature.

2.3.3 **Internet Connected Pharmaceuticals for Tracking and Patient Monitoring**

New applications of RFID and tracking technologies used in intelligent and unattended delivery solutions are central to emerging concepts within healthcare whereby stock follows the patient for improved monitoring of stock location and patient diagnostics (Stiehler 2005; Potdar et al. 2006; Alien 2008). “Smart Pills” implanted with broadcasting sensors represent one of the concepts at the forefront of advanced diagnostic medicine, Figure 2.8. Pills implanted with chips gather and broadcast information regarding dosage and timing to a small patch / implant, which in-turn relays the information to a doctor via a smartphone or fixed-internet connection. The information conveyed includes, date- and-time stamps, drug type, dose and place of manufacture as well as physiological parameters such as heart-rate activity, and respiratory rate (Hopkins 2010). Such technologies would enable more accurate diagnoses and a higher quality of patient care to be given with the medication of more appropriate drugs should the data indicate the current course of treatment is ineffective.

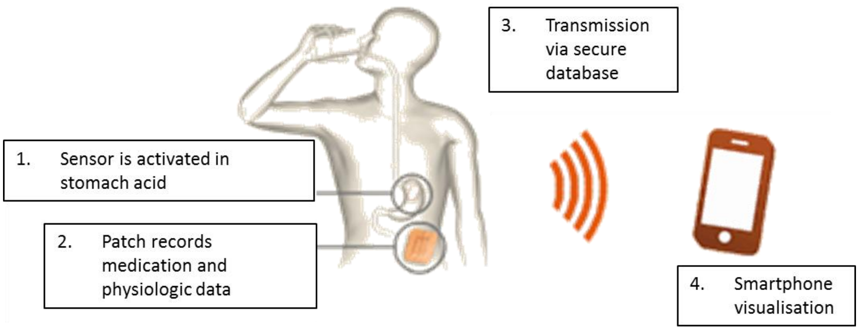


Figure 2.8 Diagram demonstrating how Smart Pills work [Source: (Novartis 2014)]

Smart Pill and RFID applications are also expected to enhance the security of the pharmaceuticals supply chain enabling the identification of unsuitable and counterfeit drugs. For example, in 2007, the U.S. Food and Drug Agency (FDA) called for the implementation of RFID technology to track the distribution of prescription drugs by tagging pallets (Li et al. 2006). Similarly in 2004, Purdue Pharma applied read-only tags to every 100 tablet bottle of OxyContin shipped to Walmart and drug wholesaler HD Smith for the same purpose (Werner 2005), increasing the locational awareness of products thereby enhancing the security of the supply chain and facilitating more comprehensive product recalls. This area of research within ICT is a key theme within wider supply chain literature, see Chui et al. (2010), intended to provide improved visibility and detailed monitoring to enable for more effective delivery scheduling to be planned, and near real-time decision making which can reduce and potentially eliminate the wastage of goods.

2.3.4 **Improved Locational Awareness**

In 2009, FedEx ran a one year trial for a new tracking device and web service package called SenseAware. The pilot was performed in association with 50 healthcare and life sciences companies for tracking delivery of items ranging from surgery kits and medical equipment to live organs (MacManus 2009). SenseAware uses quad-band world phone technology and is powered by multiple sensors able to detect light, motion and temperature. Through the web service users are able to track and trace the location of a package, and set up triggers, alerts and notifications using geo-sensors to inform one when a package arrives at a destination, Figure 2.9.

Figure 2.9 Illustration of the SenseAware asset tracking module and online platform enabling for location tracking and geo-sensor triggers and alerts [Source: (SmartPlanet 2009)]

This technology may be used for dynamic routing of inventory within the healthcare supply chain. For example, should a hospital stock-out of an urgently required item, it may be possible to determine if that item is in transit to a hospital within the same area and divert the delivery of the item to the hospital in need, whilst simultaneously re-ordering the item for the hospital it was initially intended for. The success of this system has led to the launch of a portfolio of temperature sensitive solutions for the healthcare industry, named FedEx Healthcare Solutions, deployed across Europe, the Middle East, Indian Subcontinent and Africa (EMEA). The primary aim of these solutions is to help healthcare supply chains manage expansion into new markets (Eye-for-Transport 2011). The associated website also provides a resource through which customers gain a high degree of visibility with 24-hour monitoring and end-to-end solutions to handle storage, fulfilment and distribution of inventory (Eye-for-Transport 2011).

Comparable systems have also been developed to optimise the conditions under which temperature sensitive products such as prescription medications are transported (McLeod 2011). Thereby improving the quality of drugs worldwide and enabling for global track-and-trace of each individual bottle / box of drugs throughout a supply chain, enabling for faster response to recall scenarios and greater security of shipments (IBM 2011).

RFID and Global Positioning System (GPS) technologies have also been trialled in the context of tracking the location of materials within organisations / construction sites (Mun et al. 2007; Song et al. 2007). RFID tagged materials provide an automated delivery and receipt process of supplies using portal gates equipped with an RFID reader unit, however once an item has passed beyond a portal, the locational information of where the item is placed is not known. Similar systems are used within large UK Post Office sorting warehouses, whereby sorted post is deposited into RFID tagged bags and cages to track their movement throughout the warehouse, Figure 2.10.

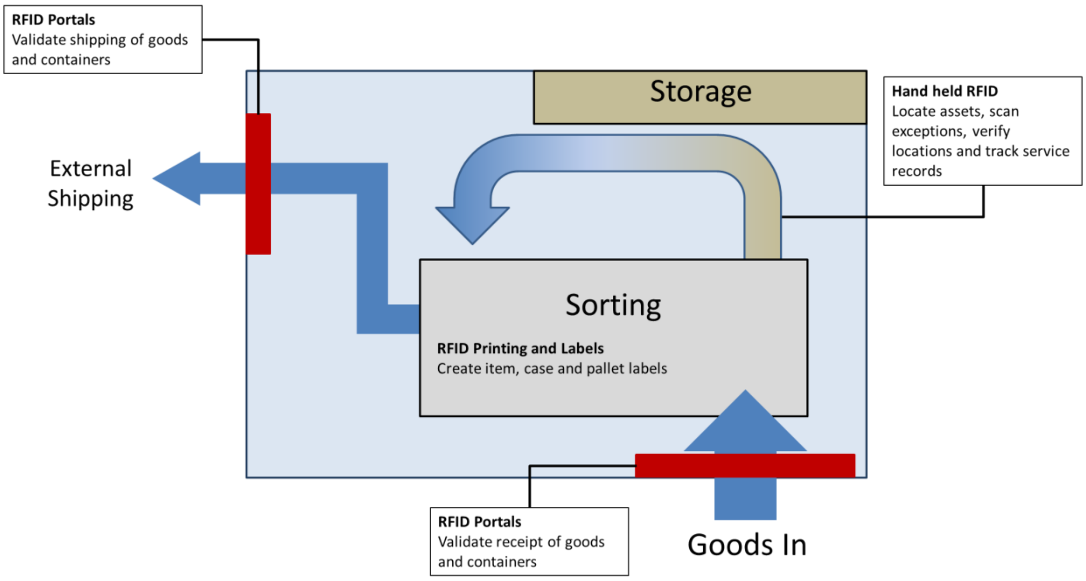


Figure 2.10 Demonstration of RFID warehouse asset tracking system [Adapted from: Compsee (2014)]

Demonstrations of more advanced locational ICT have been tested in the context of the construction industry and in a small acute care hospital, yielding greater awareness of stock quantity and physical location:

Song et al. (2007) tested the dense deployment of low cost RFID tags and mobile RFID readers equipped with GPS as part of a construction materials tracking system. This provided 2-dimensional coordinates of tagged materials using: triangulation, scene analysis (inferring location using visual images) and a proximity technique, determining whether an object is near one or more known locations. The study found that such techniques coupled with portal gates can accurately track materials throughout a supply chain and within a given area. In the context of construction resources, locating workers, materials and equipment enables management to control actual project performance such as labour hours spent completing a given activity (Song et al. 2007).

A similar concept was tested by Mun et al. (2007) in an application of an active and passive RFID system within a small 120 bed acute care hospital to track inventory including infusion pumps, beds and wheelchairs. Their study demonstrated the speed with which equipment can be located in hospitals and how reducing the amount of time clinicians spend locating equipment can lead to improved patient safety (Mun et al. 2007). This research demonstrated that asset tracking technology can provide useful insights into the frequency of asset utilisation, indicating that 20% of the Intravenous (IV) pumps in the test case hospital were unused, suggesting a potential reduction in equipment requirements, identifying the savings in equipment costs that may be achieved (Mun et al. 2007).

Whilst this demonstrated that an RFID system is viable within a hospital environment, it highlighted the need to augment the RFID system with a 2D barcoding system owing to: the restrictions of having to tag every item of equipment with RFID; and, the potential destruction of tags due to essential sterilisation processes, some of which use extreme temperatures, humidity, chemical and X-ray environments (Mun et al. 2007).

Such research demonstrates the implications for RFID systems within hospitals as a means to increase the potential for inter-departmental sharing and improved inventory management through an enhanced awareness of stock and equipment within all areas of a hospital.

2.3.5 **Increased Visibility of Inventory Holdings using ICT**

Hospitals that Implement ICT solutions generate large amounts of information enabling Electronic Data Interchange (EDI) inter- and intra- company-hospital communication to facilitate the following outcomes:

- Collaboration between logistics and distribution companies in the form of co-packaging and distribution;
- Sharing of inventory within and between hospitals to increase stock utilisation; and,
- Reduction of duplicate inventories and wastage (Hammant 1995; Bowersox et al. 2000; Thompson and Hagstrom 2008).

In response to these outcomes initiatives throughout the UK, such as the Pharmacy Business Technology Group (Finesilver 2002), China (Liang et al. 2004) and the U.S. (WEDI 1993; Woodside 2007) have been established, intended to advance the integration of technology into healthcare systems to improve care and lower costs. Owing to the significant organisational and institutional change required to implement widespread EDI, initiatives in the UK (Finesilver 2002) and China (Liang et al. 2004) are still in their infancy, and progress within the U.S. continues to be slow (WEDI 2013).

A report published by WEDI (1993) estimated that for an industry-wide EDI system in the U.S. savings of \$0.50 – \$1.00 (£0.30 – £0.60) and \$1.10 - \$2.09 (£0.65 – £1.24) may be achieved for payers and providers, respectively, for each of the estimated 150 million annual insurance claim transactions in 1993. With overall savings of between \$9.39 (£5.60) and \$17.42 (£10.40) per healthcare claim transaction due to reduced administration costs (WEDI 1993).

In the context of healthcare inventory management enhanced visibility of inventories and shipment schedules may facilitate the mutual consolidation of consignments with collaborative supplier initiatives, actively reducing the amount of hospital freight-related traffic on the road. Furthermore, increased visibility of freight movements, vehicle types and fill rates could facilitate back-loading of vehicles with non-hazardous waste materials for transport off-site to the appropriate disposal / recycling facility; and, to other hospital sites along the vehicles delivery route.

2.3.6 **Detailed Monitoring of Inventory and Patients**

As demonstrated by solutions such as smart cabinets which provide enhanced visibility of inventory, greater stock management within hospitals can deliver significant efficiency and financial savings. However, technologies such as the Smart Pill, Wireless Sensor / Body Sensor Networks, which enable near real-time diagnostic information for patients, present one of the most significant contributions to better hospital inventory management, by removing significant amounts of unpredictability in patient demand. Chui et al. (2010) reported that healthcare trials with patients suffering chronic illnesses such as congestive heart failure who were fitted with sensors continuously monitoring their weight, blood pressure, heart rate and rhythm provided practitioners with early warning of conditions which would otherwise lead to unplanned hospitalisations and expensive emergency care. Treating conditions such as congestive heart failure in this way are predicted to save \$1 billion annually in the U.S. as a result of reduced hospitalisation, treatment and the related logistics (Chui et al. 2010).

2.3.7 **Issues with Emerging ICT**

Despite the fact that many of the technologies reviewed are well-established within the logistics industry, and the benefits they provide are extensive, adoption of technologies such as RFID remains slow, owing largely to a number of inherent issues with their implementation, maintenance and management (Chui et al. 2010).

The value proposition behind RFID is as a replacement for the barcode as a non-line-of-sight identification method but significant barriers to the wide-scale implementation of RFID technologies have been identified, such as: the requirement for specialist skills to manage the multitude of devices and tags operating on varying frequencies; the read accuracy in terms of out-of-range/obscured/misaligned tags (Floerkemeier and Lampe 2004); battery life, security and data protection and the lack of standardised protocols with existing hospital systems. (Nagy et al. 2006). Underlying these issues, the cost of RFID devices, tags, middleware and software components often prevent the wider implementation of contact-less ICT (Michael et al. 2010).

In addition to this, 2-D barcodes suffer from issues such as: accidental de-facing, mis-scanning in the presence of multiple codes adhered to a single item (Mun et al. 2007).

One of the most significant barriers to the global implementation of IoT applications is legislative control. Many IoT technologies and concepts proposed may be considered a breach of ones' right to privacy (Michael et al. 2010). In particular, this issue refers to the tracking and monitoring of items which may be retained on a person in the form of a tagged package, parcel or smart-phone. Another issue regarding legislation is that of legal liability. Liability frameworks for the bad decisions of automated systems such as those implemented in smart cabinets or pills will have to be established by governments, organisations, companies and actuaries for insurers before they can be implemented within sectors such as healthcare (Chui et al. 2010).

As is evident from the literature, much research exists addressing the issues surrounding the necessary supply of medical consumables to hospitals, with little regard to its environmental sustainability, particularly within an urban context. The following section aims to fill this gap by reviewing existing sustainable urban logistics strategies which may be implemented to reduce hospital related traffic and cater for the demands of healthcare institutions.

2.4 Sustainable Urban Logistics Solutions for Healthcare

Evidence from the literature suggests that sustainable logistics operations are rarely pursued by distributors and suppliers unless commercial benefits can be gained (Lewis et al. 2010). Therefore, the onus on pushing forward sustainable logistics initiatives often falls on customers and local authorities to implement and in many cases fund. There are a range of measures which can be employed within an urban setting to encourage more sustainable UFT within healthcare, which according to MDS Transmodal Ltd and CTL (2012) and KonSULT (2014) can be divided into 6 categories of sustainable supply:

i) **Market-based measures**, which implement pricing mechanisms to assign a financial cost to negative impacts of freight;

ii) **Regulatory measures**, which implement access restrictions to contain and manage environmental and congestion-related impacts (Danielis et al. 2012);

iii) **Land-use planning**, such as the grouping of commercial and residential activities to enable consolidation of urban freight to each area (Cherrett et al. 2012);

iv) **Infrastructure measures**, which aim to provide the required road / buildings infrastructure and services;

v) **Information related measures**, which encourage the exchange of data between logistics companies and businesses facilitating higher utilisation of the existing infrastructure; and

vi) **Management measures**, which aim to control the utilisation of the existing capacity within UFT networks (Browne et al. 2012).

Each of these measures may be implemented in isolation, however, most are regarded as complimentary and are often implemented together to encourage the use of other measures. For example regulatory measures such as access restrictions within city centres may be implemented in conjunction with consolidation centres to encourage greater participation in freight consolidation services. For the purposes of this review, land-use planning measures are omitted as the scope of this research is to address the issues of existing healthcare institutions and urban areas.

2.4.1 **Market-based Freight Control Measures**

Market-based measures aim to encourage change through pricing strategies, typically associated with congestion charging and low emissions zones (LEZ), charging during peak-times and day-time hours in urban areas. The use of such measures does not restrict access to areas within charging zones, but aims to encourage more sustainable choices regarding freight transport. This can include low-emissions vehicles which may be awarded exemption or discounts during charging periods. LEZ's have been successfully implemented within London (after the implementation of the congestion charging scheme), Berlin and Stockholm achieving reductions in PM_{10} (particulate matter less than or equal to 10μm) of 19%, 25% and 40%, respectively (Browne et al. 2012).

Previous research has found that fiscal policies such as congestion tolls produce small effects on strategic and commercial decisions in the short-term, with greater impacts on the tactical operational behaviours of companies, such as night-time deliveries and re-pricing of goods and services to customers to reflect additional charges incurred by delivery vehicles (Danielis et al. 2012). For example, in the context of healthcare institutions in central London, the implementation of the congestion charge scheme affected the price of deliveries to hospital Trusts, which reside within the charging zone such as GOSH, as a result of suppliers and 3PLs recouping charges. Therefore, market-based measures may be considered inappropriate as a means to encourage more sustainable freight for healthcare.

2.4.2 **Regulatory Freight Control Measures**

Regulatory measures are often enforced during day-time hours or peak traffic times, much like market-based measures they are often used to impose access restrictions according to the time of day, parking, loading and unloading areas or particular vehicles according to: weight, low- / zero- emissions vehicles and minimum load factors (Marcucci and Danielis 2008; Häger and Rosenkvist 2012; Kaszubowski 2012).Measures such as loading, unloading and access restrictions have been successfully implemented within cities such as Utrecht (The Netherlands) in which many forms of UFT (not meeting Euro IV engine standards) are restricted from entering pedestrianized areas of the city during particular times of the day (Browne et al. 2012). Similarly in Bilbao (Spain), loading and unloading is restricted within the old city between 08:00 and 11:00, after which areas become pedestrianized. In addition to this, temporal allocation of loading spaces to specific distributors has also been trialled presenting positive impacts on goods distribution, eliminating illegal parking. Based on a Barcelona case study, whereby distributors were issued a specific time period during which they may use a space to make deliveries time savings of 22% per unit of transported volume, and reductions of 10% in fuel consumption were estimated (Álvarez and de la Calle 2011). Comparable schemes have been implemented in: Maastricht, Leiden, Arnhem and Groningen, in The Netherlands (MDS Transmodal Ltd and CTL 2012); Bristol, UK (Lewis et al. 2010), Padua, Italy (Marcucci and Danielis 2008); and Monaco (Malhene et al. 2012).

Results of LEZ in The Netherlands yielded positive impacts on air quality with an average reduction of 0.16 $\mu g/m^3$ in roadside NO_2 concentrations compared against the situation without an LEZ, and reductions of 0.15 $\mu g/m^3$ on roads with high volumes of Heavy Goods Vehicle (HGV) traffic (Buck Consultants International and Coffeng 2009). However, these were lower than expected owing to small gains from new vehicles and exemptions granted to many older, more polluting vehicles (Browne et al. 2012).

Experiments in bookable loading bays which can be reserved by operators 24-hours in advance, have been carried out in Greater Lyon (France), and London (UK). Results from the trial in Greater Lyon led: to more efficient freight trips and routes in the city; a 40% reduction in double parking for deliveries; and, less congestion and pollution in the city centre (Browne et al. 2012). However, whilst the trial in London demonstrated the technical feasibility of the concept, it indicated a need for a strict enforcement regime required to ensure the legal use of bookable bays with 80 recorded incidents of vehicles being moved on and a further 15 penalty charge notices being issued (Mcleod and Cherrett 2011).

A study by MDS Transmodal Ltd and CTL (2012) found that harmonisation of regulatory measures can provide improvements in air quality, GHG emissions and congestion, whilst incurring minimal costs to UFT operators and public authorities. However, previous research has found that larger companies are more likely to cope with regulatory policies better than smaller firms or own-account carriers, with the most affected distribution channels being those which require large quantities of frequent deliveries (Danielis et al. 2012). Regulatory measures, much like market-based measures, are likely to have a detrimental impact on the cost of hospital freight with regards to frequent deliveries of medical consumables. However, previous examples have resolved similar issues for pharmaceutical products, which are delivered frequently by small vehicles by awarding them exemption from regulatory restrictions in most case studies (Danielis et al. 2012).

Whilst both market-based and regulatory measures are proven to be effective in changing the operating behaviours of suppliers and distributors, they are widely regarded as a means to motivate innovation and change towards sustainable UFT. For example, it is commonly observed that when time or vehicle restricting measures are implemented, companies look towards solutions such as supplier collaboration, urban consolidation centres (UCCs) and out-of-hours / off-hours deliveries as a means to reduce the impact of such measures on their freight operations (Crainic et al. 2009).

2.4.3 **Freight Collaboration to Utilise 'Slack space' and Empty VKms**

The previous review of healthcare supply chain literature, Section 2.2.3, examined vertical collaboration (i.e. collaboration between supplier and hospital) as a means to: improve the flow of goods to hospitals; improve inventory management within Trusts and achieve bulk buying discounts amongst groups of hospitals within a single geographical region (Badea et al. 2014). In addition to this, horizontal collaboration, such as partnerships between mutual and competing suppliers sharing freight network capacity may also be used to achieve reductions in supply chain costs and the negative externalities of freight. Previously, horizontal collaboration has focussed on consolidating the movement of goods within an individual supply chain. Recent developments within the industry have led to coordination of business activities between shippers and carriers, to enhance their overall profitability and performance by distributing capital investments amongst partners and improving fill-rates within vehicles and in some cases eliminating empty running mileage (Gonzales-Feliu et al. 2012; Verdonck et al. 2012).

Collaborative logistics range from small partnerships representing agreements held between two companies to collaborative logistics networks supported by internet-based information systems, such as those described previously in Section 2.3.3, that electronically enable freight forwarders and carriers to coordinate freight across a supply chain (Lin et al. 2012). Small partnerships such as that established by Kellogg's and Kimberley Clark who share distribution networks to the same small retail customers have recorded savings of 7% in associated transport costs (Lewis et al. 2010). Further examples of mutual agreements held between two companies, such as the partnership formed between United Biscuits and Nestlé have also demonstrated the significant savings that can be achieved between two rival companies. The collaboration between the two companies identified that of the 15 loads per day transported from Nestlé's factories in the North of England to its distribution centre in Leicester, two to three returned empty; and that United Biscuits scheduled daily trucks to Yorkshire from its national distribution centre close to Nestlé's Leicester distribution centre (Lamb 2012). Through mutual back-loading of vehicles the companies achieved a reduction of 280,000 empty running km's per year, equating to 95,000 litres of diesel, 250 tCO_2 and financial savings of £300,000 (IGD 2009).

As previously demonstrated in Section 2.2, a lack of visibility and monitoring of items within the healthcare supply chain present significant barriers to the adoption of collaborative initiatives between suppliers. In spite of this, hospital partnerships (customer collaboration) aimed at delivering savings in procurement and reductions in traffic travelling to and from hospitals have been established internationally. Bhakoo and Singh (2012) reviewed a collaborative pharmacy arrangement between different pharmaceutical departments in hospitals within the same geographical region. Using a comprehensive and up-to-date electronic database of stock information for all participating pharmacy departments, greater levels of stock sharing were achieved minimising unnecessary journeys from manufacturers and distributors, decreasing the response time required to resolve stock-out scenarios (Bhakoo and Singh 2012).

Supply chain collaboration such as logistics pooling, akin to the GPO systems in the U.S., Canada and Singapore, and the NHS Supply Chain (UK), are common within the healthcare industry. Logistics pooling involves suppliers and / or receivers contracting a 3PL to coordinate all transport and distribution operations, consolidating all deliveries to a single or group of customer(s) (Gonzales-Feliu et al. 2012). High supplier participation in this form of collaboration typically achieves higher vehicle fill-rates and reduces the number of vehicles to customer location(s), however as demonstrated by the UK NHS Supply Chain, in which supplier participation is low, the impact on delivery volumes to customers can be minimal.

The relative success of the U.S. GPO structure compared to the UK NHS Supply Chain is linked to the complimentary competitive market mechanisms focussed on generating cost savings inherent within the privatised system (Burns 2002; Nollet and Beaulieu 2005; Panero et al. 2011; Varghese et al. 2012). Such findings are corroborated by the wider freight consolidation literature, which stipulates that UCCs are not feasible under liberal markets outside of the construction sector or without a single landlord making the use of a centre mandatory (Regué and Bristow 2013).

Interviews with hospital supply chain professionals and suppliers in the UK, undertaken by the author as part of this research and covered in depth in Section 5.5.6, suggested that poor supplier participation in consolidated routes of supply was largely due to the erosion of supplier profits associated with the additional costs accrued for participation in consolidation, and loss of control and visibility of inventories within the supply chain (Fry et al. 2012; GSTT 2014; Intersurgical 2014; Moore 2014). These issues are also highlighted in the wider freight consolidation literature, where the following key disadvantages of consolidation have been identified as:

- High start-up costs and operating costs;
- Limited benefits to intra-company (transportation of goods between locations within the same company / organisation) and parcel carriers owing to high levels of consolidation already being practiced;
- Difficulty for a single centre to cater for the requirements of many different suppliers;
- Longer lead times;
- Route diversions for supplier vehicles whereby deliveries are made to a consolidation centre for participating customers, and additional trips are made for the remaining customers, with lower fill-rates thereby making the additional trips more costly; and,
- a loss of direct contact between supplier and customers

(Browne et al. 2005; Woodburn 2005).

2.4.4 **Urban Consolidation Centres**

The concept of urban consolidation centres has been extensively researched in the U.S., Canada, Japan and Europe with the majority of trials being conducted in France, Italy, The Netherlands and the UK (Browne et al. 2005; Huschebeck and Allen 2005; Browne et al. 2007; Allen et al. 2009; Browne et al. 2012). Throughout the literature, various terms are used to describe Urban Consolidation Centres (UCC) including Freight Consolidation Centre (FCC), City Logistics Centres, Freight Transhipment Centres (FTC) and Urban Distribution Centres (UDC) (Woodburn 2005).

The underlying premise of UCCs is to address the difference in requirements between inter-city and inner-city freight transport: whilst inter-city freight favours large trucks allowing the cost of fuel and tolls to be shared across larger loads, smaller trucks and vans are considered more appropriate for inner-city distribution, particularly within smaller streets and more congested road networks (Quak 2008). However, whilst this process has been found to increase the fill-rate of urban freight vehicles, in some cases it may result in higher traffic volumes and emissions within cities owing to a greater number of small vehicles being required to replace larger vehicles (Quak 2008). Such findings led to a diversification of UCC operation, consolidating goods into both small and large vehicles to avoid the occurrence of part loads in city centres. Thereby managing the negative externalities of UFT, reducing: congestion, air pollution, visual and noise impacts as well as pedestrian-vehicular conflicts, (Lewis et al. 2010; Marinov et al. 2010; Malhene et al. 2012; Qiu and Huang 2013). For example, the Bristol Consolidation Centre situated north-west of Bristol, which serves the Broadmead area (located 10 miles away) comprising more than 300 retailers, achieved a 75% reduction in delivery vehicle movements, saving 20.3 tonnes of CO_2, 660kg NO_x and 19.7kg of PM_{10} 3 years after its inception in 2004 (Campbell et al. 2010).

As indicated by Marinov et al. (2010), Table 2.1, the effective utilisation of UCCs can also help to:

- overcome vehicle restrictions imposed by regulatory measures, acting as a cross-docking facility to transfer deliveries into smaller and 'greener' unrestricted vehicles;
- facilitate operations with freight vehicles in loading and unloading areas and where customer loading facilities may be over-capacity;
- Improve delivery services to retailers (on-time and to-date);
- reduce the volume of commercial traffic in urban centres; and,
- provide opportunities for added value services to customers, such as the removal of bulky packaging to increase fill-rates and reduce the generation of waste at the point of delivery.

Table 2.1 Main activities and benefits of UCCs [Source: Campbell et al. (2010), pp.7]

Activity	**Benefits**
Consolidation	Consolidation of multiple daily deliveries to reduce vehicle number requirements and increase fill-rates.
Cross Docking	Delivery of consignments to a UCC at the supplier's convenience with forwarding to the customer as and when goods are needed.
Stockholding	Reduction of delivery lead times, improved product availability and customer service, through short, medium and long-term storage.
Replenishment	Smaller, more regular deliveries of products for re-stocking throughout the day as opposed to a single larger consignment at one time.
Pre-retailing	Pre-merchandising activities such as unpacking, sorting, labeling, size cubing and markdowns, enabling shops to allocate more retail space to sales rather than stock storage and management.
Returns Management	Consolidating items being returned from customers to suppliers.

Consolidation of deliveries is typically achieved by temporal or vehicular consolidation. Temporal consolidation is predicated on the intentional delay of goods to a single customer until a pre-established threshold is achieved or a pre-determined delivery day / time, at which point all goods are forwarded to their final destination (Häger and Rosenkvist 2012; Nguyen et al. 2013). Such practices are implemented between couriers and some hospitals, such as GOSH. However, the success of temporal consolidation in the context of healthcare relies on a high frequency of 'threshold' volumes being achieved to ensure items reach their destinations by the time they are required. Further to this, courier companies typically strive to minimise the holding time required to consolidate items owing to the costs associated with storing inventory. Furthermore, as is the case at GOSH, the presence of urgent items within the non-urgent chain means that once an urgent item arrives at a courier's warehouse, the item is delivered along with any of the items they are temporally consolidating, resulting in sub-optimal load factors (Bailey et al. 2013; Bailey et al. 2014).

Vehicular consolidation refers to the traditional means of increasing vehicle fill rates, whereby a central warehouse location is established to receive all goods for either a single large customer or a group of customers within the same geographical location. This model of consolidation can be classified into one of three types according to a specific set of operations and services required for customer(s):

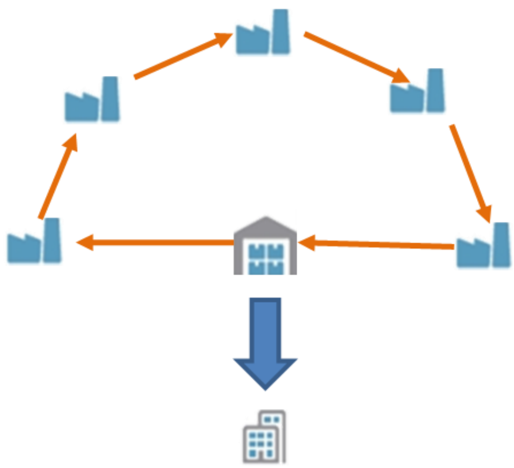
1. UCCs serving all or part of an urban area such as a city centre or town, e.g. Bristol City Consolidation Centre (BCCC), to reduce local congestion, serious environmental problems, freight driving and parking restrictions, pedestrianized areas and narrow streets;
2. UCCs serving a single large site, town / city with a single landlord possessing the governance to make use of the centre mandatory, such as Heathrow Airport Retail Consolidation Centre and Monaco 'Freight Platform';
3. UCCs serving construction projects / special events which operate with restricted available space, such as the London Heathrow Terminal 5 construction project, London 2012 Olympics Consolidation Centre and the London Construction Consolidation Centre (LCCC), whereby goods are held off-site until they are required (Huschebeck and Allen 2005; Panero et al. 2011).

Distribution services for UCCs are typically modelled using one of the following approaches:

i) Milk rounds, Figure 2.11(a), which predicate a smaller vehicle collecting small consignments of goods along a fixed route for consolidation into larger shipments at a UCC ; and,

ii) Hub (and spoke) distribution, Figure 2.11(b), the most common operating structure, whereby all goods for customer(s) in a single region are delivered by suppliers direct to a UCC where deliveries are sorted and consolidated into fewer, large vehicles (Häger and Rosenkvist 2012).

a)



b)

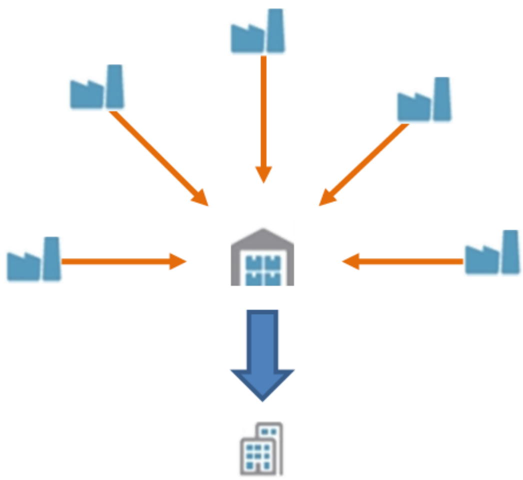


Figure 2.11 Illustrations of the operational models of supply for urban consolidation centres (a) milk round supply performed by a single vehicle collecting from multiple suppliers to group orders in a central warehouse to be forwarded to the customer; and, (b) hub supply wherein suppliers ship their goods to a central warehouse for forwarding to the customer.

Owing to the use of smaller vehicles the milk round model imposes restrictions on the number of pick-up points and the size of consignments which may be collected. Further to this, milk round models have been found to operate at low load factors (Häger and Rosenkvist 2012). UCC models based around a central depot (including milk round and hub models) typically achieve higher fill rates for the forward journey from the UCC than other means of consolidation such as temporal consolidation (Björklund and Gustafsson 2012; Browne et al. 2012; Hoyer 2012). However, owing to the need for large fixed-based infrastructure they are often associated with longer-lead times, larger administrative workloads, and increased supply chain costs (Lewis et al. 2010; Häger and Rosenkvist 2012).

Due to negative impacts on supply chains such as increased operating costs, loss of contact between suppliers and customers, and the sub-optimisation of supplier logistics, the majority of UCC schemes are supported either fully or in-part by funding from central, regional and local municipalities, or the owner of the site, e.g. Amsterdam, Monaco, La Rochelle, Nuremburg and Bristol (Huschebeck and Allen 2005). For detailed reviews of UCCs implemented worldwide, the reader is referred to: Björklund and Gustafsson (2012), an analysis of more efficient city logistics initiatives (environmental management, city logistics and collaboration) implemented by Swedish municipalities; Häger and Rosenkvist (2012), provide an evaluation of the effects of DHL freight consolidation on CO_2 emissions and costs; Malhene et al. (2012), provide an overview of the issues experienced regarding urban freight consolidation worldwide; Lewis et al. (2010), review the appropriate uses of UCCs and the considerations to be made for their implementation, focussing on implementation for shopping centres, high streets and construction sites; Marinov et al. (2010), identifies how current and state of the art urban freight consolidation concepts may be used to alleviate congestion, pollution and public dissatisfaction in urban areas thereby improving the overall urban environment; Browne et al. (2007), provides a review of urban goods vehicle activities literature; Browne et al. (2005), reviews UCC initiatives throughout the literature, analysing different UCC types using specific examples, providing a methodology for the evaluation of UCCs; Huschebeck and Allen (2005), provides a review of Best Urban Freight Solutions focussing on the advantages and disadvantages of UCCs and their appropriate applications; Klaus (2005), reviews a number of UCC concepts tested in Germany; Woodburn (2005), provides an overview of UCCs for urban and specialist use, including potential economic, environmental and social benefits using demonstrations from Germany and Sweden ; BAA-PLC (2002), investigates the issues of establishing a consolidation centre for retailers at Heathrow, evaluating the economic and environmental costs and benefits of the centre; Nemoto (1997), investigates the concept of area-wide inter-carrier freight consolidation using Tenjin district, Fukuoka, Japan as a case study assessing the social effects and establishing the conditions under which such concepts may succeed.

Despite significant support for UCCs and worldwide implementation, a small proportion of the schemes achieve commercial self-sustainability, with an average of 19%[2] of consolidation services and succeeding beyond the trial phase, Table 2.2.

Table 2.2 Synthesis of the main European experiences with urban consolidation centres [Source: Gonzales-Feliu et al. (2012), pp.3]

Country	***Number of UCCs***	***Operational UCCs, 2011***	***Success Rate[3]***
United Kingdom	32	13	41%
Italy	16	10	63%
France	16	8	50%
The Netherlands	14	6	43%
Germany	14	3	21%
Sweden	4	0	0%
Switzerland	3	1	33%
Spain	3	0	0%
Austria	1	0	0%
Belgium	1	0	0%
Finland	1	0	0%
Greece	1	0	0%
Portugal	1	0	0%

Most of the international experiences indicate that an initial investment in infrastructure, facilities, human and technical resources, (including delivery vehicles) is required, with the most

[2] Weighted average calculated from figures presented in Table 2.2
[3] Success rate is indicative of the proportion of UCCs implemented in the country that were still operational in 2011.

successful examples being supported by financial subsidies, e.g. Bristol Consolidation Centre received 62% of the necessary funds for its operation from local government (Campbell et al. 2010), and organisational support from public organisations (Gonzales-Feliu et al. 2012).

Despite such financial support, the majority of schemes require the on-costs (i.e. cost of processing and final delivery of consignments) to be paid by participants, highlighting one of the most significant barriers, with longer lead times (i.e. the time lag between ordering and receipt of an order) and larger administrative workloads also being commonly cited (Lewis et al. 2010; Häger and Rosenkvist 2012).

As demonstrated by the literature urban consolidation centre schemes are typically implemented to serve a central business district / specific area within a city with the aim to reduce freight traffic related to businesses operating within them. In addition to this there are examples of freight consolidation centres operated by a single landlord such as an out-of-town shopping centre or airport. Demonstrations of such consolidation centres such as Meadowhall, Sheffield, Heathrow Airport, UK; and Monaco) appear to be more successful compared to other models owing largely to the use of the service being made mandatory by the landlord / local authority and municipalities (Lewis et al. 2010; Allen et al. 2012). These consolidation centres operate on the same basic principles of construction consolidation centres whereby it is mandatory that all freight uses the consolidation centre. However, there are many successful examples of temporary consolidation centres being implemented for major construction projects within cities to manage the associated traffic travelling to the site and also reduce the amount of materials held on site which may obstruct building progress.

As demonstrated by the healthcare review, consolidation centres have been successfully implemented in the U.S. in the form of GPOs, Section 2.2.3. Such entities provide a means to achieve discounts for individual institutions through the bulk buying of inventory and storage within large central warehouses for shipping to multiple healthcare institutions. Further to this, examples of freight consolidation in the public healthcare sector, such as the NHS Supply Chain, have demonstrated some success with low levels of participation by suppliers (c.30%).

2.4.5 **Barriers to Consolidation**

The most significant objection to UCC schemes are the increased costs incurred by suppliers such as forward delivery of consignments from the consolidation centre and potential added mileage associated from incorporating consolidation centres within their existing delivery routes (Huschebeck and Allen 2005). As demonstrated by the literature, UCCs typically require continuous financing from the public sector to overcome this issue, the majority of UCC initiatives are supported in this way, e.g. Bristol Consolidation Centre (UK), opened in 2004, receives 62% of the required £459,000 annual operating costs for the centre (Campbell et al. 2010; Al-Azzawi and Mathie 2011). However, high levels of involvement from public sector institutions often leads to fears of municipal monopolies in the UFT market (Huschebeck and Allen 2005). Additional opposition comes from large businesses and freight operators who perceive that their already optimised supply chains suffer from this additional link added to the chain (Lewis et al. 2010), generating additional costs for their own logistics network.

As is the case for healthcare, additional opposition comes from suppliers relating to the loss of direct contact with receivers, thereby reducing: opportunities to promote additional business, establish and grow customer relationships; and the ability to control the quality of goods and services (Panero et al. 2011).

Supplier opposition to UCCs represents one of the most significant barriers to the successful implementation of initiatives (Kaszubowski 2012). In order for UCCs to achieve a critical mass whereby the cost of services are significantly less than those of traditional supply routes, they require support from suppliers to buy into the services. This review has demonstrated that supplier participation may be rallied by the: investment of public subsidies supporting the centre until critical mass is achieved; operation of centres under mandatory participation rules; or, implementation of a centre in conjunction with strict regulatory restrictions preventing access to customers during given times of day or poor existing operating conditions. If this does not happen, the initiative is unlikely to become self-sufficient, and will require continued significant subsidies to maintain operations (Gonzales-Feliu et al. 2012).

Despite consolidation services such as the London Construction Consolidation Centre (LCCC) achieving c.75% reductions in CO_2 emissions (Lewis et al. 2010), research into goods transport for 49 supermarkets (generating a weekly flow of 8,000m^3 of goods) in the City of Groningen found that the use of UCCs to reduce large freight traffic within city centres can lead to a 22% increase in emissions due to the displacement of traffic to other locations and the addition of vehicle trips to forward consolidated stock to end-consumers (Boerkamps and Binsbergen 1999). Such findings have encouraged new and innovative methods of freight transportation and consolidation for urban areas to achieve reductions in both freight-related traffic and emissions.

2.4.6 **Alternative Models for Consolidation**

The majority of this research focusses on the reduction of day-time UFT numbers whilst also focussing on the reduction of freight-related emissions. Many of the schemes achieve this through the implementation of consolidation models using alternative modes and green fuel technologies.

In Yokohama (Japan), a cooperative delivery system with a consolidation centre was implemented to address heavy concentrations of car traffic (500 vehicles per day) in Motomachi Street (Browne et al. 2012). The scheme involved a collaborative team of shop owners on Motomachi Street instructing carriers to deliver all goods and parcels to a consolidation centre situated 1km away, where the goods were transhipped onto low emissions vehicles (Compressed Natural Gas, (CNG)) and transported to three eco-cargo stations for transfer to human-powered carts for delivery to shops (Browne et al. 2012). The scheme successfully reduced the total number of vehicle-days from 40 vehicles per 30 days, to 20 vehicles per 30 days (Taniguchi 2012). However, in the context of healthcare models of consolidation which use human-powered carts for delivery of items to hospitals may be considered unsuitable owing to their diminished security of high value items transported to hospitals.

Similar models of operation have been trialled using un-utilised transport capacity within the public sector transport, such as surplus physical capacity in transport networks and scheduling capacity (i.e. on train lines). This includes partnerships with East Midlands Trains, trialling high speed freight services linking Nottingham with London (Screeton 2013); and, CityCargo, in Amsterdam (The Netherlands).

The CityCargo scheme involved a tram running on a single route through the city centre (between 07:00 and 11:00), with two points at which goods could be transferred to small electrically powered cars for final delivery, providing the equivalent of four 7.5 ton vehicles. This demonstration delivered an estimated 16% reduction in PM, CO_2 and NO_x, as well as improved vehicle fill-rates and reductions in noise pollution (Crainic et al. 2009). Both the East Midlands Trains trial and CityCargo project demonstrated the potential for reducing urban freight-related emissions through the use of low / zero carbon transport to undertake first and last mile logistics. Implementing such concepts in the context of hospitals, specifically within London wherein extensive public transport networks exist presents numerous methods through which they may be implemented. However, as is common with public transport networks in cities, many operate with high passenger demand leaving little additional capacity for freight.

Recently, alternative means of consolidating road-based freight have been tested by TNT for the delivery of goods and mail to businesses within Brussels city centre, using a mobile depot. The mobile depot, Figure 2.12, unit is loaded with all deliveries for a single day at an out of city depot, transporting them to an inner city location from where electrically-assisted tricycle couriers pick up and forward items to their final destination (Straightsol 2012a).

Figure 2.12 Demonstration of the TNT Mobile Depot [Source: (Straightsol 2012a)]

A pilot of the concept (conducted from June – August 2013), serving 3 postal codes within the Brussels-Capital Region, incorporating approximately 110 stops per day comprising deliveries and collections achieved: reductions of diesel kilometres from 0.92 km per stop to 0.52 km per stop; and, savings in CO_2 (23%), SO_2 (24%), $PM_{2.5}$ (59%), and PM_{10} (22%) (STRAIGHTSOL 2014b). However, results also indicated:

- A doubling of operating costs, compared against traditional van made deliveries; negative impacts on the quality of service with stops being performed later in the day compared to the current situation;
- An estimated 48% increase in NO_x ascribed to a low utilisation rate of the mobile depot (40%); and,
- Issues associated with the matching of freight profiles for the delivery area to match the load capacity of the cyclocargoes (electric-assisted bicycles with secure cargo hold), and requirement for the depot to be located within the delivery area to minimise the stem time of the cyclocargoes (STRAIGHTSOL 2014b).

Many trials and demonstrations within the literature, such as the TNT mobile depot and DHL Amsterdam boat and bike mail, demonstrate the positive service and environmental impacts bicycle couriers logistics can provide. Further demonstrations of bicycles and electric-assisted bicycles as a single means of delivery using a single point for consolidation of items have also been implemented in Berlin (Germany) using BentoBox.

In 2011 BentoBox, an innovative modular logistics hub (akin to unattended electronic locker bank stations, presented in Section 2.3.2) was implemented in Berlin to test its integration into CEP services using Messenger, a local CEP service provider. The system was used to collect and pool shipments delivered by multiple service providers (Roeller 2012). Deliveries addressed to- and originating from- the neighbourhood of Friedenau (Berlin) are collected in the BentoBox and repackaged before their ongoing delivery by bicycle courier (Roeller 2012). This model facilitates night-time deliveries from Berlin's whole Western inner city with forwarding to Messenger's central deposit in Tiergarten using an electric cruiser, from which they are forwarded to their national and international destinations (Roeller 2012).

Bicycle-related logistics, however suffer from a number of issues rendering such services unattractive to wider implementation, such as diminished security, limitations to delivery range and payload, driver fatigue and seasonality (Office-Depot 2010; Straightsol 2012a). Owing to such issues, many of the previously reviewed concepts which employ bicycles as a means of transporting goods may be considered unsuitable for the transportation of hospital freight given the high value and higher security requirements of many items being transported.

More conventional consolidated urban logistics solutions such as Padova Cityporto (Italy) and Distropolis (Paris, France) have been successfully implemented as a means to tranship deliveries to more environmentally efficient vehicles, whilst also achieving higher fill-rates. Padova Cityporto, achieved reductions in total VKm travelled from a daily average of 1,052 (2008) to 1,216 (2010) and reductions of 100 polluting vehicles per day using a fleet of twelve 3.5 tonne methane fuelled trucks performing 2 rounds per day, provided with preferential lanes, special parking areas and access to the town centre outside of restricted access periods (07:00 – 09:30 and 13:00 – 15:30 (Galli 2012b).

Geodis' Distropolis achieved reductions in noise pollution and 85% reductions in CO_2 (988 tonnes / year), NO_x (1.5 tonnes per year) and Carbon Monoxide (CO) (1.1 tonnes per year) from 2011-12, by implementing a programme comprising: grouped shipments to a platform in the city (Bercy platform, Paris); BLUE Environmental Urban Bases in the city close to main retail districts which are served several times a day by Euro-5 and Euro-6 compliant or hybrid trucks with a gross vehicle weight of more than 12 tonnes, and 75 electric vehicles and 56 power assisted tricycles (Galli 2012a).

Whilst environmentally friendly examples of UCC such as Padova Cityporto and Geodis' Distropolis have demonstrated reductions in VKm, noise and air pollution, they are based on the same model of consolidation found to be unattractive to suppliers. Therefore, they may be considered equally unsuitable for healthcare consolidation within the public sector. However, assessment of alternative sustainable city logistics literature indicated a range of lower cost solutions which enable the consolidation of goods to be both financially and environmentally viable and beneficial to participants. Furthermore, the previous review of sustainable city logistics literature indicated that measures such as night-time deliveries may be suitable for healthcare and potentially deliver greater reductions in traffic and emissions (Marcucci and Danielis 2008; Lewis et al. 2010; Álvarez and de la Calle 2011; Browne et al. 2012; Danielis et al. 2012; Häger and Rosenkvist 2012; Kaszubowski 2012; Malhene et al. 2012; MDS Transmodal Ltd and CTL 2012).

2.4.7 **Out-Of-Hours / Off-Hours Deliveries**

Night-time deliveries are often perceived to be more efficient owing to lower traffic volumes and more widespread free-flow traffic conditions, enabling more sustainable driving behaviours (more constant speeds and less stop-start driving), resulting in decreases in: emissions generated from accelerating and idling activities; and, day-time UFT which reduces peak traffic congestion and the potential for pedestrian-vehicular conflicts.

Research into out-of-hours deliveries has also found improvements to staff utilisation and operational efficiencies in addition to reduced CO_2 emissions. Studies by Brom et al. (2011) and Holguín-Veras et al. (2011) found that pilots of off-hours delivery programs provided reductions in costs and improvements in delivery conditions and staff utilisation 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).

Comparable trials for night-time delivery have also been conducted in Barcelona and Dublin (Huschebeck 2007), Paris (Crainic et al. 2009), Brussels (Straightsol 2012b), and The Netherlands as part of a nation-wide programme (PIEK) to promote early morning, evening and night deliveries through the use of low noise loading and unloading vehicles. The Barcelona demonstration comprised of:

- Deliveries carried out between 23:00 and midnight and between 05:00 and 06:00 in the morning;
- The use of an adapted 40 tonne truck, fitted with a carpeted loading platform and truck bed, low-noise pneumatic lifting-system technology (truck ramp and fork lift), low-noise rubber wheels, and the capability of delivering goods to inner-city stores without requiring stops at a regional distribution;
- The introduction of experimental traffic regulations to measure noise; and,
- Noise minimising unloading operating procedures aimed at minimising verbal communications and other noise.

The results from noise level measurements surveyed over a 4 month period (April – July 2003) taken outside on the street environment and within 6 occupied residences close to the supermarket, found noise levels differed very little from ambient conditions (Huschebeck 2007). Average levels recorded within residences ranged between 23.5 and 33.4 dB(A) (0.3 dB(A) greater than before the trial, and an average maximum of 52.2 dB(A) on streets (0.1 dB(A) greater than ambient levels (Huschebeck 2007).

Results from the Brussels demonstration indicated reductions in CO_2, NO_x and PM_{10} emissions by 20%, 40% and 40%, respectively (STRAIGHTSOL 2014a).

Whilst night-time and off-hours deliveries have been shown to provide significant benefits, the financial requirements to provide such services, such as additional staff, and insurance agreements are often regarded as a significant barrier to their implementation. However, unattended delivery solutions such as electronic locker banks provide a resolution to these issues, enabling smaller businesses to receive night-time deliveries of products to a secure location without the implementation of night-time business operations (ByBox 2012). Comparable concepts have been implemented within the healthcare sector for NHS Supply Chain deliveries to small healthcare institutions such as GP practices and pharmacies. Further to this, hospitals such as GOSH equipped to receive larger night-time deliveries of NHS Supply goods have also proved to be successful. Night-time deliveries to GOSH are typically performed between 19:00 and 20:30 to prevent noise disturbing residences located opposite the hospital loading bay.

However, the implementation of night-time deliveries at Trusts in London is severely limited by the amount of space available on-site to allocate to a secure over-night storage facility. As demonstrated by the Barcelona demonstration some solutions exist to overcome many of these issues, including: quiet running engines (Huschebeck 2007), enclosed loading and unloading docks, silent rolling stock such as plasticised cages and wheels to reduce rattling, and driver education to encourage quiet working practices such as turning engines off, quiet closing of doors and communication (STRAIGHTSOL 2014a).

2.4.8 **Sustainable Courier Services**

As highlighted in chapter 1, Courier Express and Parcel (CEP) services are a significant issue in urban areas owing to its growth, worldwide, as a result of e-commerce and distance selling (Ducret and Delaïtre 2013). In the urban context CEP services represent up to 35% of urban goods traffic (Menge and Hebes 2011). Within cities the CEP sector is typically characterised by small volume frequent deliveries between both business-to-business and business-to-consumer markets.

Whilst previous research has focussed on the transportation of freight to hospitals to reduce carbon emissions (Chung and Meltzer 2009; NorthShore LIJ 2013), wider supply chain research suggests that ancillary goods services can also contribute significantly to traffic generation (Cherrett et al. 2012). In the context of healthcare, this includes all services from waste, catering, hospital plant and machinery service trips to laboratory courier services.

Transportation of specimens via CEP services is pervasive within healthcare, with laboratories situated within specialist Trusts providing analytical services for hospitals worldwide. Transportation of samples and equipment (such as heart rate and blood pressure monitors) is typically challenging owing to the fragile, confidential, and time-critical nature of items, often requiring specialist patient-specific dedicated collection (Revere 2004). The requirements of these services can represent significant costs for hospitals, and are responsible for generating high levels of traffic to and from hospital sites (Revere and Roberts 2004). Therefore, optimising courier routes and schedules could help realise more sustainable hospital supply chains and improved customer service levels (Yan et al. 2013). Much of the research surrounding courier services in healthcare has focussed on developing cost-efficient operations (Revere 2004; Revere and Roberts 2004).

In the wider context, research using dynamic route optimisation tools has investigated the ability to increase the efficiency of CEP services whilst also reducing the negative externalities such as vehicle kilometres and emissions (Menge and Hebes 2011). However, the presence of ad-hoc orders, which require immediate pick-up resulting in a new vehicle being sent out for a dedicated trip, often makes more sustainable practices, such as vehicular consolidation, limited and in some cases impracticable (Menge and Hebes 2011). Given such characteristics of healthcare related courier services, alternative modes of transport such as bicycle and electric-assisted bicycle couriers which have no- tail pipe emissions may be considered. Such alternatives represent a growing trend in the literature.

2.4.9 **Bicycle Couriers**

Attempts to accommodate the need for fast, on-demand, dedicated courier services within city centres, such as London, without negatively affecting service performance has led to the trial and implementation of more sustainable modes of transport, such as bicycle couriers, which have been found in many instances to improve the speed and reliability with which items are delivered.

Office Depot launched Cargo Cycles, a service for all addresses within the City of London (UK). 75% of Office Depot's deliveries are within the City of London, Figure 2.13, distributing approximately 1,350 cartons of office supplies per day (BikeHub 2014). Around 900 cartons were transferred to Cargo Cycles via a cycle hub in SE1 in London (Office-Depot 2010) and the concept is intended for the transportation of documentation and parcels. Running costs were estimated at £13,000 per annum to accommodate the salaries of the cyclists (Office-Depot 2010). The initial outlay of the scheme was low with low ongoing running costs, providing congestion charge avoidance and greater overall speed achieved in congested times of the day (Office-Depot 2010). However, despite the numerous benefits yielded by bicycle courier schemes issues of security, seasonality, and restrictions of serviceable distance present barriers to wider implementation of bicycle couriers, particularly in the context of healthcare.

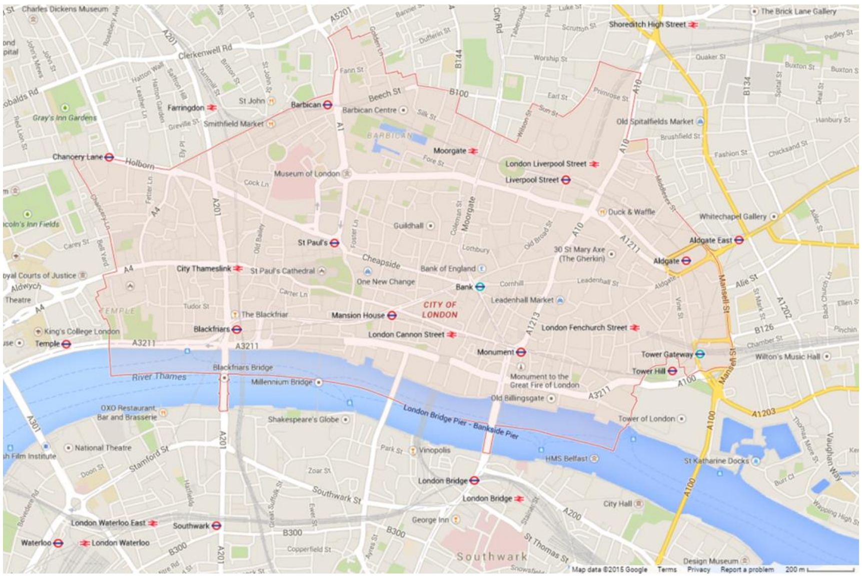


Figure 2.13 Map illustrating the location and boundaries for the City of London

For additional case studies on bicycle courier schemes the reader is referred to the following literature: Basterfield (2012) reviewed a Coventry (UK) based service provided by Yellow Jersey Delivery; Stadtschreiber (2011) assessed bicycle courier business in Cambridge (UK); and, Foucras (2013) reviewed the implementation of an electric-assisted bicycle courier pilot scheme in Pamiers (France).

2.5 Summary of Main Travel Generators for Hospital Supply

As demonstrated in the literature, hospital supply is widely regarded as inefficient, owing to the unpredictable nature of demand and the complex, fragmented structure of healthcare services and the supply chain. These characteristics may be identified as key travel generators, resulting in a number of primary and secondary outcomes characterising healthcare related freight, Table 2.3.

Table 2.3 Outline of the primary and secondary outcomes of travel generators related to healthcare

Travel Generator	**Primary Outcomes**	**Secondary Outcomes**
Unpredictable demand, requiring an agile supply chain	Agile supply focusses on time efficiency, not vehicle efficiency resulting in sub-optimal vehicle load factors	The presence of urgent and non-urgent goods within the same supply chain routes prevents sustainable practices such as temporal consolidation of non-urgent goods
Poor flows of information due to a lack of product visibility and monitoring of demand	Result in increasing variations in demand propagating up the chain leading to insufficient catering for demand; thereby resulting in additional orders to cater for actual demand and stock-outs	Lack of tracking and visibility of items in hospitals and schedules of deliveries to hospitals present a significant barrier to supplier collaboration. Furthermore, low levels of inventory monitoring within hospitals also leads to duplicate ordering and inhibits inter-departmental sharing within hospitals, to maximize stock utilization and reduce wastage
External – Internal supply chain interface, resulting in multiple procedural and information systems	Leads to further incoherent flow of information and goods. This can result in the duplication of orders to account for the delay of time-critical items	
Supply of inventories from multiple suppliers owing to the unique nature of goods from specialist suppliers	Results in high numbers of deliveries to hospital sites	Specialist inventory requirements prevents their integration into more sustainable supply models such as consolidation, shared vehicle capacity and back-loading
Laboratory courier services	High numbers of individual and dedicated trips to and from hospital Trusts for single sample transport	

As demonstrated in Table 2.3, the unpredictability and poor communication of demand backwards up the chain, and the procurement of supplies from multiple distributors / manufacturers has been found to directly contribute to high delivery frequencies to institutions. With the exception of the latter these characteristics perpetuate the need for large inventories to be stocked within hospitals and at nodes throughout the chain. The use of agile supply chain methods have been found to directly contribute to inefficient freight vehicle frequencies and load factors (McKone-Sweet et al. 2005), thereby reducing the efficiency of healthcare related freight, and increasing the amount of CO_2 generated per unit in transit. In addition to these primary outcomes, such characteristics of healthcare supply inhibit the optimisation of the existing freight as well as the implementation of more sustainable freight practices reviewed in this chapter, such as: freight collaboration; lean inventory planning and scheduling; increased stock usage and reductions in stock wastage; and, the consolidation of suppliers.

Physical characteristics of the supply chain such as the external-internal supply chain interface have been found to diminish the communication of demand specific information and the flow of goods throughout the chain. Due to the disparities in information systems between suppliers and hospitals, and the absence of track-and-trace technologies to provide the continued visibility of items once they have entered the hospital, items may become lost within the internal supply chain. This can increase the volume of duplicate orders and the delay in the delivery of time-critical items to the point of use.

The combination of these primary and secondary outcomes have been found to act as significant barriers to the implementation of supply chain best practices and more sustainable forms of supply.

Further to this, institutional behaviours within hospitals have also been highlighted as a significant barrier to the implementation of more sustainable freight practices. This is best highlighted by the practice of booking laboratory courier services, which are typically booked according to their time of arrival into individually dedicated delivery trips as opposed to consolidating non-urgent items for couriering into single vehicles with multiple drops.

2.6 Way Forward

The purpose of this literature review has been to understand how hospital supply chains operate, identify the key generators of unsustainable freight patterns, and identify the main areas to address in order to facilitate more sustainable healthcare supply.

As demonstrated in Table 2.3, the inefficiencies of the internal supply chain contribute to the external inefficiencies related to sub-optimal freight patterns and low vehicle load factors (McKone-Sweet et al. 2005; Jarret 2006; Costantino et al. 2010; Black and Zimmerman 2012; Azzi et al. 2013).Whilst there are numerous solutions available to solve much of the observed inefficiency, many require wide-scale institutional and organisational restructuring and, process re-engineering throughout all hospital Trusts within a single region, to have a significant impact on supplier operations.

However, the review of sustainable urban logistics solutions has provided numerous solutions which may be implemented to accommodate the current inefficient complexities of the healthcare system whilst creating more sustainable logistics practices within urban centres, to reduce UFT-related congestion and emissions.

As reviewed in the literature, market-based and regulatory-based measures are designed to encourage suppliers to increase vehicle load factors and decrease freight volumes on the road. However, such measures have been found to be ineffective with freight operators continuing with established service frequencies within urban areas, and passing additional costs accrued from market- and regulatory- measures on to the customers (Danielis et al. 2012). Furthermore, in the context of healthcare, owing to the vital nature of supply to hospitals, previous examples of market-based measures, indicated that freight to healthcare institutions is typically granted exemption from charges (Danielis et al. 2012).

Evidence of the remaining sustainable urban solutions reviewed in the previous sections (Collaboration, Urban Consolidation, Out-of-Hours Deliveries, and Sustainable CEP services) indicated, from previous demonstrations, that all are compatible in the context of healthcare, with successful examples implemented worldwide. Furthermore, each solution provides a means to significantly reduce city freight CO_2 emissions, in line with the 2011 EU Transport White Paper, 'to achieve essentially CO_2 free cities by 2030'.

In light of this and in accordance with the aims of the project sponsor, to: reduce, retime, reroute and re-mode freight, this research focusses on the following three themes:

2.6.1 Healthcare Consolidation

Consolidation is prevalent within the literature, commonly cited as a solution for high delivery frequencies characterised by sub-optimal product flows and low vehicle load factors (McKone-Sweet et al. 2005; Jarret 2006; Costantino et al. 2010; Black and Zimmerman 2012; Azzi et al. 2013). Conversely, as demonstrated by the stockless inventory method, Section 2.2.3, employed in the U.S. healthcare sector, consolidation of hospital suppliers to the point at which all hospital suppliers are provided by one or two suppliers may also achieve the same end. However, applying such concepts to specialist hospital trusts such as GOSH is impracticable owing to the requirement for numerous products manufactured by only one supplier. Given these circumstances, it may be considered that freight consolidation is the most appropriate measure to reduce the volumes of healthcare related freight within urban areas.

Attempts to implement consolidated supply of goods to hospitals are evident internationally throughout the literature (refer to Section 2.2.3), with much success predominantly within privatised healthcare markets such as the U.S. (Chapman et al. 1998; Aptel and Pourjalali 2001; Burns 2002; Nollet and Beaulieu 2005; Pan and Pokharel 2007; Kumar et al. 2008a; Varghese et al. 2012; Toronto Atomospheric Fund et al. 2013). However, experience within the public-sector healthcare industry suggests that high participation rates in healthcare consolidation are seldom achieved in the absence of complimentary market mechanisms present within privatised healthcare markets. A view which is corroborated by demonstrations of municipal urban consolidation centre projects, worldwide (MDS Transmodal Ltd and CTL 2012).

Whilst the reasons for poor subscription to consolidation schemes have been well-documented, the majority of research and schemes focus on how greater participation can be achieved through financial and operational incentives. The aim of this research theme is to test the environmental impacts of a new model of consolidation designed to provide the benefits of traditional consolidation whilst overcoming the barriers cited in the literature.

Increased utilisation of the current parallel supply chain model, utilising one chain for consolidated supply of non-urgent goods; and another for agile supply of urgent goods, may provide significant benefits towards a more sustainable and effective medical supply chain. Furthermore, a greater use of consolidation amongst suppliers and hospitals facilitates collaborative bulk-buying opportunities and therefore potential discounts to be achieved amongst groups of Trusts within the same geographical region.

2.6.2 **Urgent Goods Supply**

In parallel to healthcare consolidation, it is necessary to address the requirements of urgent goods: ensuring the expedient delivery of such items to the hospital, and maintaining the separation of urgent items from non-urgent items within the hospital, to ensure higher load factors and lower volumes of traffic. This represents an area of research that has not been well covered in the literature.

Separation of urgent goods supply requires the creation of a separate supply route using dedicated vehicles. However, as is the case with hospital couriers, this is likely to generate increases in hospital related freight volumes. Whilst alternatives such as bicycle couriers present viable alternatives for the transportation of urgent goods within close proximity to the hospital, concerns regarding their security present significant barriers to their implementation within the healthcare sector. As demonstrated in the literature, night-time delivery measures can deliver fast and efficient means of delivery within urban areas, whilst also reducing congestion on networks during the day. However, implementation of night-time delivery operations at hospital trusts present a potentially significant cost preventing their wider implementation. Technological advances in secure unattended electronic deliveries do however present a solution to night-time deliveries without the required employment of night-time staff.

Therefore, the second research theme focusses on the implementation of unattended electronic locker banks for the supply of urgent goods to hospitals, enabling for night-time delivery of items and potential added benefits such as faster and more traceable delivery of time-critical items.

2.6.3 **Laboratory Courier Services**

As demonstrated, urban centres are characterised by high volumes of business-to-business freight being completed by a large number of small carriers, typically CEP services, accounting for up to 35% of urban goods traffic (Menge and Hebes 2011). The traffic generated by CEP services is typically characterised by duplicated journeys between CEP service providers, using partially filled trucks to pick up and deliver a large number of very small shipments (Marinov et al. 2010). A review of the literature has found such trends characterise hospital laboratory courier services (Revere 2004; Revere and Roberts 2004).

As is evident from the literature, little research has been done on the environmental impacts of laboratory courier services to and from hospitals. Existing literature on hospital courier services focusses on the economic efficiency with little focus on environmental efficiency (Revere 2004; Revere and Roberts 2004). However, environmental impacts, such as vehicle emissions and fuel consumption, related to laboratory courier services may be reduced through the consolidation of items being couriered into fewer vehicles with optimised vehicle routing, with the added potential of reducing the overall costs of services. This focus forms the third and final research theme of this thesis.

2.7 Need for Research

The review of the literature in this chapter has identified the following gaps in healthcare supply chain management and logistics knowledge:

- There is a large amount of research on urban consolidation centres, identifying the high start-up and operating costs; the difficulties of a single centre to cater for the demands of numerous suppliers; and, a loss of interaction between suppliers and customers as significant barriers to successful implementation of consolidation centres. Much of the existing literature has attempted to overcome poor UCC participation rates using government subsidies, and the implementation of schemes alongside other sustainable UFT measures such as vehicle restrictions, congestion and low emissions zones. However, little has been done to address the barriers to implementation through the redesign of existing infrastructure solutions such as consolidation centre models in order to make them more attractive to suppliers with greater transparency afforded by ICT. This highlights an important gap in the sustainable urban freight and freight consolidation literatures. Further to this, there is a lack of research into solutions for inner-city hospitals which due to limited loading / unloading space are unable to manage their incoming demand. In an attempt to fill these gaps, a novel consolidation model intended to overcome the issues of traditional consolidation and resolve space issues in inner-city hospitals is tested;
- The presence of urgent items within the supply chain which have been found to sub-optimise ‘normal’ operations are recognised within the literature. However, little research focusses on addressing how the supply of such items may be made

more sustainable and better managed with regards to their track and trace throughout the external and internal supply chains with the implementation of: information related measures (e.g. ICT) and dedicated infrastructure provisions. Therefore, this research assesses the novel application of unattended delivery locker banks for the receipt of urgent goods into hospitals;

- A review of the literature indicated little research has been done with regards to the optimisation of courier services for hospital laboratory samples. The majority of the existing literature focusses on the optimisation of laboratory courier services with a focus on cost-reduction. However, there appears to be a gap in the literature reviewing the optimisation of courier services from an environmental perspective with the implementation of managerial policies and protocols. Therefore, this research explores the impacts of service consolidation for laboratory sample couriers ordered by GOSH.

2.7.1 **Mobile Consolidation for Sustainable Non-Urgent Goods Supply**

This thesis presents a new ‘mobile’ consolidation concept as a means to consolidate goods with minimal negative economic and environmental externalities. As outlined in the literature, consolidation centres with multiple depots provide greater benefits and capabilities to cater for the demands of many different supplier requirements than those operating from a single site (Browne et al. 2005; MDS Transmodal Ltd and CTL 2012).

The aim of the concept is to provide a ‘remote’ receipts and distribution department location to which all orders are delivered. The concept is designed to maintain the same number of nodes within the supply chain, by keeping the mobile depot as the final point of delivery whilst maintaining the same levels of visibility between supplier and customers through the use of ICT. The system also reduces the overall costs associated with depots implementation by avoiding the use of fixed-based infrastructure, and off-setting the actual costs by the elimination of duplicate services within the hospital.

In addition it also enables for more than one site operation without the need for duplicate infrastructure. Furthermore the proposed model attempts to overcome the issues regarding costs, visibility, poor reductions in CO_2 emissions and supplier uptake of consolidation centre schemes which are commonly cited as the main barriers to their successful implementation

(Boerkamps and Binsbergen 1999; Browne et al. 2005; Woodburn 2005; Panero et al. 2011; MDS Transmodal Ltd and CTL 2012).

This fills a gap in the literature by modelling a new novel consolidation concept and receipts and delivery model enabled by a new operating structure afforded by new and existing ICT, reviewed in the literature. The central methodology for the feasibility, impact assessment and qualitative review of this concept, using data from a delivery and servicing survey at GOSH are presented in Chapter 5.

2.7.2 Unattended Locker Bank Delivery to Separate Urgent and Non-Urgent Goods

With the implementation of the consolidation centre, it becomes necessary to provide a separate urgent goods supply channel to the hospital. The separation of urgent and non-urgent goods will ensure that time critical items arrive at the hospital as and when they are required, whilst also enabling non-urgent items to be delayed to maximise vehicle fill rates.

As is evident from the literature, much research exists addressing the issues surrounding the general supply of medical consumables (Rivard-Royer et al. 2002; McKone-Sweet et al. 2005; Pan and Pokharel 2007; Costantino et al. 2010; Aronsson et al. 2011). 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) encouraging the acceptance of sub-optimal load factors to ensure timely delivery of urgent items (McKone-Sweet et al. 2005). As previously established, the separation of items with differing demand profiles, such as urgent and non-urgent items, is typically managed with the restructuring of manufacturing and supply operations into separate parallel agile and lean supply chains to cater to the different demands of each product type (Christopher 2011). Unattended electronic delivery systems provide a low-cost means through which urgent items may be delivered in dedicated vehicles, at night, to hospital locations, thereby providing the necessary form of separation from non-urgent goods.

This research intends to fill a gap in the literature, exploring the potential for an alternative route of supply for time-critical items. It builds on previous research which indicated that the process of disintermediation within supply chains can provide a viable solution, enabling suppliers to make deliveries direct to PCUs as opposed to communal goods-in facilities (Kowalski 1991; Shapiro and Byrnes 1992; Rivard-Royer et al. 2002). This has been found to improve the speed of response in terms of goods and information flows between consumers (i.e. hospitals) and suppliers (Shapiro and Byrnes 1992). Whilst this concept has been implemented in 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, increasing the tracking-and-traceability of urgent items, and reducing the amount of freight-related congestion and CO_2 emissions by enabling night-time delivery of goods.

In this thesis the central methodology and feasibility testing of unattended electronic locker banks as a potential tool to: reduce the delay and potential loss of items experienced at the communal goods-in facility; create a more direct route of supply to PCUs and improve the visibility of urgent items within hospitals; and, separate urgent and non-urgent goods supply, are presented in Chapter 6.

2.7.3 Sustainable Courier Services to Reduce CEP Service Impacts on Urban Networks

Research surrounding hospital laboratory couriers has focused on the economic savings and improvements to the levels of service which can be achieved through improved visibility of information and scheduling and of bicycle journeys. However, little healthcare related literature addresses the frequency of courier journeys to Trusts and the number of journeys which may be consolidated into a single vehicle and transferred to more sustainable methods of transportation such as bicycle couriers, much like the Office-Depot and TNT bicycle courier trials presented in the literature review.

The aim of this study was to quantify the impacts of current laboratory courier operations in both economic and environmental terms. Further assessments were performed to determine the extent to which laboratory consignments could be grouped. The final assessment of this research theme was to identify alternative means of courier transport, taking into account distance and existing forms of traffic travelling between the Trust in which the laboratory is situated and the consignee Trusts. The main methodology and findings for this study are presented in Chapter 7.

2.8 Assessment of the proposed initiatives against the literature

Each of the three proposed initiatives may be sorted into one or more of the six categories given at the beginning of Section 2.4:

The proposed mobile consolidation centre concept seeks to provide new infrastructure through which non-urgent medical supplies can travel, thereby providing new services to reduce the number of vehicles travelling to GOSH through freight consolidation. In addition to this, the concept also provides a means to increase information provisions using the proposed ICT systems which enable for the implementation of track-and-trace technologies and unattended deliveries, thereby reducing the overall operating costs of the service. The physical operation of the unit enhances the visibility of items within the supply chain through the separation of goods by ward level, which also expedites the transfer of items internally. The collective outcome of the new infrastructure and information-related measures aid to decrease the physical and 'virtual' separation between the external and internal supply chain and by extension the issues associated with its presence, Table 2.4.

Similarly the proposed unattended locker bank conforms to the criteria of infrastructure measures and information provisions through the implementation of new services for the delivery of urgent goods. The overall outcomes of this measure are the enhanced levels of track-and-trace and the increased ease of goods transfers between the external and internal supply chains. Most importantly, the infrastructure and ICT provided by the locker bank system provides a direct route of delivery to an individual without requiring a signature, providing potentially significant gains with the elimination of staff duties to receipt urgent items and transport them to their end user.

Both the proposed mobile consolidation centre and unattended delivery locker bank concepts provide measures exclusive to GOSH, demonstrating the potential to integrate new infrastructure into the existing freight networks at lower costs and with less disruption.

Finally the proposed consolidation of couriers at the hospital may be classified as a management measure since it does not involve the implementation of new physical infrastructure, external policies or forms of regulation. The concept of courier consolidation involves the implementation of internal management strategies at GOSH imposing restrictions on the ordering of non-urgent courier services which deviate from pre-established ordering times / periods of delay.

Each of the proposed solutions adhere to at least two of TfL's four goals to Reduce, Retime, Reroute and Re-mode, Table 2.4, which seek to accommodate the existing structure and operations of healthcare which has been established to be inefficient by the literature.

Table 2.4 Synthesis of the three proposed solutions with TfL's four goals

	Reduce	**Retime**	**Reroute**	**Re-mode**
Mobile Consolidation	Increase vehicle fill rate and decrease the volume of traffic travelling into central London	Move all consolidated deliveries to night-time hours and increase the delivery window for suppliers thereby spreading the traffic profiles	Divert traffic volumes associated with hospital deliveries to an out-of-town location	Potential use of electric vehicles for forward journeys into the city
Unattended Delivery	Enable for separation of urgent goods and non-urgent goods facilitating consolidation of non-urgent goods	Enable for the night-time delivery of goods to the Trust, yielding benefits of more efficient vehicle running.		
Sustainable Laboratory Couriers	Increase vehicle fill rate and decrease the number of vehicles required to complete the delivery of laboratory samples	Re-schedule the movement of courier samples to fixed times of the day, allowing for scheduling during off-peak periods and demand smoothing	Increase the number of destinations within a single delivery route as a result of service consolidation	Reduces the number of vehicles thereby re-moding deliveries to larger vehicles, and transferring deliveries to more sustainable means such as bicycle couriers

2.8.1 Reorganisation of Healthcare Supply Chains

As demonstrated by the literature previous attempts to improve the healthcare supply chain have included the reorganisation of its structure and operations (i.e. stockless inventory) delivering varied results. Whilst the proposed solutions do not dramatically alter the roles of current 'agents' within the healthcare supply chain, the proposed MCC and unattended delivery solutions act to disintermediate nodes of the internal supply chain and points of goods-in access to the hospital.

2.8.2 Relocation of Healthcare Services and Hospitals

As previously stated, the earlier review of sustainable urban logistics solutions for healthcare omitted the option for land-use planning measures, due to the aims to address issues pertaining to existing hospital infrastructure(s). However, in many cases such as GOSH in which a hospital is located within a densely populated urban area, redevelopment of the site is limited by strict planning regulations and the requirement to purchase additional property or land. Under such circumstances hospitals are presented with the option of relocating to a purpose built site within a less central urban location. In the context of GOSH, this particular solution was considered in past. However, the process of relocating a hospital represents a significant economic and logistically complex task, which can detrimentally affect:

- The reputation and brand of the hospital which for GOSH is firmly grounded in its current location which is of great historical importance to the Trust;
- The existing workforce, which need to be within a specific distance or journey time to the hospital. This aspect of healthcare for some Trusts is of great importance as their on –going reputation may be underpinned by the provision of particular reputable clinical staff. Therefore any relocation may hamper the continued employment of such key members of staff; and,
- Access to the Trust by patients, which currently ensures easy access via numerous forms of public transport for all socio-economic demographics and mobility types.

Finally, whilst the relocation of the hospital to a purpose built site may achieve the reduction of healthcare-related freight within urban centres, it may do little to address the long-term growth in patient demand and existing characteristics of freight. As demonstrated by the prevalence of healthcare supply chain issues worldwide within different types of hospitals, the physical provisions within a hospital may have few effects on the long-term sustainability of freight.

2.9 Summary

This chapter reviewed the nature and structure of hospital supply, highlighting the unpredictability of demand, poor information flows and requirement for agile supply chain practices as the main reasons for unsustainable supply chain practices, such as low vehicle fill-rates within the industry. A review of the previous and existing methods of supply chain operation such as the conventional semi-direct multi-echelon supply chain and the stockless inventory methods was conducted to identify the previous attempts made towards improving healthcare supply chains. Following this, a review of new and innovative supply chain management solutions, enabling enhanced visibility of items within the supply chain using 2-D coding and RFID, and detailed monitoring such as intelligent storage solutions was performed; highlighting the opportunities for new and emerging ICT applications to facilitate more sustainable supply chain practices employed within the wider logistics industry, such as supplier collaboration and consolidation, through greater and more comprehensive amounts of information. The review proceeded with an assessment of sustainable urban logistics solutions implemented throughout a wider range of industries, their potential application / relevance within the healthcare industry. This chapter closed highlighting the gaps in literature to be explored throughout the remainder of this research.

2.9.1 **Key Findings**

Healthcare supply is widely perceived to be inefficient owing to the unpredictability of demand and incoherent flow of demand specific information throughout the supply chain. This has been found to engender unsustainable freight patterns to hospitals. Whilst there are many operational and technological solutions available to remedy such characteristics of the healthcare system, many require wide-scale institutional change within healthcare institutions and suppliers to yield operational and environmental benefits.

A variety of engineering, enforcement and operational measures available within wider industry sustainable urban logistics have the potential to provide economically and environmentally sustainable solutions for hospital supply, with positive impacts to current service performance.

Findings in the literature indicated that key generators of hospital traffic such as: the incoherent flow of products into hospitals via the external-internal supply chain interface; the lack of separation between non-urgent and urgent goods; the inability to consolidate suppliers owing to specialist items; and, the requirements for courier laboratory samples may be addressed by three main solutions:

- Freight consolidation, to resolve the number of deliveries travelling to hospitals thereby addressing VKm, journey time and emissions associated with the hospital; and further addressing issues of limited space within loading bays;
- Unattended Electronic delivery, to enable for night-time delivery to yield improved driving efficiencies within urban areas owing to reduced congestion; and to achieve the separation of urgent items from non-urgent goods supply.
- Consolidated CEP services for laboratory samples, to directly address the environmental impacts of the high volumes of CEP journeys generated by hospitals.

Chapter 3: Case Study - Great Ormond Street Hospital for Children

3.1 Introduction

As identified in Chapter 1, hospitals represent significant UFT generators. For the purposes of this research, Great Ormond Street Hospital (GOSH) is used as a case study to quantify the impacts of hospitals as UFT generators.

This chapter describes the main travel generators for hospital freight into GOSH, opening with a background to GOSH and the services it provides. Following this, an audit of the internal (inventory management) and external (deliveries and servicing) supply chain activities at the Trust is provided; finishing with a review of the nature of demand, and operating practices for, laboratory courier services at the Trust.

3.2 GOSH

GOSH is a tertiary care NHS Trust for Children, located within the Borough of Camden, London, Figure 3.1. It comprises 27 NHS wards and 2 private healthcare wards, which are staffed by 3,336 clinical and non-clinical staff who help to provide more than fifty different clinical specialties, treating more than 192,000 patients per annum (GOSH 2011).The majority of patients are referred from general practitioners and other hospitals throughout the UK and internationally. Therefore much of their patient demand is predictable, with the exception of emergent cases.

Great Ormond Street Hospital is the UK's largest paediatric centre for many services and is one of the world's leading children's hospitals. Partnered with the UCL (University College London) Institute of Child Health (ICH) GOSH represents the UK's only specialist paediatric academic research centre placing it at the forefront of paediatric medicine and diagnostics. In addition to patient treatment, GOSH provides training to more children's nurses that any other hospital, and plays a leading role in training paediatric doctors.

GOSH is typically representative of an inner-city hospital within London, restricted to its current physical footprint, and subject to strict planning restrictions. Specifically for GOSH, the hospital is unable to extend vertically above 13 floors, thereby limiting the space available for primary activities such as patient care, resulting in minimal space allocated to support activities such as logistics and supply.

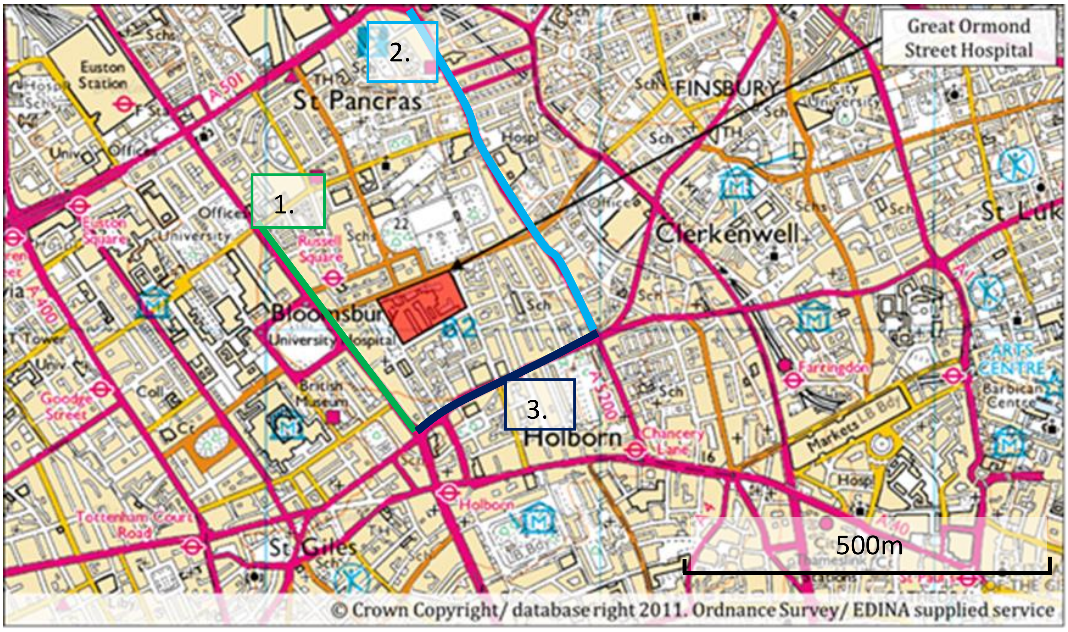


Figure 3.1 Location of Great Ormond Street Hospital

GOSH is situated within a largely residential area of Camden, surrounded by three major thoroughfares, Figure 3.1:

1) Woburn Place / Southampton Row, the two of which form a single continuous traffic route providing a major access road to / from Euston Road (A501) south through the city to Aldwych, from which traffic flows onto the Strand (providing east and west routes through the West End) or south over Waterloo Bridge;

2) Gray’s Inn Road (A5200) which provides services for traffic travelling north and south between Euston Road and Holborn; and,

3) Theobald’s Road, which forms part of a western and eastern traffic route through the city centre from Chiswick in the west to Old Street in the east.

Given their strategic nature as thoroughfares and the access they provide for residents within Bloomsbury, reduction of freight related congestion and emissions on these roads is of great interest. Annual Traffic Census Counts produced by DfT (2010), indicated that a total of 23,240 and 24,186 motor vehicles trafficked Woburn Place and Southampton Row, respectively. Of the total number of motor vehicles observed on these roads, 5,270 and 4,120 were LGV's (Light Goods Vehicles) and HGV's, respectively.

Northern screenline counts produced by TfL (2009), for vehicle movements on the smaller streets providing access to GOSH, comprising Great Ormond Street (public and courier access), Guildford Street and Bernard Street (freight access), indicated a total of 2,995, 6,584 and 6,983 vehicles on each street, respectively. Of these total vehicle numbers: 604 (Great Ormond Street), 1,377 (Guildford Street) and 1,539 (Bernard Street), were freight. Analysis of the breakdown of freight vehicle numbers within the area indicated a dominance of LGV's within the area.

These figures demonstrate the proportion of freight vehicle traffic on the road network surrounding GOSH. As highlighted by the external freight survey at GOSH, Section 3.3.2, on-street parking by freight vehicles delivering to GOSH seriously affects the flow of all other traffic through the area, in some cases bringing all traffic on Guildford Street to a standstill. In addition to this such volumes of freight traffic sitting idle are likely to generate significant quantities of emissions and noise pollution.

These data and observations underpin TfL's four main goals and the main aims of this research to reduce the negative externalities of freight associated with healthcare within the local road network and the city-wide emissions, whilst ensuring the high standards of care expected and delivered at GOSH.

3.3 Internal and External Supply Chain Activities

A Delivery and Servicing plan (DSP) commissioned by TfL and GOSH was undertaken as part of this research to provide a hospital-wide audit to assess the amount of traffic generated on the adjacent road networks by hospital freight operator activities. The audit process encompassed an assessment of: the internal inventory management operations, compiled from hospital documents and staff interviews, related to the procurement of medical consumables; and, a survey quantifying the traffic volumes and types of freight activities to the goods yard, undertaken in November 2011, over a 5-day period between 07:00 and 17:00, described in Section 3.3.2 and provided in Appendix A.

3.3.1 Internal Inventory Management

In recognition of the impacts internal inventory management can have on the efficiency of the external supply chain, a review of the internal inventory management processes and system was conducted to understand how inventory was stocked, the nature by which it was consumed and how consumption was measured. This highlighted three paths of distribution for goods within the hospital, Figure 3.2:

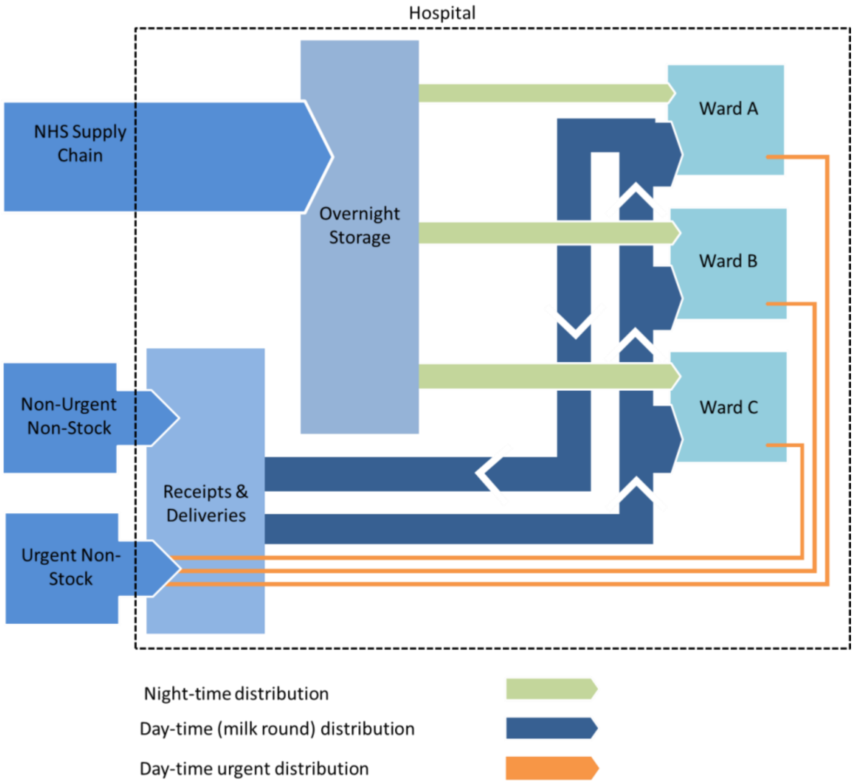


Figure 3.2 Illustration of the internal distribution network at GOSH

The first path is the **NHS Supply Chain (Stock-route)** whereby goods are delivered to the hospital, out-of-hours, in pre-sorted cages for each ward / requisition point. Each cage is deposited within a secure locked area for night-time storage. After the delivery has been completed, night-porters wheel each cage to their respective wards before, depositing them outside the ward store before Materials Management staff, responsible for managing the stock within specified wards arrive the next day to transfer items to the stock room. The empty cages are transported to the secure over-night area for collection after the next NHS Supply Chain delivery.

The second route is termed **Non-Stock (non-urgent goods)** comprising ad-hoc deliveries (direct from supplier to hospital via supplier operated logistics networks or 3PLs) to the hospital during the day (07:00 – 17:00). Deliveries of medical supplies are received at a R&D location within the hospital yard. Upon receipt of a delivery, each item is sorted into a cage pertaining to the ward the item is intended for. Items may remain within this area whilst materials management staff or porters perform milk rounds, collecting the sorted goods within the R&D department and forwarding them on to their final destination (i.e. ward), where items are either deposited within the ward store or receipted at the front desk of the ward, to be taken to the store by materials management staff or the ward housekeeper.

Finally, a sub-section of, **Non-Stock 'Urgent' goods**, are receipted through the same processes as non-stock, non-urgent goods. However, upon receipt they are expedited up to ward level by a member of the materials management team or a clinical member of staff who may journey to the R&D department from the receiving ward to collect the item. Interviews with staff corroborated the findings within the literature indicating the mixing and potential loss / delay of urgent goods within the supply chain due to mixing with non-urgent stock.

Each member of the materials management team is allocated a ward to manage ensuring staff are familiar with specialist items the needs of the ward and the clinical members of staff working within the ward. Materials Management staff are responsible for monitoring stock levels within ward stores and placing re-orders for inventory items which are close, equal to- or below pre-established re-order thresholds, fulfilling a CPFR method of stock management. In addition to this, each ward is allocated a ward sister (in charge of ward budgets, ordering and re-order levels), and a ward housekeeper, who oversees the management of stock within ward stores.

Analysis of hospital spend reports indicated that 30% of goods procured into the Trust are sourced via the NHS Supply Chain. Analysis of product orders for Interventional Radiology at GOSH translates this spending pattern to the department receiving on-average 3,021 non-stock items and 124 stock items, per week.[4] However, it should be noted that the number of orders via the stock route does not predicate smaller physical volumes as stock items are characteristically bulk.

A review of ward stores at the Trust indicated that provisions of inventory levels are not exclusively dictated by the inability to estimate more than 2-weeks inventory requirements.

[4] Interventional Radiology orders 364 non-stock lines and 69 stock lines with an average weekly issue for each line of 8.3 and 1.79, respectively.

They are also largely governed by the availability of space to stock goods. Assessment of hospital wide plans indicated that the size of stores ranged between 13.8m^2 and 285 m^2, with an average of 86.5m^2.

3.3.2 **External Supply Chain**

The DSP survey was conducted in accordance to guidance provided by TfL, see: TfL (2012a) pp.14. The survey was undertaken by a group of 4 surveyors who recorded the: date, arrival and departure times, supplier and courier names, vehicle registration, vehicle type (according to DVLA (Driver and Vehicle Licensing Agency) vehicle classifications), the nature of a delivery (drop or collect), the destination hospital (required to differentiate between deliveries for GOSH and those for the National Hospital for Neurology and Neurosurgery), the fill-rate of the vehicles making the deliveries, the type of containment (i.e. loose, cages, dollies, bags, boxes and other), the contents of boxes, and specialist trailer units such as freezer or refrigeration. See Appendix A for an example of the survey sheet.

Each delivery driver was also interviewed upon arrival (with a 72% response rate) into the yard to obtain the contents of the deliveries, and details of the delivery route such as the origin and destination, the number of deliveries in the route, the locations of the previous and next drops in the route, and the total number of drops on the route. During the interview process the courier and supplier names were also confirmed. Once this process was complete a label recording the number plate was attached to the consignment being delivered to enable the pairing of each item being receipted into the hospital with the delivery. This information was used to increase the amount of information gathered pertaining to the purpose of deliveries, and also to compile a list of exact items to the hospital presented to the head nurse, for identification of urgent items being delivered to the hospital to inform the model used to assess the feasibility of unattended delivery solutions, Chapter 6.

The survey found that 403 deliveries were made by 223 vehicles, on behalf of over 300 suppliers. This indicated a 9% growth in the number of deliveries from a comparable autumn 2010 survey conducted by Steer Davies Gleave, which showed that 366 deliveries were made by 219 vehicles on behalf of 145 suppliers. This increase may be in accordance with the 9% growth in patient numbers in 2010 from 175,000 to current levels (GOSH 2011).

Analysis of the deliveries during the survey indicated medical supplies, catering and couriers account for 32%, 13% and 14% respectively, Figure 3.3. 'Other' deliveries, which comprise unclassified deliveries and collection of items to / from the hospital without an identifiable department or requisition location, also account for a further 14% of all ad-hoc deliveries. An assessment of the vehicle populations indicated: 24% of all deliveries were made by 3PL CEP companies; and, a 40% fill-rate (weighted average) indicating poor utilisation of vehicles travelling to the hospital. The dominance of medical supplies and courier deliveries, many of which are likely to contain medical supplies, further demonstrates the significant impact ad-hoc direct deliveries have on the number of vehicles travelling to the Trust.

Analysis of the remaining services, including catering, indicated 41% of traffic to the hospital accounts for ancillary services.

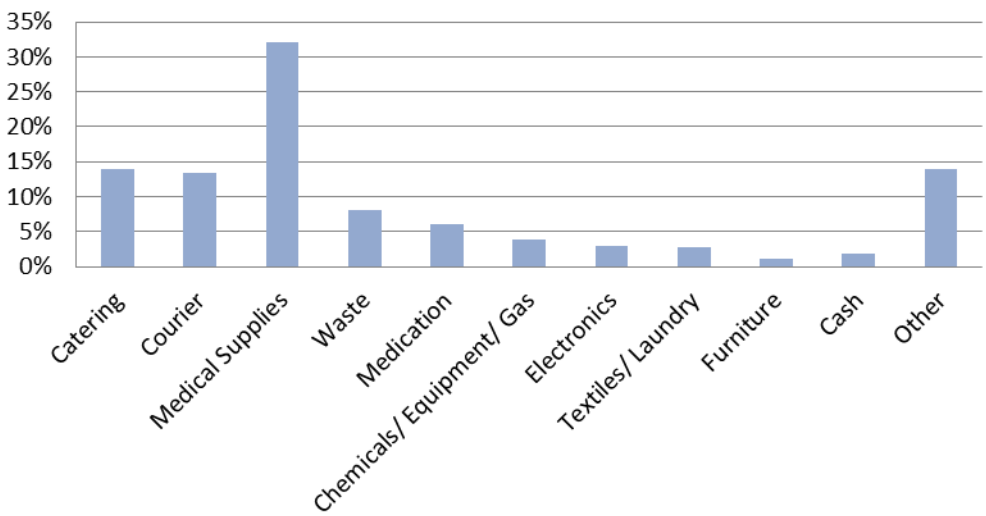


Figure 3.3 Proportion of deliveries by type observed during the 5-day DSP survey

During the November 2011 survey, drivers were questioned with regards to their route starting point with 277 providing a route origin. The results, Figure 3.4, indicated that the majority of couriers and suppliers travel from within a 50 mile radius to GOSH, with 144 originating from within central London (highlighted red).

In addition to the high frequency of deliveries to the hospital, a number of issues which may be addressed by consolidation were also observed:

- The use of the delivery and servicing yard by numerous hospital functions, i.e. hospital waste storage, goods in and out, couriers, contractor / servicing parking, and mortuary services;
- Over-capacity usage of the yard, resulting in on-street parking for deliveries; and,
- Duplicate vehicles from the same companies delivering separate orders, simultaneously.

Analysis of the impacts for the business-as-usual supply chain, assessing 167[5] of the vehicle movements recorded during the survey week, indicated a total 26,262 VKms and 5.38 tCO_2 were generated for the survey week[6].

Analysis of the freight movements observed during the week, Figure 3.5, indicated a peak in freight activity (n=93) at GOSH on Friday, with small fluctuations in freight volumes for the remainder of the week. Assessment of the average daily traffic profiles for the week, Figure 3.6, with traffic counts grouped into 30 minute time periods, indicated that 33% of all deliveries to the hospital were made between 06:30 and 10:00, with the daily peak of 9 deliveries (10%) arriving between 10:30 and 11:00. Comparison of these findings against TfL data for Vans entering the Congestion Charge zone indicated a disparity in the results with a peak van flow entering / exiting the Congestion Charge zone above 8% occurring between 07:00 and 08:00, and 21% of vans entering / exiting the Congestion Charge zone between 07:00 and 10:00 (TfL 2012b).

[5] 167 of the 403 records provided the data necessary to perform the assessment, see Section 5.2.2 for further explanation.

[6] Figures are derived from the base case analysis of the supply chain for the survey week performed in Chapter 5 as part of the research to assess the feasibility and impacts of the proposed mobile consolidation centre study. See Section 5.3 for the methodology.

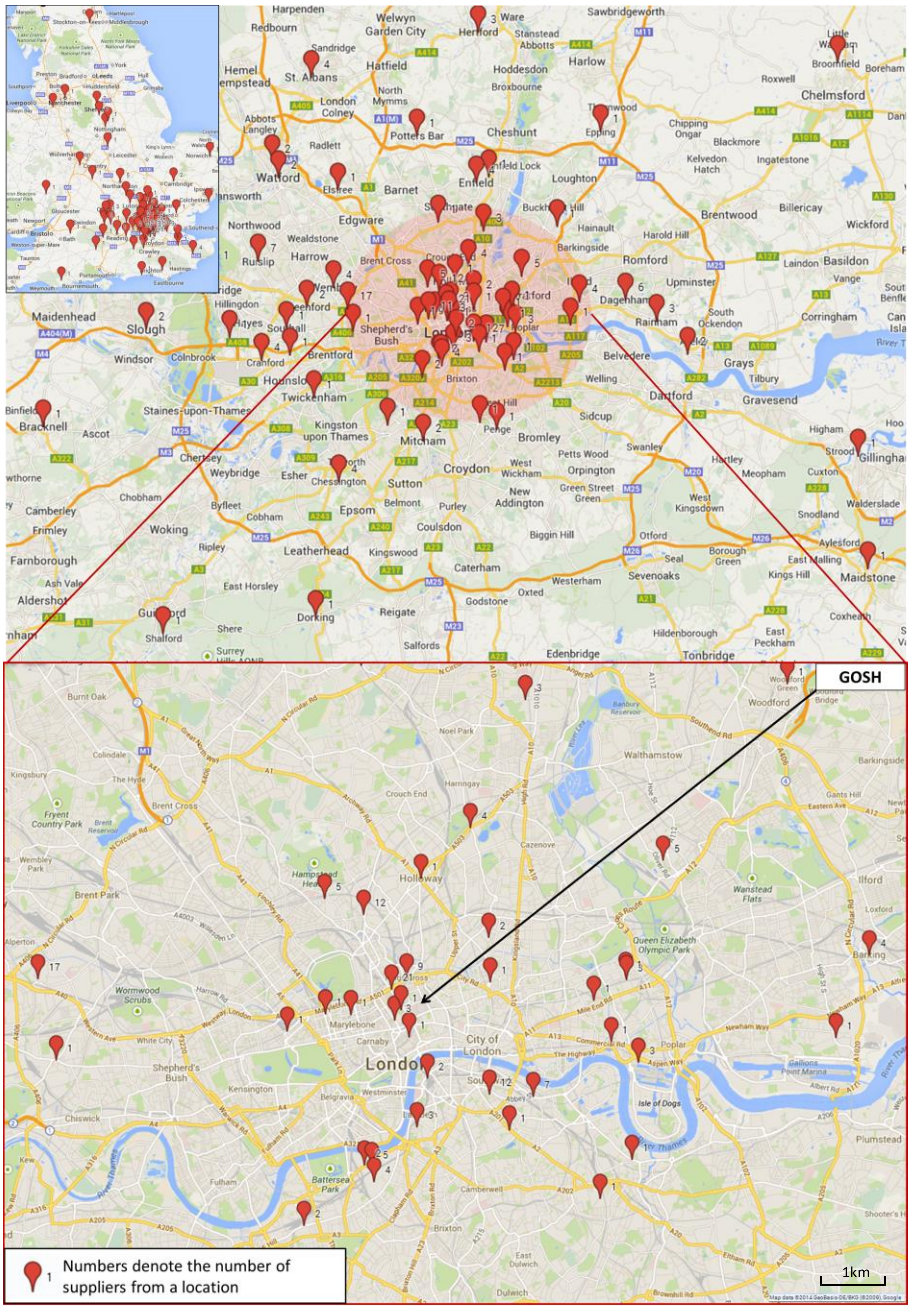


Figure 3.4 Map of delivery route origins for drivers making deliveries to GOSH

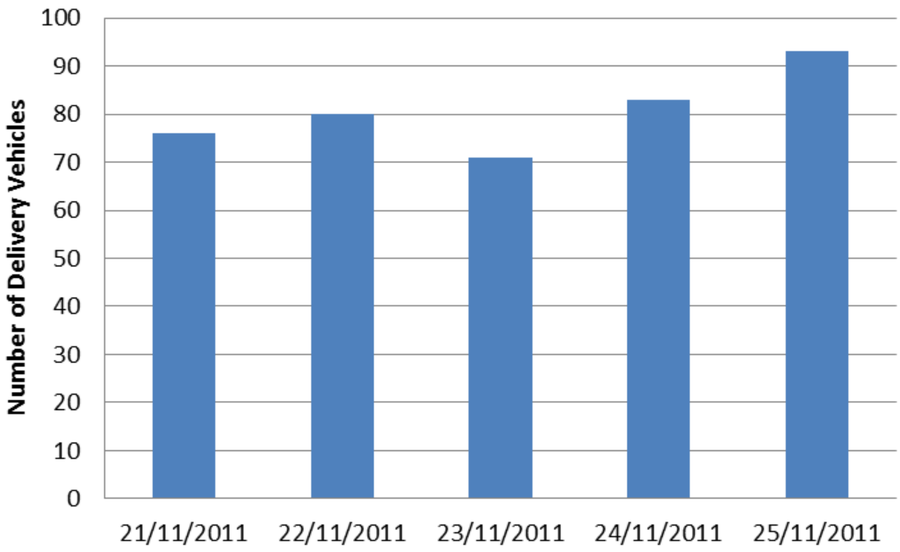


Figure 3.5 Analysis of delivery volumes by survey day

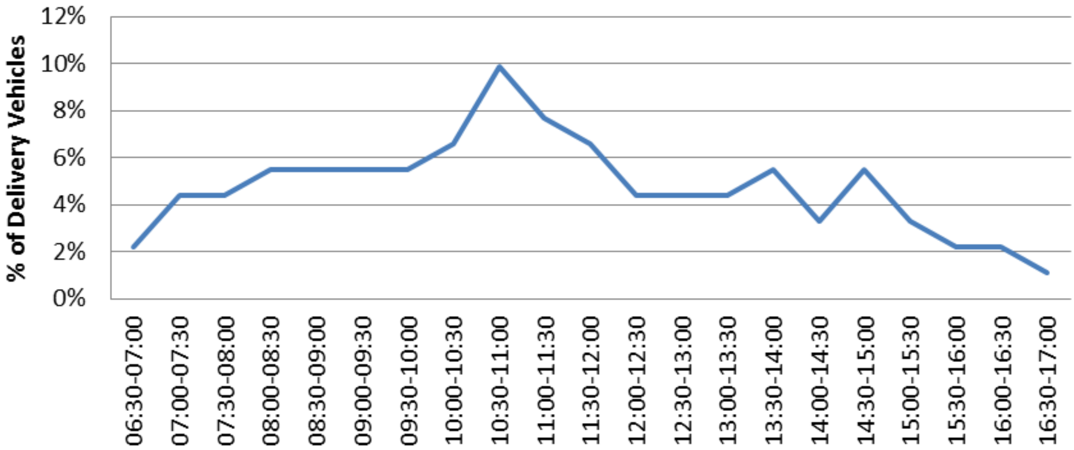


Figure 3.6 Average daily traffic profiles for survey week grouped by 30 minute time period

3.4 Laboratory Courier Services

As established in Chapter 2, the transportation of specimens via CEP services is pervasive with laboratories situated within specialist Trusts providing analytical services for Trusts worldwide.

The arrival of samples to GOSH is often time critical and unpredictable owing to the unpredictability of patient demand. The process of patient sampling involves the receipt of samples into the Trust, testing and couriering of samples and results back to the customer hospital. Interviews with hospital staff indicated that items were typically transported in vehicles within close proximity to GOSH at the time of booking therefore the selected vehicle type (i.e. bicycle / motorbike / van) for a job is not based on the smallest and most efficient vehicle for the job.

A survey of historical courier records between January and March 2014 revealed that 476 consignments were couriered over a total of 47 days. Approximately 442 of the items couriered were to a UK address, 50% of which were journeys less than 10km from GOSH. Further analysis of the data indicated that only 9 records were considered urgent, suggesting that the remaining consignments to be couriered may be suitable for consolidation into vehicles for delivery.

Examining the total courier record population, Figure 3.7, the majority of items couriered were Sub Category B (34%) (i.e. items requiring dry ice for transportation such as tissue samples), blood samples (25%), and journeys for the collection / delivery of blood pressure monitors (10%) from / to patient addresses. With the exceptions of patient samples (6%), which included swaps or are otherwise unspecified, the remaining items which are couriered represent 5% or less of the total population of items couriered.

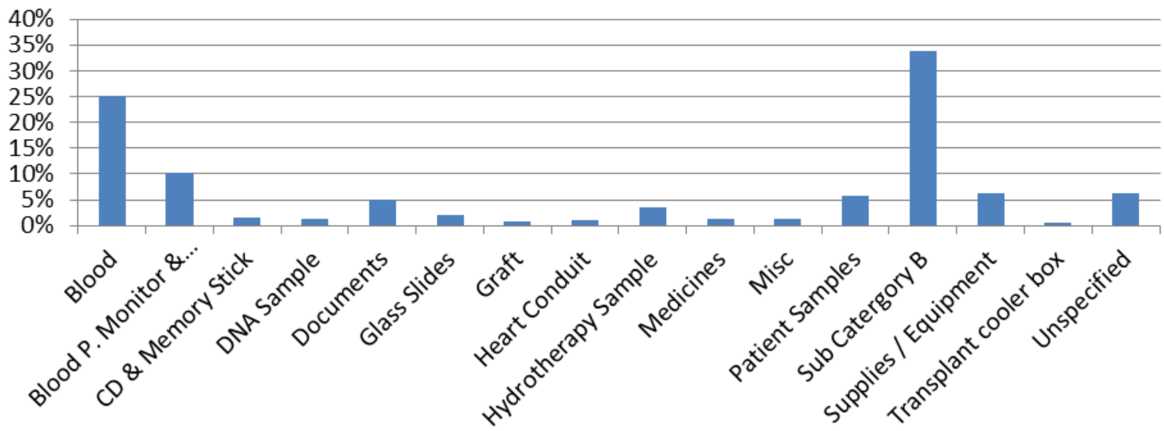


Figure 3.7 Breakdown of courier record population by item type

3.5 Summary

Following an overview of the literature on healthcare supply chains and sustainable urban logistics, this chapter presented Great Ormond Street Hospital (GOSH) located in London, UK which served as the case study for this research. GOSH was selected to demonstrate how inner-city hospitals manage their inventory requirements internally, ancillary services such as laboratory courier services, and the traffic they can generate.

Chapter 4: Methodology

4.1 Introduction

This chapter outlines the experimental approaches taken to quantitatively assess the feasibility of the three proposed logistics solutions to improve GOSH's operations, using computational modelling methods: mobile consolidation, unattended deliveries, and sustainable laboratory couriers. The main methodologies for each of the three research themes, including descriptions of the data sets used to inform the methodologies explained in this section are provided in each of the results chapters 5 (Mobile consolidation for more sustainable non-urgent supply), 6 (Unattended delivery for urgent items), and 7 (Assessment for more sustainable laboratory courier services).

In response to TfL's main aims to develop a set of recommendations for sustainable methods of supply for healthcare institutions in an urban setting, this research performed a delivery and servicing assessment of the freight activities at GOSH. The DSP served to identify the key activities (Medical Supplies, Couriers and Catering, see Section 3.3.2) at the hospital responsible for freight trip generation. The literature review served to identify the existing collection of research and solutions within the healthcare and wider logistics literature as a means to develop three solutions: Mobile Consolidation, Unattended Delivery and Sustainable Courier services for hospitals. On-going dialogue with TfL and GOSH identified, as demonstrated in Section 2.6, that each of the proposed solutions addresses at least two of TfL's underlying goals to: Reduce, Retime, Reroute and Re-mode freight within the city.

Within the field of logistics, the transportation of goods and use of physical storage space for inventories represent the most significant financial outlays, thus service providers continually explore methods for optimising vehicle routing and capacity utilisation whilst minimising wasted space (Lin et al. 2011). These aims have led to the use of computational complexity theories such as heuristic techniques to find solutions to problems which would otherwise be impractical owing to the vast number of permutations (Russell and Norvig 2010). The most common examples of such techniques in transport and logistics are the 'Travelling Salesperson Problem' (TSP), which attempts to find the shortest tour between a number of cities (destinations), visiting each city exactly once (Russell and Norvig 2010); and, the Container Loading Problem / Knapsack

Loading Problem (which attributes values to goods by weight or monetary value), which attempt to effectively utilise available container capacity for the transportation of goods (Lin et al. 2011).

4.2 Rationalisation of modelling approaches

As stated in Chapter 1, the demand for UFT is growing at a faster rate than personal travel due to online consumer purchasing and increasingly individualistic logistics services such as next-day deliveries. Therefore the significance of freight within urban transport network infrastructures and its adverse impacts on urban amenities is increasing (D'Este 2000). Modelling of urban freight using optimal vehicle routing algorithms to determine freight distribution patterns and optimal locations of facilities such as UCCs can enhance the understanding of urban freight activity. Thereby aiding in the design and appraisal of policy, planning and operational initiatives designed to increase its efficiency and reduce its negative impacts (D'Este 2000). One of the most common forms of freight modelling is the vehicle routing problem (VRP), typically used for distribution management to minimise the total route cost by finding the optimal number and combination of fleet vehicles to service a number of customers served by a centralised depot (Cordeau et al. 2007). Study of the VRP has given rise to both exact and heuristic approaches to find the optimal solution within large combinatorial optimisation problems, a process identified as an NP-Hard (Non-deterministic Polynomial Hard) problem[7]:

Branch and Bound

Branch and bound based algorithms were the most effective exact methods based on combinatorial relaxation (i.e. the approximation of the solution for a larger and more difficult problem by the solving of a simpler 'nearby' problem) (Cordeau et al. 2007). Branch and bound based algorithms can be considered as a tree search, Figure 4.1, whereby at any decision point on the tree the algorithm must make a decision and set an unbound variable (Land and Doig 1960). In addition to this, assuming the algorithm can prove solutions, i.e. combinations, outside a given range of characteristics will not produce viable results, then upper and lower bounds may be set in the algorithm to reduce the size of the 'search space' (number of available

[7] A problem is defined as NP-hard if its solving algorithm can be used for any NP-problem (nondeterministic polynomial time) Weisstein, E. W. (2015). "NP-Hard Problem." Retrieved 27/05/15, 2015, from http://mathworld.wolfram.com/NP-HardProblem.html.

combinatorial solutions), and thereby reduce the amount of time required to search for the optimal solution (Cordeau et al. 2007).

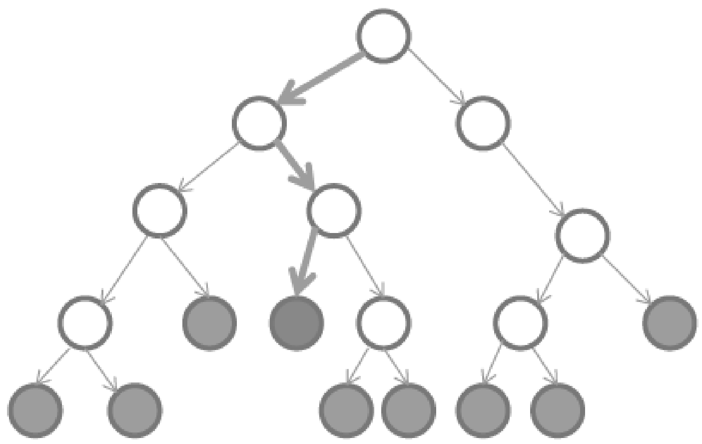


Figure 4.1 Illustration of a branch and bound approach to combinatorial problems. - The algorithm groups all combinatorial solutions according to their ability to satisfy a defined range of performance criteria according to the performance capabilities of specific characteristics in each solution. This process reduces the number of acceptable combinatorial solutions, thereby speeding up the search [Source: (Gurobi Optimisation 2015)].

Whilst the implementation of branch and bound algorithms have been found to produce the most optimal solutions for large combinatorial problems for the Travelling Salesperson Problem, the amount of CPU time required to solve them may be found to be impracticable (i.e. years) (Rego et al. 2011). Therefore, heuristic algorithms are used to find solutions to combinatorial problems that are of high quality (e.g. within 2-3% of the optimal solution) but not necessarily optimal (Rego et al. 2011).

Heuristic Algorithms

Heuristics typically begin by iteratively incorporating elements of combinatorial problems to build a starting solution. In the context of the TSP this likely involves randomly selecting a starting location and then iterating through all possible remaining locations until the next nearest is found. This process is continued until all locations have been visited (Cordeau et al. 2007). It is likely that this process will produce a result known as a local optimum (i.e. the most optimal combination that can be formulated from the routes starting location). From this point the algorithm seeks to improve upon the existing solution, by means of mutating specific characteristics, i.e. changing the order in which locations are visited to 'search' for a better result than the current one. The process of mutation can have a significant impact on the likelihood of an algorithm finding a result close to the global optimum. In heuristics there are three main approaches characterising the process of mutation: Local search, population search and learning mechanisms (e.g. Artificial Intelligence and machine learning). Given the scope of the research within this thesis, the following review will focus on local search and population search algorithms.

Local Search Algorithms

Local search algorithms, such as Tabu search, explore the solution space (all available combinations to a problem) by iteratively moving from a solution to the next by checking solutions that are similar except for one or two minor details (neighbours). If one of the neighbours is found to be an improvement on the existing solution it is discarded and the local search is repeated using the new solution. This process is repeated until no further improvements can be made indicating that an optimum has been reached (Cordeau et al. 2007). However, due to the nature of searching neighbouring solutions local search methods have a tendency to become stuck in local optima Tabu searches attempt to overcome this by allowing lesser performing solutions if no improving move is available. This is typically achieved by introducing prohibitions whereby if a potential solution has previously been found within a given period of time, it is market as 'tabu' (forbidden) to prevent the algorithm becoming trapped within continuous loops (Cordeau et al. 2007). However, using this approach does not guarantee a global optimum will be found.

Genetic Algorithms

Genetic algorithms are predicated around the concept of evolutionary mechanics and natural selection. In the context of combinatorial problems, genetic algorithms create offspring solutions ('Children') from 'Parents' by means of:

- Crossover, combining the characteristics of each parent to form a child;
- Mutation, using a local search algorithm (e.g. Tabu search) to alter characteristics of the child resulting from the inherited characteristics of the parents;
- Selection, deciding upon the survival of a 'child' according to a pre-established fitness criteria against which the performance of a solution is measured; and,
- Inheritance, incorporating characteristics from previous generations of solutions which have helped in their survival (Russell and Norvig 2010; Cordeau et al. 2007).

Owing to the complexity in the number of criteria and the conditions under which they are determined, genetic algorithms are less likely to become trapped within local optima, thereby increasing the chances of them converging upon the global optimum solution. However, they typically require larger amounts of computational time to achieve a final solution, whereas local search algorithms have been found to produce near optimal results within much shorter periods of time (Russell and Norvig 2010; Rojas 1996). Given: these findings, the time and resource restrictions related to the overall project and the need for the models developed in this research to demonstrate commercial application with regards to short "run times", two local search approaches are used for this research:

- A TSP algorithm based on a local search model with a randomising function destroying parts of local optimum solutions to 'globalise' the search is used to determine the optimal routing for: the mobile consolidation centre study (Section 4.3 and Chapter 5) and, the consolidation of laboratory couriers (Section 4.5 and Chapter 7).
- A local search hill climbing algorithm is used to determine the optimal combination of: locker partitions for the unattended delivery locker bank system (Section 4.4 and Chapter 6); and courier vehicles for the transportation of temporally consolidated laboratory samples for delivery to multiple destinations (Section 4.5 and Chapter 7)

Both modelling approaches use a multiple starting point methodology to increase the proximity of the final solution to that of the global optimum by means of convergence of final solutions from multiple starting points around the same area of solutions (Russell and Norvig 2010). (Section 4.4 and Chapter 6).

C# programming language is used to develop the TSP (comprising c. 1,000 lines of code) and Hill Climbing models (comprising c. 1,000 – 2,000 lines of code) for this research.

4.3 Analysis of the Shortest Delivery Path for the Mobile Consolidation Centre Unit

The intended outcomes of the proposed Mobile Consolidation Centre (MCC) concept, detailed description of the full concept is given in Chapter 5, are to reduce total VKms travelled, journey time hours for suppliers and vendors and tonnes of CO_2e emitted by using an adapted trailer which can be moved to different locations within the city, into which suppliers feed consignments for later delivery into the hospital. Therefore this concept is assessed according to the network (VKms), journey time and vehicle emissions (full methodology provided in Chapter 5) (Browne et al. 2005; Huschebeck and Allen 2005; MDS Transmodal Ltd and CTL 2012). Part of this assessment requires the evaluation of impacts directly related to the movement of the MCC unit to different sites and to destination hospitals, according to the optimal (shortest path) delivery routes. To achieve this, a TSP model was used to find the optimal delivery routes for the forward delivery performed by the proposed mobile consolidation unit. This approach was selected to minimise the distance travelled, thereby minimising the emissions generated. Such methods are commonly used within the logistics industry to solve problems of delivery rounds (Mallampati et al. 1991; Kizilateş and Nuriyeva 2013).

The TSP model used is a hybrid algorithm, detailed by Mallampati et al. (1991), comprising three separate functions, Figure 4.2: a nearest neighbour method (tour constructor algorithm) to generate a starting tour, a two-opt technique (primary tour improvement algorithm) used to randomly mutate the starting tour until no further improvement can be achieved, and a ‘swap cities’ function (secondary tour improvement algorithm) which randomly destroys part of the optimised sequence from repeated two-opt iterations to create a new tour from which a new set of mutations are run (Mallampati et al. 1991; Kizilateş and Nuriyeva 2013).

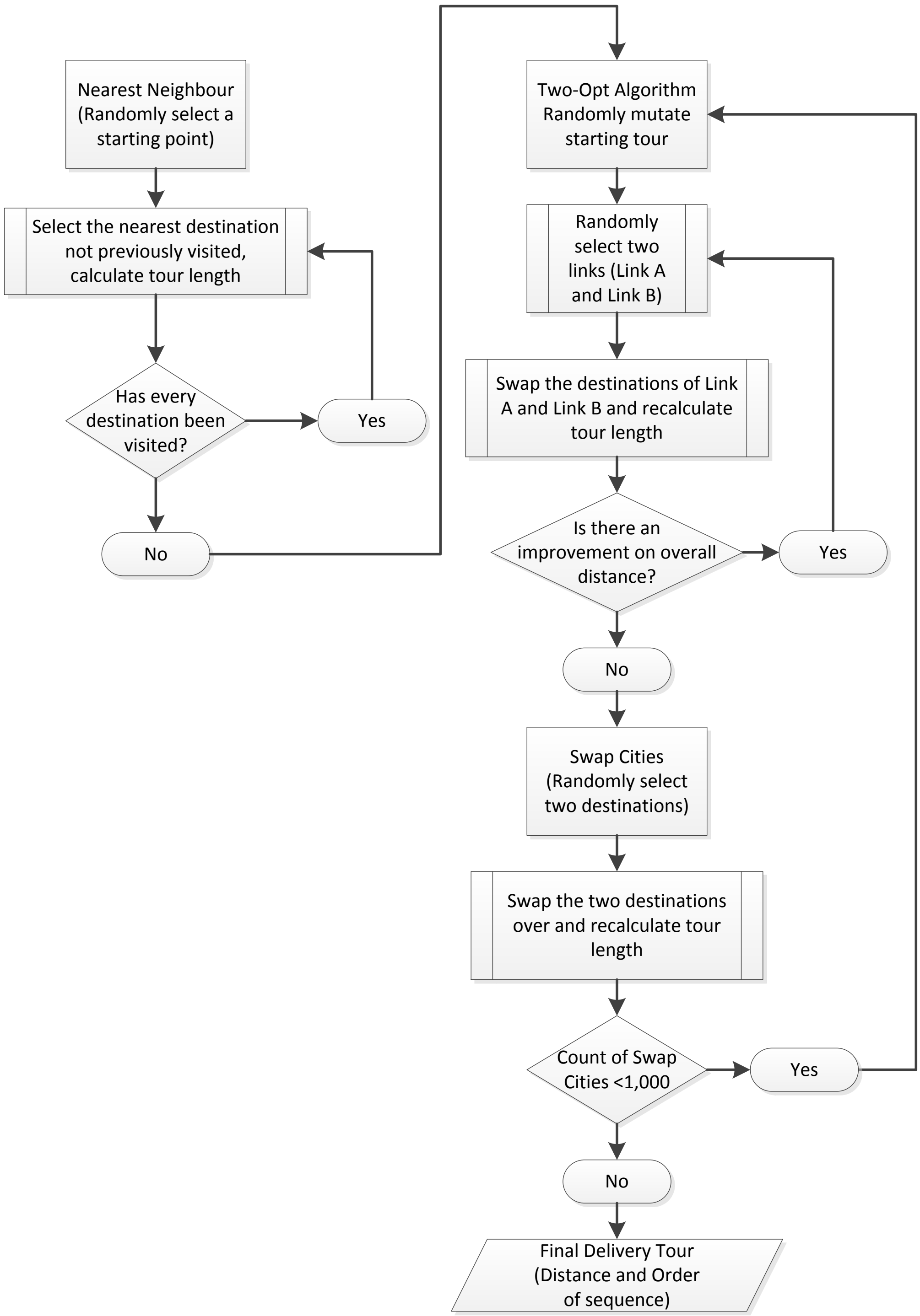


Figure 4.2 The Process of simulation for the Travelling Salesperson algorithm, indicating the three modelling components (Nearest Neighbour, route initiator; Two-Opt Algorithm, route mutation; and, Swap Cities, solution mutation to convert the model to a global search algorithm)

Nearest Neighbour Algorithm - Development of the Initial Delivery Route

The nearest neighbour algorithm begins with a matrix of destinations providing the distances between each destination determined using the ArcGIS Network Analysis Tool to assess the shortest distance between all possible destinations. It begins a tour by randomly selecting a destination from the matrix. It proceeds by selecting the next destination according to the shortest distance. This process is repeated until all destinations have been visited exactly once to achieve a delivery route (Mallampati et al. 1991; Russell and Norvig 2010; Kizilateş and Nuriyeva 2013).

4.3.1 Two-opt Algorithm - Mutation of the Starting Delivery Tour into an Alternative Tour

The Two-opt algorithm begins with the tour generated by the nearest neighbour algorithm. It randomly selects two links between destinations and swaps the paths over, Figure 4.3. Thereby altering the order of sequence in which the destinations are visited, changing the overall length of the route. This process is repeated until no further improvement to the overall length of the route can be achieved.

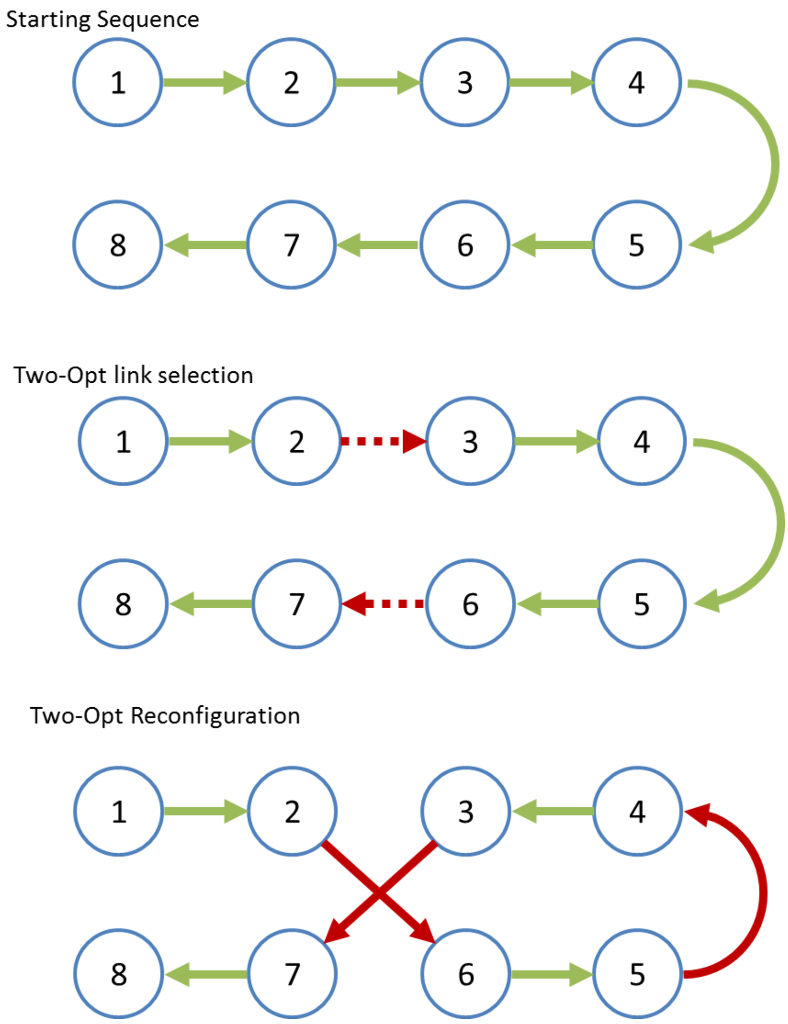


Figure 4.3 Modelling Process beginning with a starting sequence (Nearest Neighbour), progressing to a two-opt selection and reconfiguration for mutation

4.3.2 **Swap Cities - Method for Mutation of the Optimal Tour Solutions**

Once the two-opt algorithm converges upon a locally optimal solution, the tour is partially destroyed, selecting two destinations at random and swapping them over to create a new tour for the two-opt improvement algorithm to optimise, Figure 4.4. This process is repeated until a more optimal result is achieved.

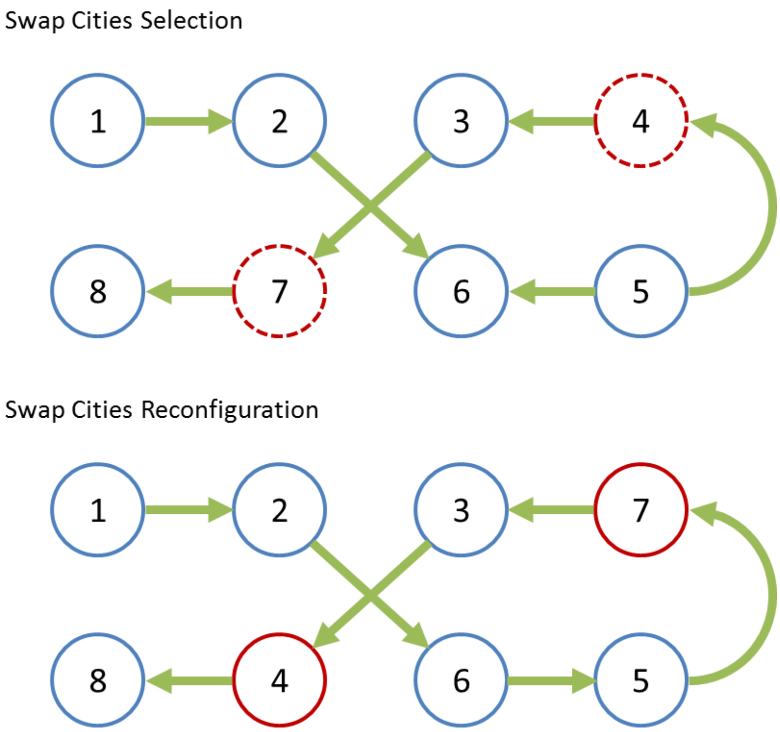


Figure 4.4 Process of sequence alteration for the Swap Cities function subsequent to no further improvement yielded from Two-Opt mutations

The purpose of this approach is to prevent the algorithm from becoming 'trapped' within local optima, a commonly cited problem for TSP and hill climbing algorithms (Mallampati et al. 1991; Russell and Norvig 2010). Destruction of the existing tour solution enables part of the previous locally optimal solution to be kept, whilst moving it away from a range of permutations which may prevent it from achieving a globally optimal solution for the problem, i.e. the shortest total route to make deliveries for each of the 31 hospitals, including 1 stop for the MCC.

As part of the analysis for the MCC, Section 5.3, a London-wide test of the unit is performed. This model of operation is predicated on the delivery of items to the unit for 31 hospital Trusts throughout London with the addition of 1 stop to account for the MCC location. Therefore, 32 stops represent the greatest number of destinations in any tour analysed by the TSP. In accordance with this validation of the model was performed using 32 stops to be included into a single tour. However, it should be noted that during the assessment of the MCC, the number of hospitals was reduced to 29 due to a lack of sufficient data for two hospitals, therefore the overall number of stops in a tour is 30 (including one stop for the MCC unit). However, since the number of possible combinations for a 30 stop tour is less than for a 32 stop tour, the forthcoming validation may still be considered valid. Figure 4.5, demonstrates the variation in the overall distance for tour solutions, indicating one tour to be significantly shorter than the next in a simulation of 100 mutations for a 32 stop tour[8].

For a more detailed narrative of the TSP genetic algorithm see: Russell and Norvig (2010) and Kizilateş and Nuriyeva (2013).

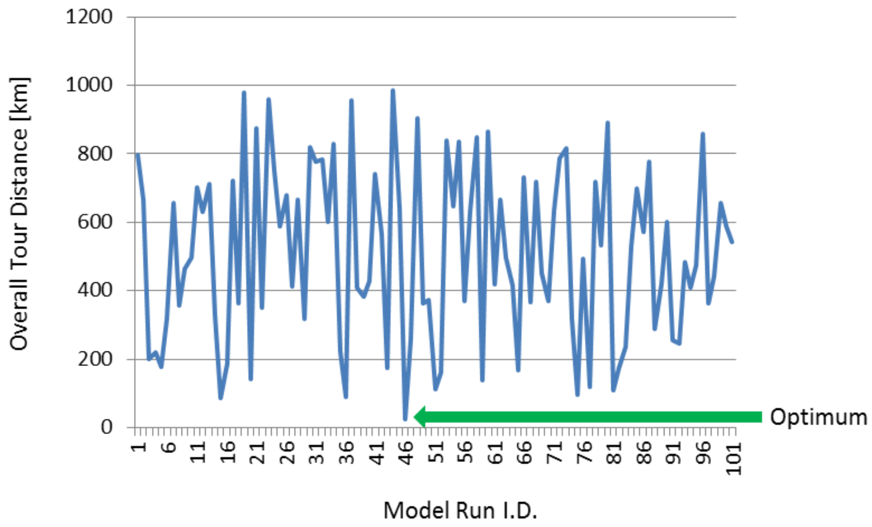


Figure 4.5 Final solutions yielded from 100 mutations for a 32 stop tour demonstrating the 'search space' for the Travelling Salesperson Algorithm used to determine optimal (shortest) overall tour distance

4.4 Tests for the Feasibility of Unattended Delivery for the Receipt of Urgent Items into Hospitals

As highlighted in Chapter 3, a mixing of urgent and non-urgent items within the supply chain was observed at GOSH during the site assessment and staff interviews. This is a problem documented within the literature, found to encourage sub-optimal freight patterns operating with less-than-full truck loads (Poulin 2003; McKone-Sweet et al. 2005).

Considering this issue in relation to the items in the literature review (Chapter 2) and discussions with staff at GOSH, it was proposed that an unattended delivery locker bank, such as those

[8] This result is caveated as it may not be the global optimum. However, it demonstrates the variation in final solutions obtained from a single iteration of the algorithm.

provided by Amazon, DHL and ByBox may be appropriate for the receipt of urgent goods into the Trust as a means to separate the urgent and non-urgent supply of goods and expedite their delivery within the hospital to the end-users.

Assessment of the unattended delivery concept, as presented in Section 2.3.2, indicated that hospital service requirements, such as the ability to divert parcels to the locker bank and ensure delivery within the 48-hour lead time are in accordance with the existing service level agreements. Therefore, the limiting factor regarding the feasibility of unattended delivery for GOSH is the required dimensions of the overall locker bank unit, and the internal specifications (i.e. the number of partitions and composition of partition sizes) required to accommodate a given percentage of urgent goods-in demand.

The following sections detail the modelling theory used to find the optimal dimensions of the required locker bank. Further details of the methodology pertaining to the data and parameters used are described in Sections 6.2 and 6.3.

A genetic optimisation algorithm was used to search for the optimal locker partition combination. 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 optimisation algorithm is selected over a full genetic algorithm to find optimal combinations of box partitions owing to the relative small size and smoothness of the 'search space' being optimised, therefore minimising the possibility of the algorithm becoming 'trapped' within local optima (Russell and Norvig 2010). As previously stated, research has indicated that hill climbing algorithms can achieve similar or the same optimal as other 'efficient' genetic algorithms with greater speed (Rojas 1996).

Hill climbing algorithms are predicated on the same principles as the TSP algorithm, whereby a starting solution is formulated, and improved upon by varying a single element of the solution to search for improvements. This process is continued until no further improvements can be found. The algorithm comprises two steps: Sequence Initiation and Sequence Mutation, Figure 4.6.

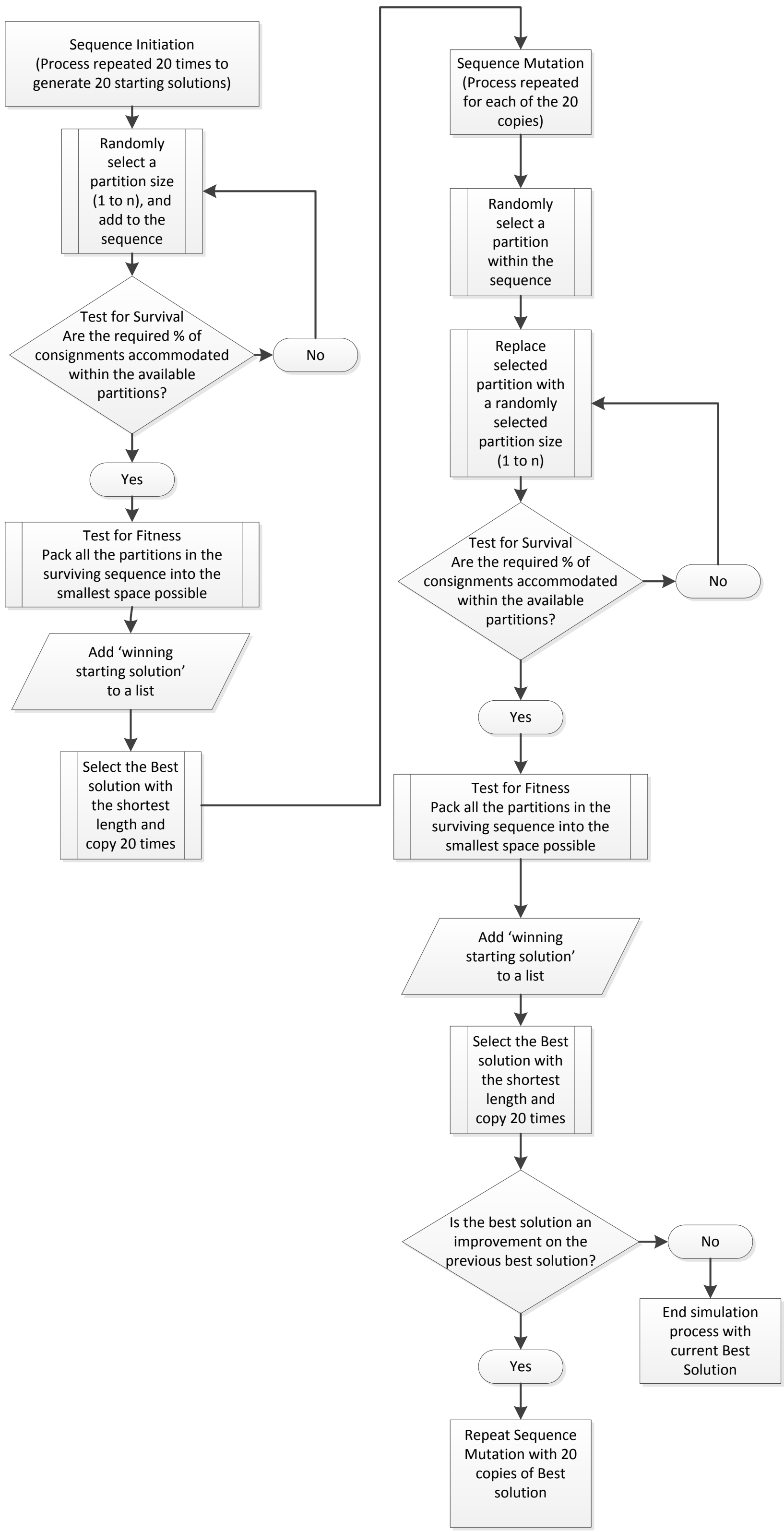


Figure 4.6 The process of simulation for the locker bank model, illustrating the two main model components, the decisions and flows of information throughout the model

4.4.1 **Sequence Initiation**

The sequence initiation begins by randomly selecting a locker partition from a list of partition sizes. It proceeds to perform a 'Test for Survival' packing each of the consignments from the demand profile into the locker partition. If the percentage of consignments which can be accommodated does not meet the 'Survival Hurdle' (e.g. 100% of all consignment requirements are met) the Sequence Initiator randomly selects another partition to add to the sequence, and the Test for Survival is performed once again. This process is repeated until a surviving starting sequence is generated. Once a starting sequence (comprising a number of locker partitions) is established, a 'Test for Fitness' is performed, which packs all of the locker partitions in the surviving sequence into the smallest space possible, within 1.7 metres tall, see Section 6.3 for discussion on the limiting parameters. This process generates the required length of the bounding box necessary to accommodate the locker box partitions.

The process of sequence initiation is repeated 20 times to generate 20 different starting solutions. The sequence for the 'winning' starting solution, i.e. the shortest, is then copied 20 times for mutation.

4.4.2 **Sequence Mutation**

Each copy of the winning starting solution is mutated. Sequence mutation randomly selects one of the partitions within the sequence and changes it for another partition, randomly selected from the list of possible partitions. The mutated sequence is then tested for Survival. If it does not survive then the same partition is randomly changed again until the mutated sequence survives. Once the sequence passes the survival hurdle the same test for fitness, performed during sequence initiation is run.

The process of mutation is repeated for each of the 20 copies of the winning starting solution. Once each of the 20 copies has been mutated, they are compared against each other, selecting the 'Fittest' solution, i.e. shortest. This sequence is copied 20 times and the process of mutation is repeated.

The outcome of the locker bank model is an overall required length for a locker bank and the specification of lockers i.e. the size of each locker and number of duplicates of each locker size within the locker bank.

4.5 Assessment for the Consolidation of Laboratory Couriers

As highlighted by the literature CEP services represent a significant proportion of urban goods traffic (35%) (Menge and Hebes 2011). A review of the existing literature on hospital couriers indicated that much of the research focusses on improving the economic efficiency of courier services, whilst giving little attention to their impacts on the environment and urban road network. A survey of the laboratory courier services at GOSH between January and March 2014 quantified the traffic impact, indicating that 476 consignments were couriered over 47 days. Assessment of the items couriered identified 9 records to be urgent, suggesting that the remaining consignments may be suitable for consolidation into vehicles for delivery. These findings were of particular interest to the project sponsors in the interest of reducing urban congestion (TfL) and reducing hospital related carbon emissions.

The aim of this study was to quantify the impacts of temporally consolidated courier operations from an environmental perspective. In order to assess the required number of consolidated items needed to be established to determine the potential impacts on vehicle emissions accrued from a single or group of vehicles performing delivery rounds to deliver all consolidated items. A detailed assessment of the data and methodologies used is provided in Chapter 7.

This process requires: the assessment of several time periods in which to consolidate items to determine the most beneficial amount of time with which to delay items; and, the establishment of the number and type of vehicles required to transport goods consolidated into each time period in the most environmentally and practically efficient way.

4.5.1 Travelling Salesperson Function – Finding the Shortest Route

Of key interest here was the extent to which patient samples could be delayed in order to batch them into more efficient order sizes for dispatch to their final destinations. This problem also requires the number and type of vehicles used to transport items to be optimised and consolidated within each time period, to their final destination. Owing to the numerous factors affecting the environmental impact (e.g. number of vehicles used to meet demand, emissions coefficients for each vehicle, trip length etc.) measured in vehicle emissions for this problem, there are a high number of potential permutations to test in order to establish the optimal operating scenario. Therefore tests of optimal vehicle numbers (i.e. the overall number of vehicles and the types of vehicles used), into which items are packed thereby determining the overall number and location of stops per vehicle for a range of time period scenarios (1tp = 10 hours, to 20 tp = 30 minutes) were performed using a hill climbing genetic algorithm, as described in Section 4.2 and Figure 4.7.

The hill climbing algorithm, described in Section 4.5, was used to find the optimal combination of vehicles (according to size and quantity) required to pack a given number of packages of various weights and sizes. The TSP model, described in Section 4.3 was used in the algorithm to test the fitness of the solution, by producing the overall delivery route distance for each vehicle, to be multiplied by an emissions factor (KG CO_2e per Km) provided by CitySprint, Section 7.2.1 (Table 7.2), producing a metric against which to compare the environmental performance of each solution. A detailed description of the data used in the laboratory courier model is provided in Chapter 7.

4.5.2 **'Test for Fitness' – Assessment of Route Performance against Alternative Routes**

The fitness of a vehicle route sequence was established using the same Travelling Salesperson function described in Section 4.2 to determine the optimal vehicle route for each vehicle in the sequence, according to the destinations each is assigned.

Once an optimal route solution had been established the two trips to and from The Trust were assessed, selecting and removing the longer of the two trips. This was performed to alter the route to a one-way journey as opposed to a round trip. Subsequently, the overall distance of the route was multiplied by the emissions factor for the vehicle. This process was repeated for each vehicle in a vehicle sequence, adding the emissions for each vehicle together to provide the final metric to assess the vehicle sequence's fitness.

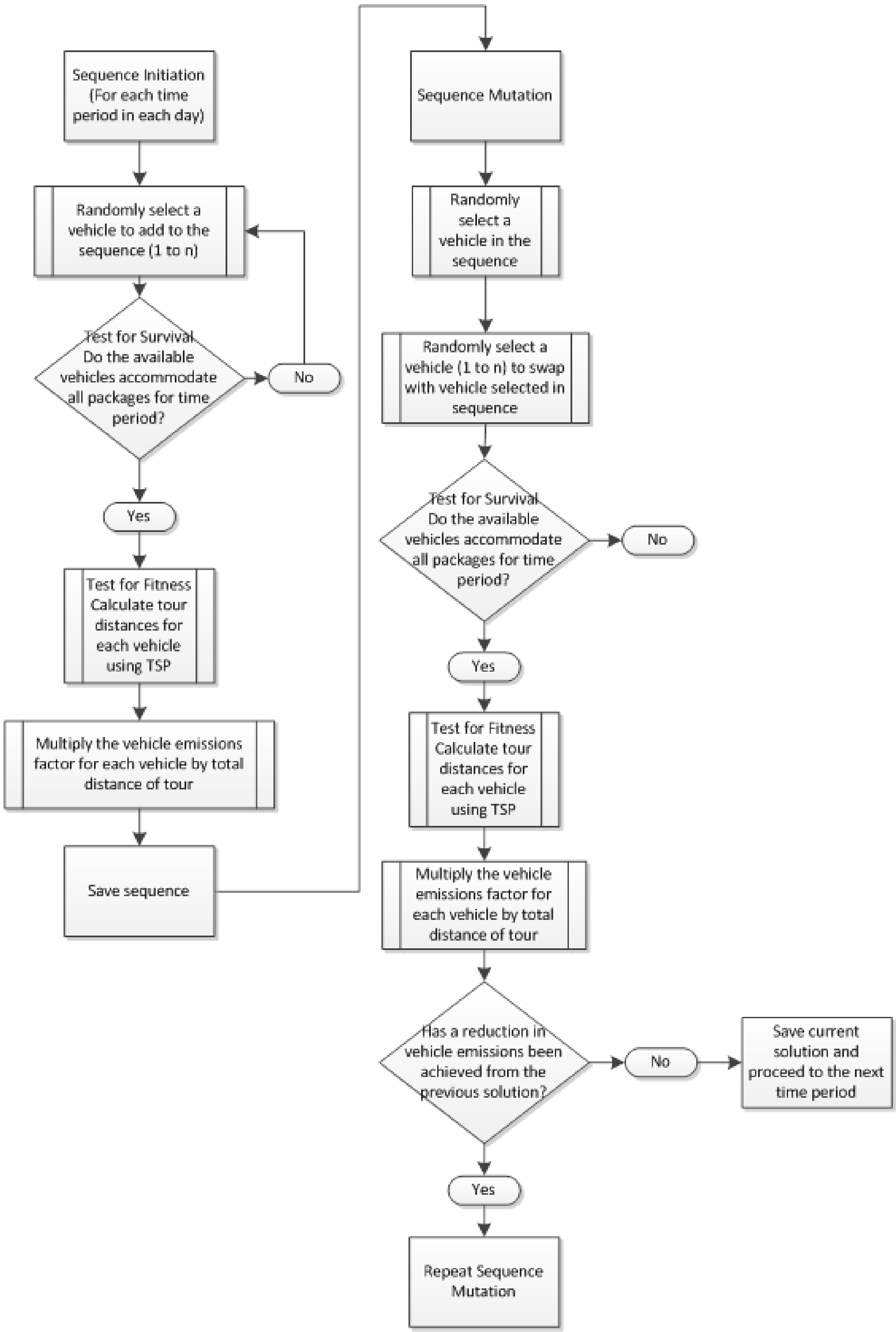


Figure 4.7 The process of simulation for the courier model, illustrating the two main components of the model (sequence initiation and sequence mutation), including the Test for Fitness which uses the Travelling Salesperson Model (Figure 4.2)

Chapter 5: Mobile Consolidation for the Reduction of Traffic to GOSH

5.1 Introduction

The transport audit undertaken as part of the delivery and service plan for GOSH (Chapter 3) identified that 403 deliveries of medical suppliers were received per week, which were on average only 40% full. As identified in the literature review, poor load factors may be characteristic of the agile supply chain and unpredictability of demand observed in healthcare (McKone-Sweet et al. 2005; Jarret 2006; Costantino et al. 2010; Black and Zimmerman 2012; Azzi et al. 2013). As is typical with high delivery frequencies and low fill-rates, freight consolidation is often considered a viable solution (Woodburn 2005). However despite the NHS Supply Chain, a freight consolidation network, described in Sections 2.2.3 and 3.3.2, established in 2006 to provide a dedicated supply chain to NHS England (NHS Supply Chain 2014), supplier participation remains low, owing to increased supply chain costs, loss of visibility and control of products, and sub-optimisation of supplier's logistics services. In addition to this, poor participation in the primary 'route of supply at GOSH, determined to be 30% of annual goods volumes (Section 3.3.2), has also been found to contribute further to sub-optimal supply owing to the mixing of urgent items with non-urgent items within the secondary chain, both at suppliers' and couriers' warehouses and the external-internal supply chain interface.

Little research appears to have been done to address the barriers to UCC implementation specifically through the redesign of the consolidation centre model in order to make them more attractive to suppliers, see Section 2.4.4. This chapter proposes a novel mobile consolidation centre (MCC) equipped with ICT enabling secure-electronic receipting of goods, eliminating the need for fixed-based infrastructure, intended to reduce the overall operating costs of a UCC and increase the visibility of items to end-customers for suppliers. In addition to this, being portable, the depot can be: situated in more optimal locations relative to suppliers and their existing customer bases; and moved to multiple locations thereby providing similar VKm reductions as multiple consolidation site operations whereby suppliers may elect to make deliveries to their closest depot. The aim of this study was to assess the feasibility, environmental and economic performance of the concept against the current model of operations.

5.2 Mobile Consolidation Concept

The mobile consolidation centre concept is similar in design to a groupage lorry and the TNT Mobile Depot demonstration (Straightsol 2012a), with the exception that deliveries are made direct to the unit, and are automatically sorted, receipted and consolidated for forwarding on-board the same trailer to the final destination(s).

The concept comprises a mobile trailer, equipped with electronic receipting capabilities and secure deposit facilities which enable unattended delivery of all items, situated in an outer-city location at a hospital Trust or dedicated stabling facilities to which the receiving hospital Trust instructs all deliveries to be made. Upon arrival at the depot, suppliers and couriers scan each consignment, Figure 5.1, at which point the console on the unit instructs the items to be deposited within a specific partition in the trailer (allocated to a ward or zone within the hospital), therefore by process automatically sorting the items by their destination ward. Should a carrier be delivering multiple packages for different wards, they will scan and deposit each item in their respective partitions. Upon depositing the item Figure 5.2(1), the unit locks and confirmation of the delivery is sent to the carrier and customer.

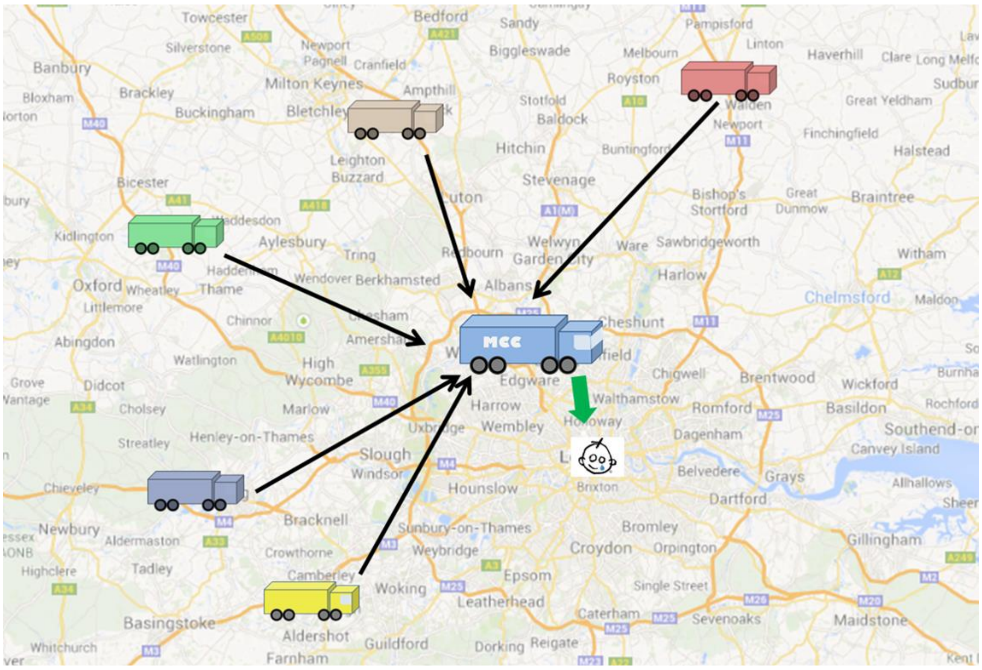


Figure 5.1 Process of delivery for the proposed Mobile Consolidation Concept. Deliveries for GOSH are made by each supplier to the MCC (located e.g. in the North West of London), with the goods delivered to the MCC being forwarded to GOSH in a single consolidated trip

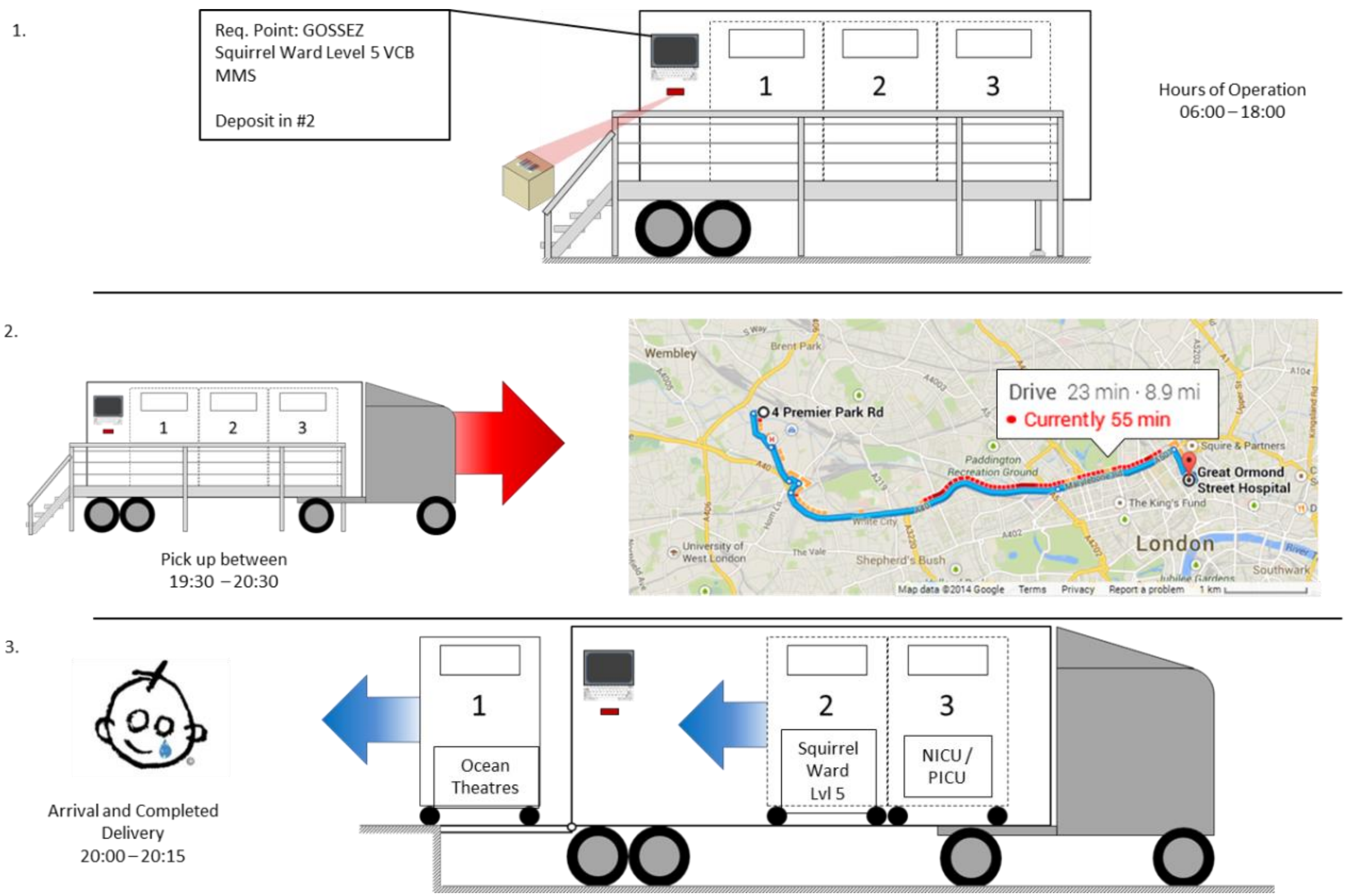


Figure 5.2, Illustration of the operational process for the mobile consolidation centre (1) process of scanning and delivery of items into the unit, (2) transfer of the unit to the final delivery destination, and (3) transfer of goods from the unit into the hospital

Technology for the confirmation of the correct items within the correct partition may be designed according to item weight or an RFID system similar to those used in unattended electronic delivery solutions, Section 2.7.2. However, should a driver post an item into the incorrect slot, the weight of the item would be registered as being deposited into the incorrect partition. In such circumstances the items delivery would still be confirmed and the cage manifest on the computer would be adjusted to take a note of a likely error in parcel transfer thereby allowing for the transfer of the parcel once the cage is at its final destination in the hospital.

In order to ensure the trailer does not contravene health and safety executive guidelines for delivery drivers, the final design of the trailer (i.e. the process of scanning and depositing of items) may be planned in such a way that drivers are not exposed to any additional health and safety implications to those which are already implied in their job (i.e. lifting of items from the delivery vehicle and conveyance to the place of deposit.

Once all deliveries have been made during day-time hours (07:00 – 17:00), the deposit doors lock preparing it for collection and transportation to the destination hospital Trust, Figure 5.2(2). Upon arrival at the hospital, the trailer is unloaded with each separate partition being wheeled off and taken direct to the final delivery point (i.e. ward / department) where the items are transferred into the store room(s) and the empty cages are returned to the loading bay for collection after the next delivery, Figure 5.2(3). As is common with all consolidation centres the mobile depot displaces delivery traffic to a location outside the city, reducing inner-city UFT associated with the Trust. The pre-sorting of items allows for the disintermediation of the receipts and distribution room, and streamlining of the internal supply chain within the hospital, speeding up supply, reducing the potential for loss or delay of items, and releasing capital to offset the operating costs of the MCC, Figure 5.3.

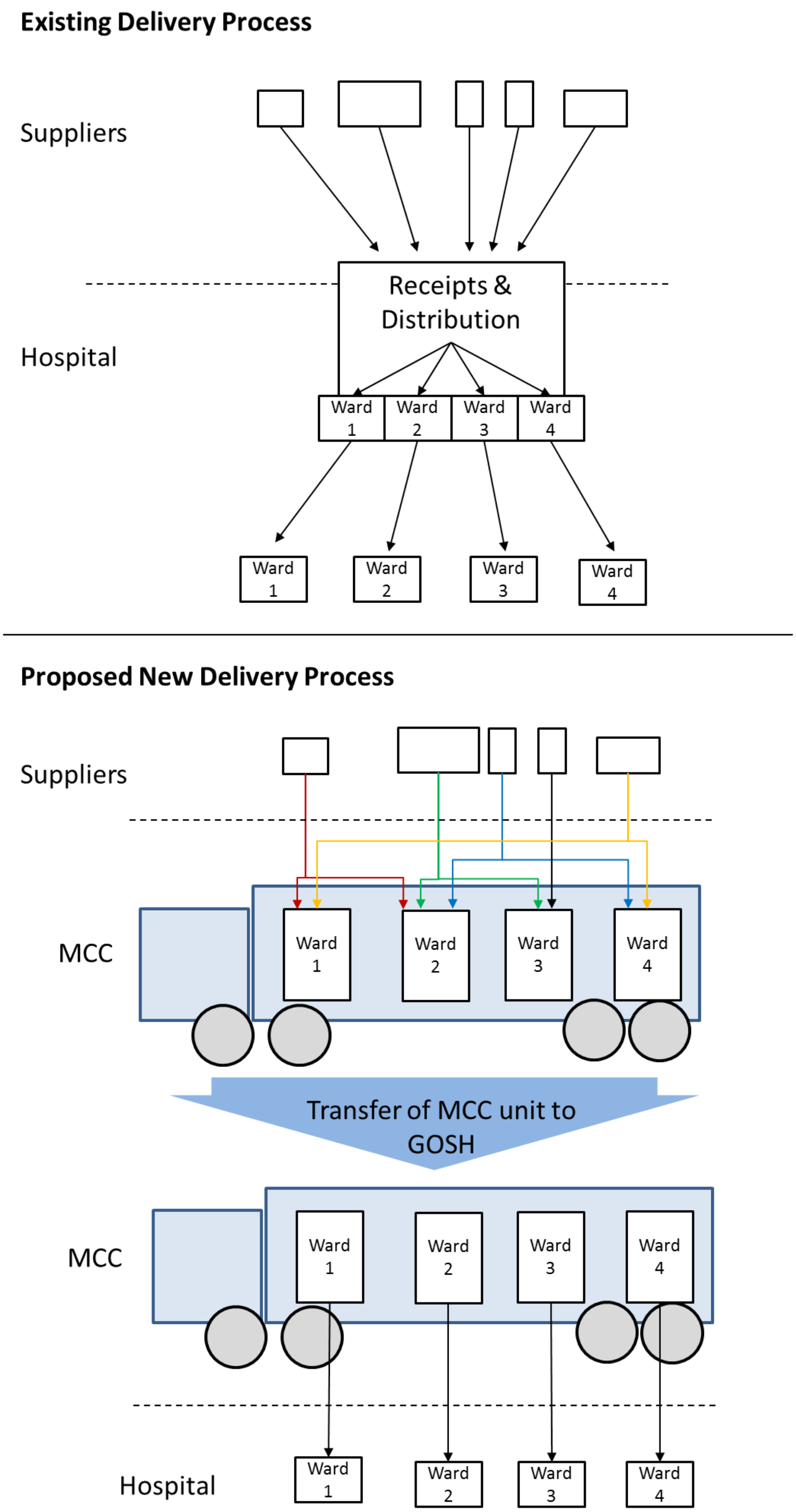


Figure 5.3 Comparison of the existing model of delivery into GOSH against the proposed process of delivery using the MCC

The mobile consolidation concept differs from traditional consolidation, providing only a short-term holding position for hospital inventory where deliveries are held during the day and delivered during the night of the same day, opposed to the NHS Supply Chain whereby large inventories are stored and replenished by suppliers in central warehouses, from which hospital orders are sent. This enables the costs associated with holding inventory to be avoided. The mobile nature of the concept enables the depot to be re-located during set times of the day to provide a more convenient delivery location for suppliers entering urban areas from opposite directions.

The assessment of the MCC will be conducted for GOSH to assess impacts of the concept for a single hospital, and also on a London-wide scale to all major NHS Trusts and Foundation Trusts within the city to assess the wider impacts of the concept. Implementation of the MCC on a London-wide scale would require the use of multiple trailer units each dedicated to a single hospital due to the likelihood of the cumulative volume of incoming goods for multiple hospitals exceeding the capacity of a single MCC unit; and the potential of multiple trailer units required for a single large hospital Trust to manage the larger volumes. The requirement for multiple trailer units would require larger stabling facilities and potentially new road infrastructure, such as reinforced road pavements and wider access roads to cope with the high volumes of HGVs accessing the site. However, due to the mobile nature of the concept, scheduling of each unit at locations throughout London may help to spread the requirements of multiple trailers throughout a single day, i.e. rotating equal numbers of trailers between various sites. Operating on a London-wide scenario, the concept lends itself to two distinct models of operation:

1) Delivery of inventories to dedicated MCC units for each hospital, with each MCC unit making forward journeys to their respective hospital, Figure 5.4; and,
2) Delivery of inventories to MCC units, fixed in dedicated geographical locations assigned to a group of suppliers, with each unit performing a delivery round of goods for all central London hospitals, Figure 5.5.

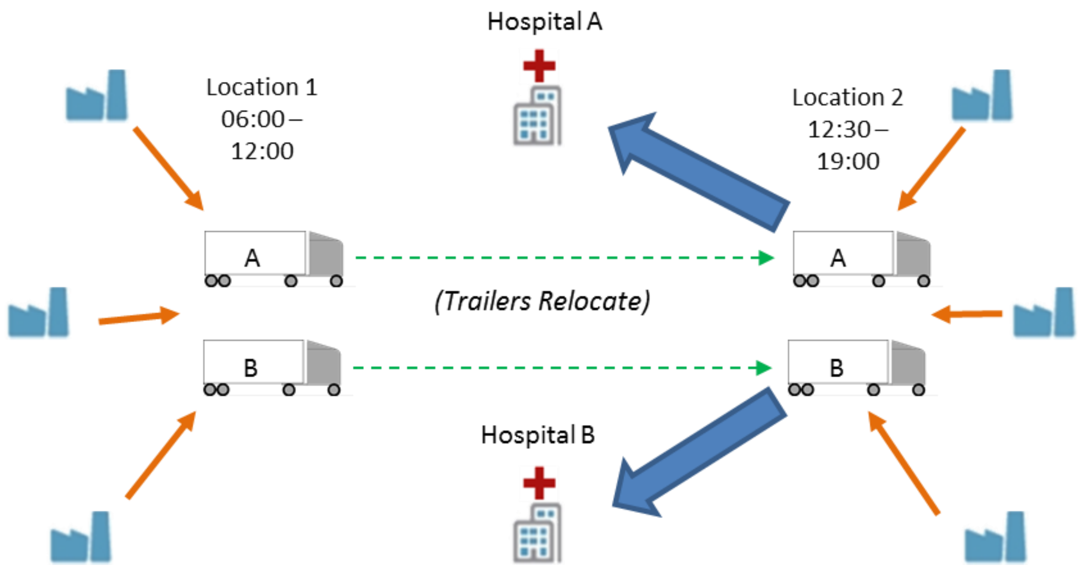


Figure 5.4 Process of delivery for MCC units assigned by hospital. Suppliers make deliveries to MCC units assigned by hospital. Each trailer forwards its contents on to their respective hospital

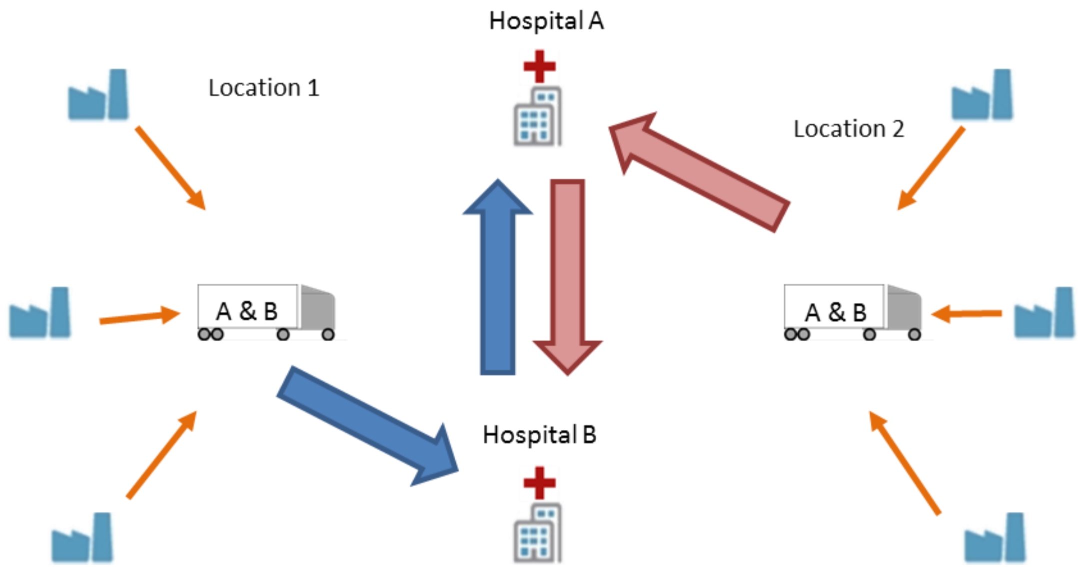


Figure 5.5 Process of delivery for MCC units assigned by supplier group. Suppliers make deliveries to an MCC geographically closest to their point of distribution. Each trailer performs a milk round to each hospital incorporated in the scheme dropping off consignments of stock

Whilst the first model of operation would retain the concepts “automated sorting” function for each hospital ward and department, the second model supports London-wide hospital collaboration when accompanied by a joint procurement strategy, providing a location for the delivery of common goods which are bulk bought between hospitals thereby potentially yielding savings through discounts.

5.2.1 **Space Requirements for the MCC**

The proposed MCC concept was modelled on an 18 tonne NHS Supply Chain lorry (DAF LF 220) measuring 10.5 m in length and 2.54 m wide(DAF 2015b). Based on truck access platforms provided by a UK manufacturer the proposed width of the access platform (pictured in Figure 5.2(1)) is assumed to be 1.25 m (Steps and Stillages 2015). Therefore the proposed footprint of the unit on any given site will be 10.5m x 3.79m (L x W).

Analysis of the November 2011 DSP survey indicated that on the busiest day, 93 deliveries were made to the Trust over a 10 hour period, therefore yielding an average arrival rate of 1 delivery every 6.45 minutes. Further assessment of the survey data indicated an average vehicle dwell time of 13 minutes across the 5-day period. According to the average arrival rate and vehicle dwell time it is likely that 2-3 vehicles are likely to be making deliveries at the same time.

Based on the above and following assumptions, the overall required site dimensions are 48.36 x 55.65 metres, Figure 5.6:

- the width requirements to accommodate three of the largest delivery vehicles to the Trust (18t DAF LF 220);
- 21.06 metres provided for the turning radius of the MCC and an 18t DAF LF 220 from the furthest space from the MCC (DAF 2015a);
- 2 metre staggering of parking spaces to enable turning (DAF 2015a); and,
- 1.25m width provided between vehicles.

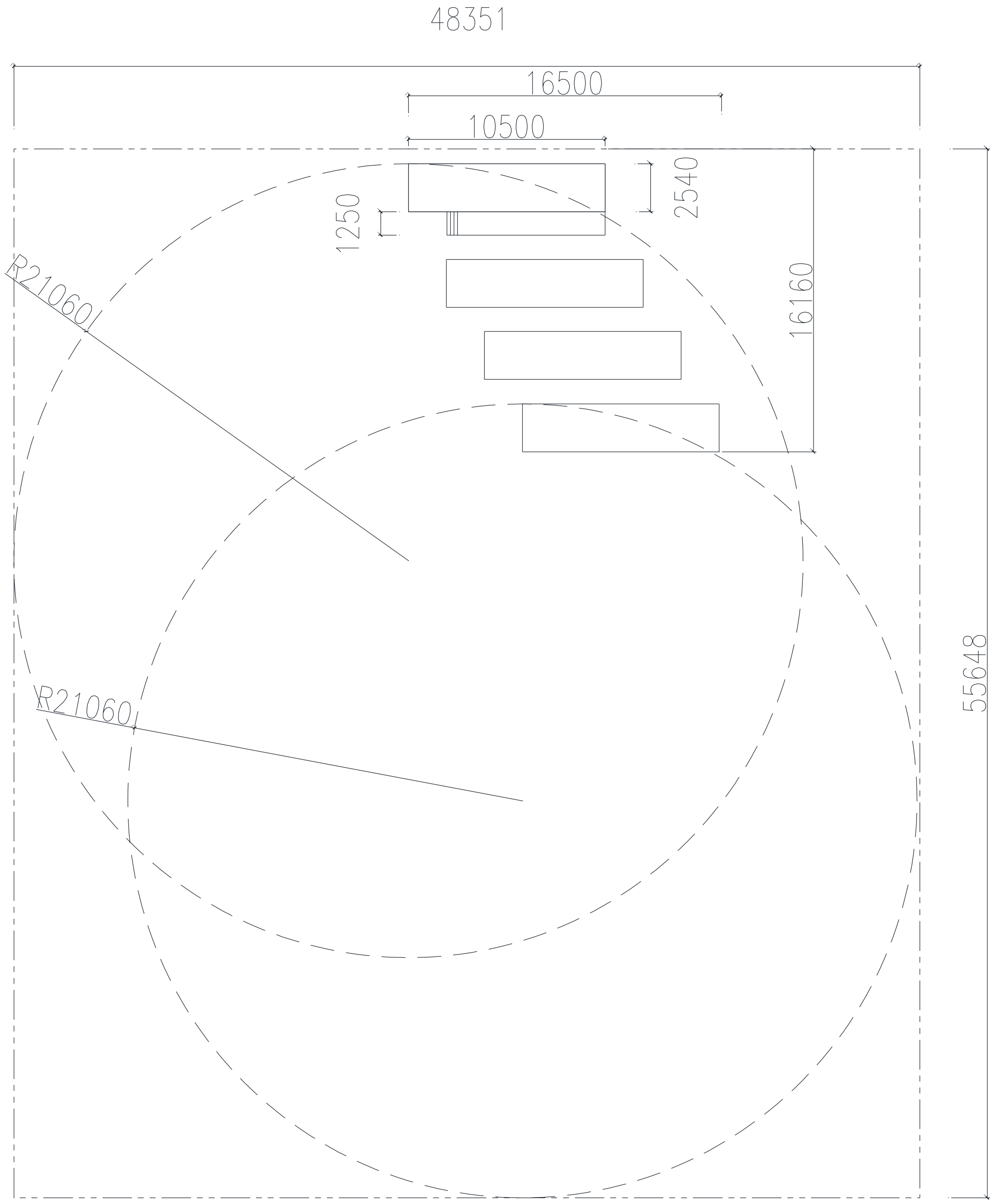


Figure 5.6 Site Plans for the MCC. Dashed circles indicate the turning radius for the MCC located at the top of the site, and for an 18t lorry parked in the furthest position from the MCC. Dashed and Dotted Line indicates the outer boundaries of the proposed site. (Measurements are provided in millimetres).

5.2.2 **Datasets used to evaluate the MCC concept**

The mobile consolidation centre was evaluated using two separate datasets:

Cage Survey to determine the spatial requirements of Goods-in to GOSH

A 2013 5-day audit survey (15th – 19th July) of hospital roll cage fill rates was undertaken. Hospital cages, Figure 5.7, measuring 83 x 167 x 72 cm (L x H x W), are the main method by which goods are sorted and grouped in supplier warehouses and transported to hospitals. Once delivered to the hospital each cage may be wheeled to their respective ward store ready for decanting onto the shelves.

Figure 5.7 Illustration of a typical NHS Supply Chain hospital cage used at GOSH [Source: (A2B 2015)]

The findings of this survey were used to test the practical feasibility of the concept. Owing to resource limitations the survey comprised visual assessments of cage fill to log the number of cages filled per day (a common unit of containment used throughout hospitals) in order to determine the space requirements of all goods-in to GOSH, ranging from an envelope and jiffy bag to a large box. According to the data gathered from urgent item deliveries the size of a box can range between approximately 22 x 15 x 3 [cm] and 57 x 37 x 26 [cm].

Freight Survey to Assess the Traffic Impacts at GOSH

Of the 403 recorded deliveries from the 2011 5-day delivery and servicing survey, 23% (93) were selected for the environmental and economic appraisal of the MCC concept. The 93 samples represented all the deliveries suitable for consolidation [n=167] [9], minus those for which wider supply chain data such as previous drop and next drop location were not obtained.

Assessment of the cross-section revealed that 54 of the 93 samples used for the appraisal did not have a confirmed supplier location. To address this issue, supplier origins were superimposed onto the 54 samples using an approach similar to Monte Carlo Rejection sampling (Kulis 2012). For each of the 54 samples a known supplier origin was selected according to a random choice approach selecting suppliers according to the underlying distribution of known supplier origins (i.e. the frequency of deliveries each supplier made). Therefore the more frequent deliveries occur from a given supplier origin the greater their chance of being selected by a random number generator. This process was performed independent of the outcome of allocation for each of the 54 samples.

For example, assuming: 20 unknown supplier origins; and, 100 known supplier origins with a delivery distribution indicating 50%, 30% and 20% of deliveries originate from Supplier A, B and C, respectively. Then the chosen methodology would assign the origins of 10 deliveries to Supplier A, 6 Supplier B, and the remaining 4 deliveries to Supplier C. However, since the process is performed at random and independently for each of the unknown supplier origins (i.e. the origins previously selected to superimpose on unknown supplier origins does not affect subsequent choices of origins), all unknown supplier origins may be assigned in any proportion to Supplier A, B and C.

[9] excluding all vehicle movements related to all catering maintenance and servicing (including shredding services), as well as blood media, the delivery and collection of empty crates and pallets, ethanol, liquid nitrogen, failed deliveries, pharmaceuticals, unknown, large equipment deliveries (vacuum pumps, vending machines, weather proofing, wheel chairs and sterilised and non-sterilised theatre equipment and supplies.

5.2.3 Feasibility Study

The data gathered during the cage survey, Appendix B, was extrapolated to an annual cage demand profile according to a weekly uplift factor, derived from historic weekly hospital order volumes for the financial year 2012-13, Appendix B. The maximum daily cage requirements for the hospital were compared against the maximum lorry capacity (30 cages), based on an 18 tonne NHS Supply Chain lorry to determine the concepts practical feasibility.

5.3 Methodology

The MCC was evaluated quantitatively against a set of key performance metrics (fuel emissions, traffic volumes, journey distance and time) to determine its economic, environmental and social impacts; and qualitatively, through a set of interviews with key stakeholders (hospitals, suppliers, 3PLs and local authorities) to determine the industry-based perceptions of the concept.

5.3.1 Economic and Environmental Impact Assessment

A review of the literature highlighted a lack of clear methodologies for the appraisal of urban consolidation centres, identifying the individual characteristics and objective functions (e.g. economic, environmental, social and supply chain efficiency) of centres as key barriers to the development of a single evaluation process (Browne et al. 2005).

Huschebeck and Allen (2005) recommend detailed measurement of the flow of traffic and goods in the prospective location(s), followed by a period of consultation about the precise nature of the UCC scheme to be tested, and then an extended pilot that is managed and scrutinised by representatives from all the potential stakeholders (local authorities, logistics companies, retailers and other users).

MDS Transmodal Ltd and CTL (2012) identify three categories with which to appraise the impacts of UCCs: Network Impacts, Economic Impacts and Environmental Impacts, each of which can be quantified using key metrics, Table 5.1. In addition, social impacts can be included to consider abstract effects of metrics, such as changes in numbers of vehicles potentially reducing the number of road traffic accidents; and, reductions in noise, thereby reducing the impact of social disturbances (MDS Transmodal Ltd and CTL 2012).

Using the metrics provided in Table 5.1, Browne et al. (2005) suggested that certain key areas needed to be addressed when evaluating the effectiveness of UCCs:

i) A clear definition of the supply chain boundaries impacting on the UCC; and,
ii) The KPIs with which to measure success (vehicle utilisation rates, on-time deliveries, transport and handling costs, fuel consumption, emissions and congestion, VKms, vehicle trips and journey times.

Economic metrics, Table 5.1 can be sorted into benefits and costs accrued by the relevant stakeholders of the scheme, including: suppliers, transport providers, receivers, and local authorities, to generate a ‘Benefit-Cost’ Analysis (BCA) for the purposes of comparison (Browne et al. 2005).

Table 5.1 Metrics used to appraise the implementation of UCCs in the context of their positive or negative impacts on network infrastructure, economic industry factors and environmental factors such as air quality

Metric	**Impact**
Changes in the number of vehicle trips	Network, Economic
Changes in the number of vehicle kilometres	Network, Economic
Changes in the number of vehicles	Network, Economic
Changes in travel time	Network, Economic
Goods delivered per delivery point	Economic
Vehicle load factor	Network, Economic
Changes in parking time and frequency	Economic
Changes in total fuel consumed	Economic, Environmental
Changes in vehicle emissions	Environmental
Changes in operating costs (vehicle operation and per km)	Economic
Changes in noise pollution	Environmental
Changes in vehicle waiting time	Economic, Environmental
Sources: (Browne et al. 2005) and (Gazzard 2013)	

5.3.1 **Performance Indicators for the Assessment of Consolidation Centres**

Given the theoretical nature of the study and the data made available from the delivery and servicing survey, and TfL's main aims to reduce freight related traffic and emissions, the MCC was appraised using:

- Fuel emissions, Table 5.2, measured in Kg of CO_2 equivalents per km were allocated according to a vehicle's class (LGV or rigid HGV) and gross vehicle weight (GVW) (obtained via the DVLA registration plate database). This approach was selected to ensure consistency of the overall result as individual factors for kg of CO_2, CH_4 and N_2O are not issued for LGVs by DEFRA (Department for Environment, Food & Agriculture) and DECC (Department for Energy & Climate Change) methods (DEFRA et al. 2013b). Emissions factors were calculated using the emissions associated with a 1% fill-rate, multiplied up to match the recorded fill-rate (Table 5.2), in accordance with DEFRA guidance which states a linear relationship between fill rate and vehicle emissions (DEFRA et al. 2013a). If a fill rate was not recorded for a vehicle, the survey average (39%) was used. This correction was applied to 25% of the total survey population being assessed. Emissions for the consolidation centre HGV are assumed to be in accordance with an 18 tonne articulated lorry at 100% load factor;
- Traffic volumes to GOSH for the 2011 survey week; and,
- Journey distance and time, assessed using the shortest and quickest journey options, were calculated using ArcGIS Network Analysis Tool. As observed in Section 3.3.2 traffic patterns vary considerably by time of day, day of the week, an attempt was made to obtain data around the survey site during the survey, however this was unavailable. Further to this, owing to resource restrictions no traffic assessments were made on the surrounding network to determine what may be considered normal traffic volumes. Therefore, journey distance and time were calculated with the omission of time of day and day dependent. Journey origins and destinations were represented by the Eastings and Northings for all supply chain nodes using their respective postcodes to search the Ordnance Survey 'Code-Point' database for the correct Easting and Northing values.

Table 5.2 Fuel Emissions factors for LGVs and Rigid HGVs of various Gross Vehicle Weights (GVW) by percentage load factor [Source: (DEFRA 2009; DEFRA et al. 2013b)]

	100% Laden	**1% Laden**
GVW	***Kg CO_2e / km***	***Kg CO_2e / km***
LGV		
< 1.305 tonnes	0.153464	Note: emissions factors for LGVs are only given for 100% laden vehicles.
1.305 – 1.74 tonnes	0.226977	
1.75 – 3.5 tonnes	0.268817	
Rigid HGV		
> 3.5 – 7.5 tonnes	0.64201	0.0009418
> 7.5 tonnes – 17 tonnes	0.840441	0.0018504
> 17 tonnes	1.131033	0.003419

5.3.2 Scenario Testing for the Appraisal of the Proposed MCC Concept

In accordance with the guidance given by Browne et al. (2005), the analysis incorporated the greatest number of nodes possible, comprising: supplier to courier, to previous drop, to GOSH, to next drop, to courier, to supplier.

The following scenarios were tested to assess the performance of the MCC for GOSH:

1. Base Case assessment, Figure 5.8(1), to assess the impacts of the current model of operation including journeys from the supplier warehouse to the courier warehouse (supplier to courier), from the courier warehouse to the previous drop (courier to previous drop), onwards to GOSH (previous drop to GOSH), and then next drop after GOSH (next drop to GOSH), with the inclusion of the return journey

from the next drop to the courier warehouse (next drop to courier), and then then return journey from the courier to the supplier warehouse[10] (courier to supplier);

2. Base Case assessment without GOSH, Figure 5.8(2), to determine the impacts of GOSH on the current supply chain operations. The aim of this test was to quantify the additional vehicle-kms and subsequent emissions associated with the diversions necessary to include GOSH in the delivery route. The assessment was performed in recognition that if a consolidation centre for all goods to GOSH was implemented in isolation, suppliers are likely to continue making deliveries within the city for other customers;
3. Consolidation Case Scenarios, Figure 5.8(3), return journeys to the proposed consolidation centre for a range of scenarios ranging from one to four site operations. The supply chain for the purposes of this assessment includes return forwarding journeys from the consolidation centre to GOSH.

[10] It is recognised that courier vehicles may not perform dedicated journeys to a supplier from the receiving warehouse, with the nearest couriers performing the supplier to courier trip. This variable cannot be accurately quantified. Therefore return journeys are used. This factor is used for all scenarios.

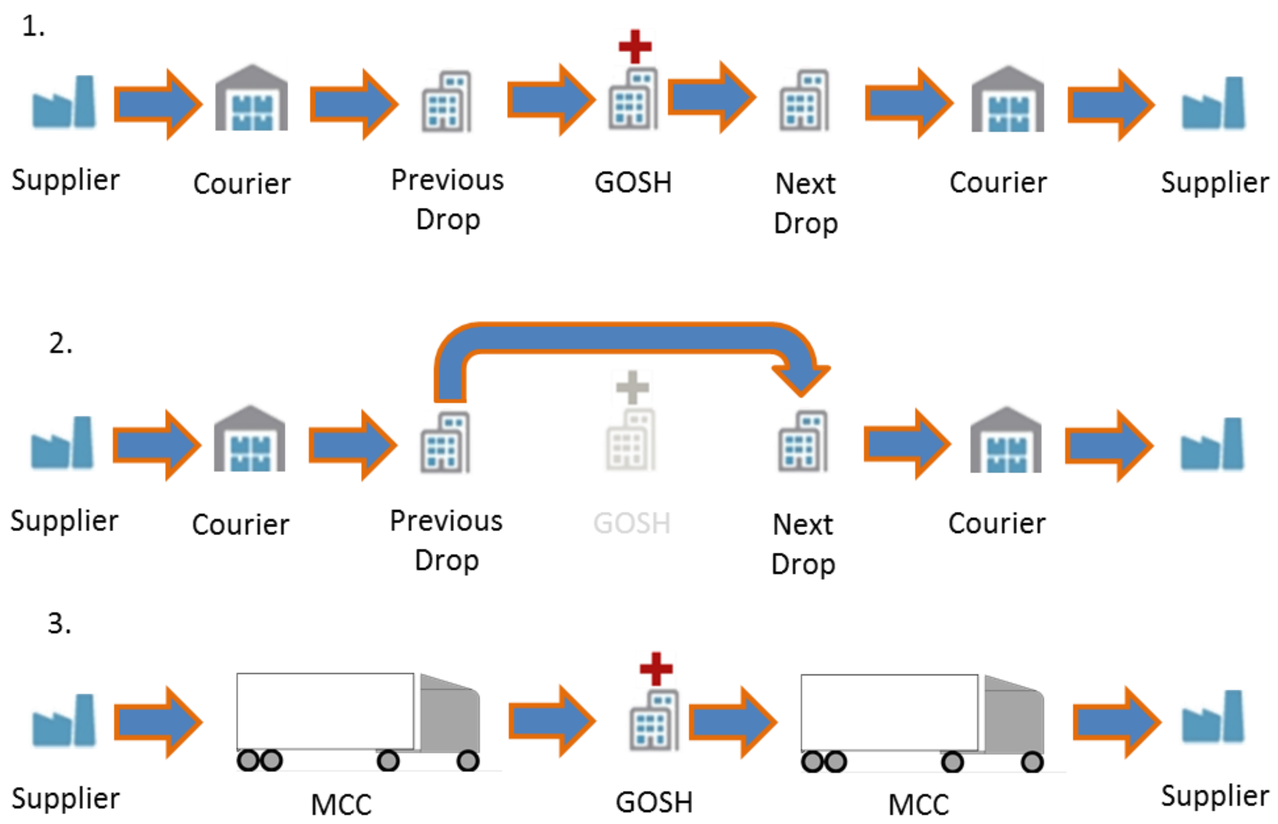


Figure 5.8 Illustration of the supply chains assessed for scenario: (1) Base Supply Chain with GOSH, (2) Base Supply Chain without GOSH, and (3) Proposed Supply Chain incorporating the Mobile Consolidation Centre (MCC) unit.

5.3.3 Determining consolidation Centre Locations

Prospective locations for the consolidation centre were determined using: a 'gravity model' approach provided by DPS Logix to assess the most central location to site a depot in relation to the nationwide distribution of suppliers, a commonly used tool within the logistics industry (Bosona 2013); and, a database of 775 suppliers of goods to GOSH grouped over a 10-year period. This approach assessed the distance of 775 suppliers to GOSH, and their distribution nationwide, indicating a location central to the suppliers. Assessment of the database indicated a large concentration within the M25, Oxford, Cambridge, Birmingham, Liverpool and Manchester, Figure 5.9. The final location for the centre was used to provide an area near to which a consolidation centre site may be chosen based on the appropriate road network (i.e. avoiding B-roads).

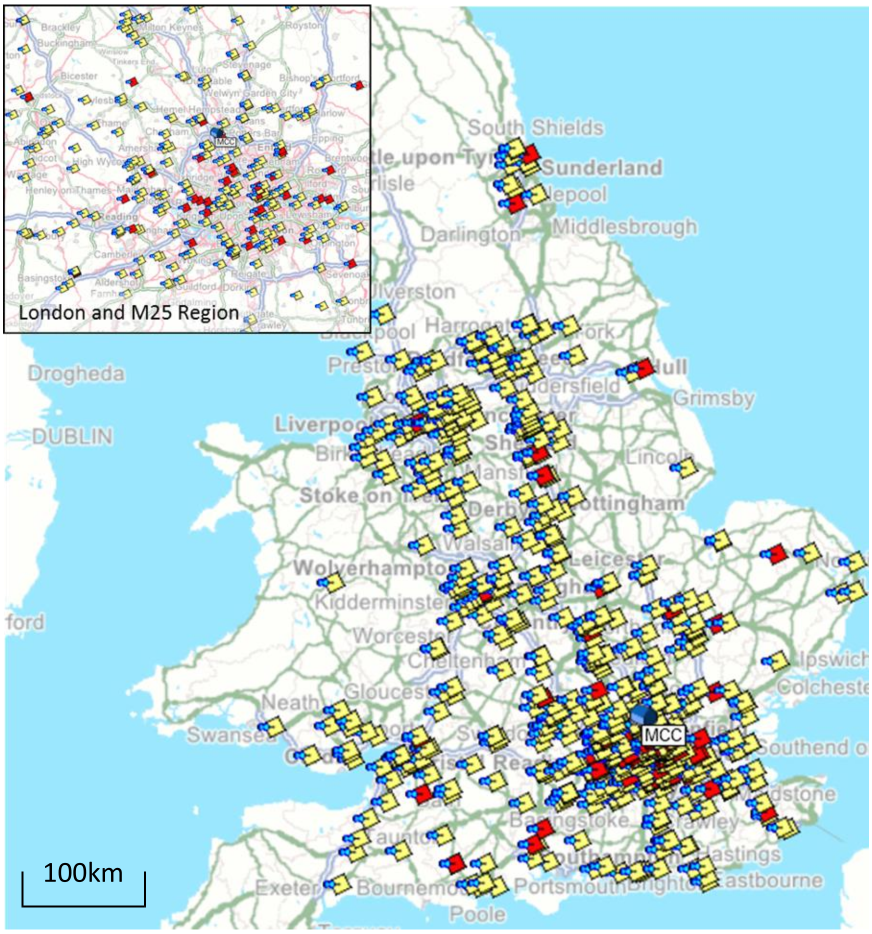


Figure 5.9 UK-wide distribution of suppliers for GOSH [red pins indicate the presence of multiple suppliers within the same location]

Following on from this analysis, the exact location of the depot was varied for the following operating scenarios:

1. Locating the MCC within the parking facilities of an NHS Trust outside central London, at northern, eastern, southern and western locations, and the availability of parking space for the MCC unit; and,
2. Locating the MCC at a dedicated parking facility outside of central London, near existing large logistics and distribution operations, at northern, eastern, southern and western locations. Selection of the eastern, southern and western sites is based on availability of parking space for the MCC unit, proximity of site to buildings infrastructure to provide wired electrical and communications services, as required by the TNT Mobile Depot demonstration (STRAIGHTSOL 2014b).
3. Selection of the best performing northern, eastern, southern and western MCC options from 1 and 2 according to the lowest number of vehicle-kms and emissions generated, with analysis of combined scenarios for a time variable depot location, varying between 1 and 4 sites, assuming suppliers and couriers will make deliveries to the closest respective north, east, south and west London locations.

Each hospital-based depot location was selected according to an assessment of the available parking facilities using map and satellite data to: measure the space available for the unit, assess their central location within each respective geographical focus (i.e. northern, eastern, southern and western London), and the ease of access to major trunk routes. Dedicated parking sites were selected based on established logistics depots in the area.

In addition to the analysis of consolidation for GOSH, a London-wide scenario was tested using 29 NHS Trusts, situated within the north and south circular ring roads of London, Figure 5.10. As indicated in Table 5.3 a number of Trusts included in the assessment belong to NHS Foundation Trusts whereby all ordering and procurement is consolidated and managed by a single department. To reflect this, deliveries to all hospitals assigned to a Foundation Trust are made by suppliers in a round (generated by the TSP model, specified in Section 4.2), with each supplier making a single journey into the city and delivering to each member of a Foundation Trust during the same visit.

In order to accurately assess the traffic and emissions for each hospital and NHS Foundation Trust, the vehicles for each supplier from the GOSH dataset were adjusted according to an uplift factor, Appendix C. The uplift factors were derived from the difference in annual product order volumes for NHS Supply Chain deliveries between GOSH and each hospital and NHS Foundation Trust, Table 5.3. This factor was applied to the fill rate of each vehicle from the GOSH dataset to provide the number of vehicles required to fulfil the order volumes. If the requirement of the vehicle exceeded the size of the surveyed vehicle size, the subsequent larger vehicle was selected until all orders could be accommodated within a single vehicle. The emissions factors for each uplifted vehicle were taken from those provided by DEFRA, Table 5.2.

As discussed in Section 5.2, the MCC lends itself to two main London-wide operating scenarios: MCC units dedicated to each major NHS hospital Trust or Foundation Trust, which can be relocated at different periods of the day to improve accessibility for suppliers travelling from different directions; and, fixed-MCC units assigned to groups of suppliers.

Table 5.3 List of hospitals and Trusts included in the London-wide assessment for the proposed MCC and uplift factors calculated according to the proportion of annual orders compared against the annual orders made by GOSH

NHS Foundation Trust	Hospital	Order Quant[11]	Uplift Factor
	Great Ormond Street Hospital	**10,503**	**1**
	King's College Hospital NHS Foundation Trust Saint Pancras Hospital University College Hospital	38,155 1,699 24,414	4 1 3
Guy's and St Thomas' NHS Foundation Trust	Guy's Hospital, St Thomas' Hospital, Moorefields Eye Hospital	74,431	8
The Whittington NHS Trust	The Whittington Hospital, NHS Islington, NHS Haringey	8,126	1
East London NHS Foundation Trust	Mile End Hospital, Newham University Hospital, The London Chest Hospital, The Royal London Hospital, St Bartholomew's Hospital, Whipps Cross University Hospital	43,573	5
	Royal Free Hospital	10,523	52
Lewisham and Greenwich NHS Trust	Lewisham Hospital, Queen Elizabeth Hospital	17,588	2
	Homerton University Hospital Chelsea and Westminster Hospital North Middlesex University Hospital	6,385 10,793 8,792	1 2 1
The North West London Hospitals	Northwick Park Hospital, St Mark's Hospital, Central Middlesex Hospital	15,815	2
Imperial College Healthcare NHS Trust	Charing Cross Hospital, Hammersmith Hospital, Queen Charlotte's & Chelsea Hospital, St Mary's Hospital, Western Eye Hospital	31,388	3

[11] Annual orders of a specific product by whatever product quantity they order it in. e.g. a single item order may comprise multiples of 10, 100 and in some cases 1,000 items of a product line.

1. North Middlesex University Hospital
2. St Ann's Hospital
3. Whipps Cross University Hospital
4. The Whittington Hospital
5. Royal Free Hospital
6. Central Middlesex Hospital
7. Hammersmith Hospital
8. Hospital of Saint John and Saint Elizabeth
9. The Wellington Hospital
10. St Mary's Hospital
11. Saint Pancras Hospital
12. Homerton University Hospital
13. University College Hospital
14. Great Ormond Street Hospital
15. Saint Bartholomew's Hospital
16. Moorfields Eye Hospital
17. London Chest Hospital
18. The Royal London Hospital
19. Mile End Hospital
20. Saint Clement's Hospital
21. Newham General Hospital
22. London Bridge Hospital
23. Guy's Hospital
24. St Thomas Hospital
25. Charing Cross Hospital
26. Chelsea and Westminster Hospital
27. King's College Hospital
28. University Hospital Lewisham
29. Queen Elizabeth Hospital

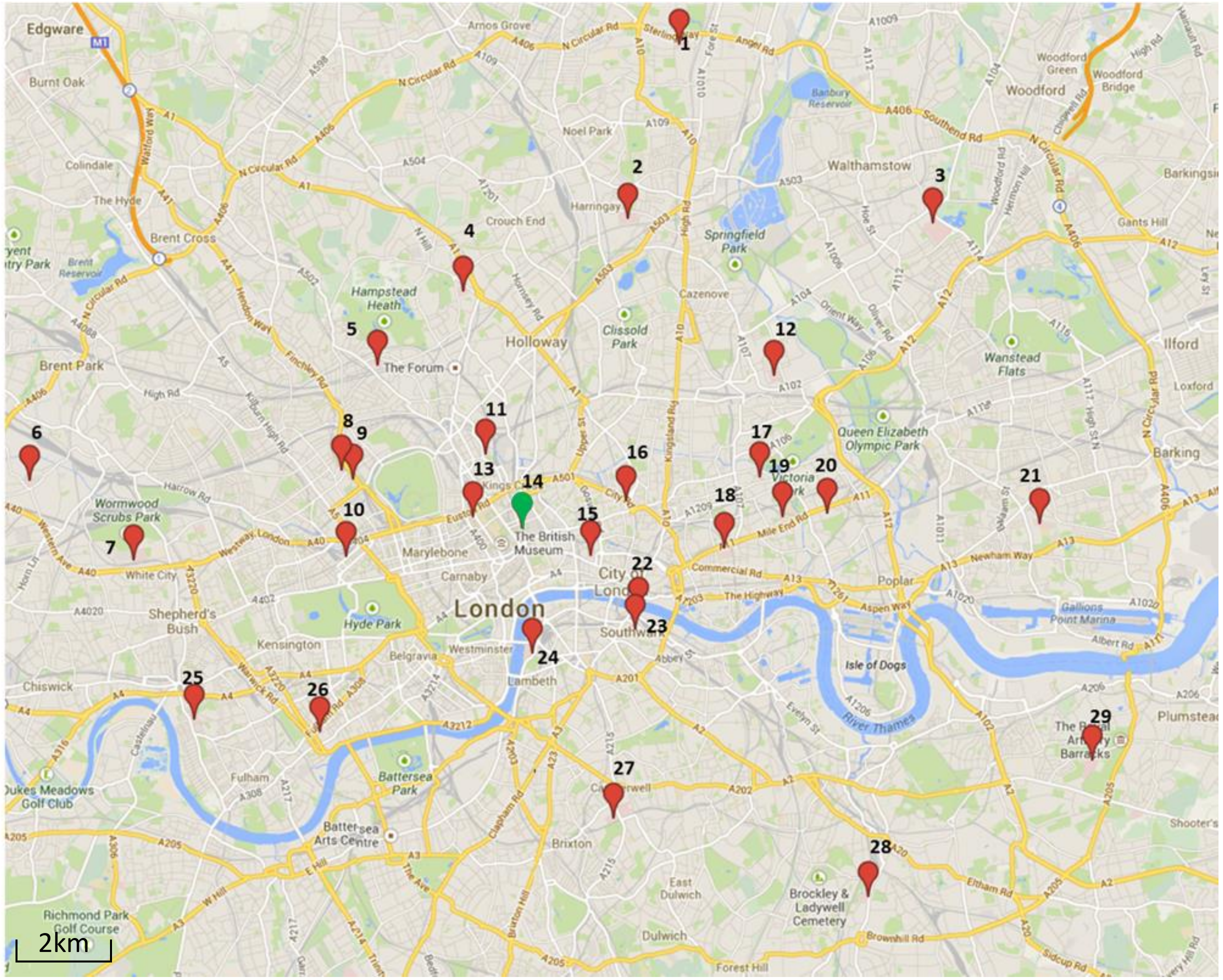


Figure 5.10 London-wide hospital locations [GOSH – highlighted in green]

To provide a measure for the performance of each operating scenario a base case scenario for London-wide NHS Hospitals and Foundation Trusts was assessed:

1) Base case: owing to a lack of data, the supply chain for the base case scenario was limited to return journeys from supplier to courier, to hospital / NHS Foundation Trusts. Of the 29 Trusts, 22 belong to NHS Foundation Trusts. Where hospitals belong to a Foundation Trust, each supplier was assumed to make one trip into the city and perform a round to each member Trust to complete their deliveries, Figure 5.11(1);
2) Consolidation Case A: the best performing north and south MCC sites, established in the GOSH MCC operating scenario were used for the assessment of a 1 and 2 site London-wide operating scenario. Consolidation Case A comprised of dedicated MCC units for each hospital/ foundation Trust, Figure 5.11(2);
3) Consolidation Case B: based on the same siting assumptions as Consolidation Case A, it tested an MCC unit for each supplier group, with suppliers using the MCC unit closest to their origin, Figure 5.11(3). For this scenario the MCC performed a delivery round to all 31 hospitals within London.

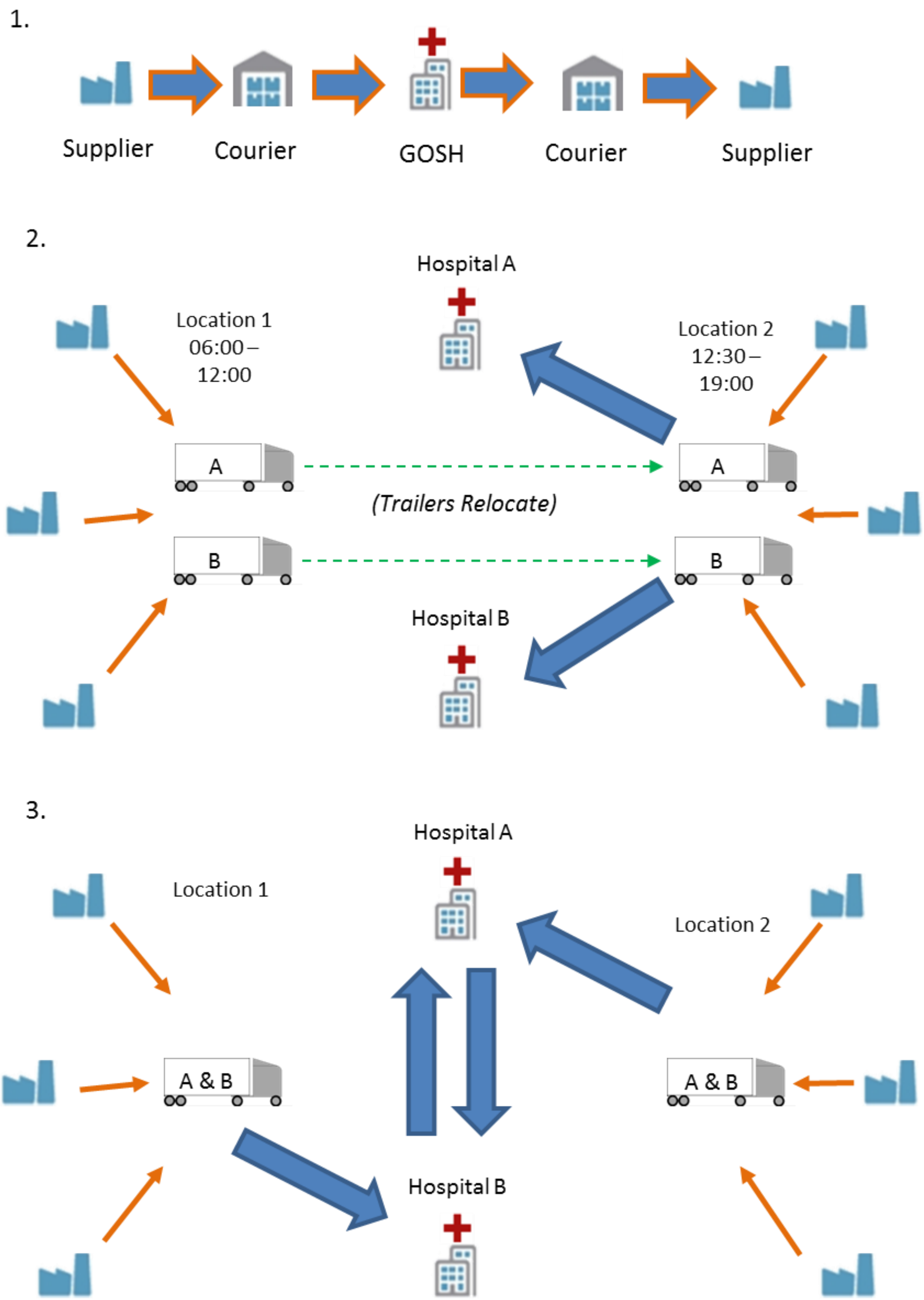


Figure 5.11 Illustration of supply chains for the London-wide scenario: (1) Base Case comprising full supply chains for each of the 29 Hospital Trusts, (2) Consolidated supply chain with a Mobile Consolidation Centre (MCC) assigned to each hospital trust, and (3) Consolidated supply chain with an MCC assigned to each supplier group.

5.3.4 Qualitative Assessment of the MCC

A qualitative assessment was conducted using one-to-one interviews with 14 healthcare industry professionals including: hospital supply chain and sustainability directors, major UK healthcare suppliers, third-party logistics providers, members of local government and the UK Department of Health. During interviews, participants were presented with the concept and its proposed functionality, as described in Figure 5.2 and Section 5.2. They were then asked to provide feedback to questions covering the technical and practical feasibility of the concept, and the policy issues which may positively and negatively affect implementation of the proposed concept, Appendix D.

5.4 TSP Model Validation

As described in Chapter 4, the Travelling Salesperson problem is a heuristic modelling approach, whereby the process of mutation iterates through the potential combinations and permutations for a solution (i.e. the order in which all destinations on a given route are visited) to search for the globally optimal result, yielding the shortest distance travelled. Owing to the nature of mutation, whereby a solution is progressively improved upon by changing one or two characteristics, it is possible for a solution to become trapped within a locally optimal range of potential solutions. This can result in the algorithm mutating the solution to a point at which the range of possible mutations cannot produce the global optimum. As explained in Chapter 4, the 'Swap Cities' function in the TSP to some extent mitigates the potential for the model to settle upon a local optimum as a final solution. However, there are a number of tests which can be performed to contextualise how optimal a final solution is within the available combinations of a given problem. This process comprises the establishment of a number of mutations and starting points required to produce the most optimally achievable result within the time constraints of this research.

5.4.1 Validation of Mutations

Owing to the Swap Cities Function which destroys part of the 'winning' sequence, there is expected to be less dominance in the number of mutations required to converge on an optimal result as each time the algorithm cannot find an improvement on a solution, part of the winning solution is destroyed, making for a broader range of permutations available from a single starting point (Mallampati et al. 1991). This trend is demonstrated in Figure 5.12, where runs of 30 destinations (29 hospital destinations and 1 MCC location = 2.652528598 x 10^{32} potential permutations[12]) for the MCC have been used. Results from these tests indicated that the number of mutations have little impact on the optimal result achieved (i.e. the shortest tour which includes a visit to each of the 30 destinations), with significant variability in the end result for each run of mutations.

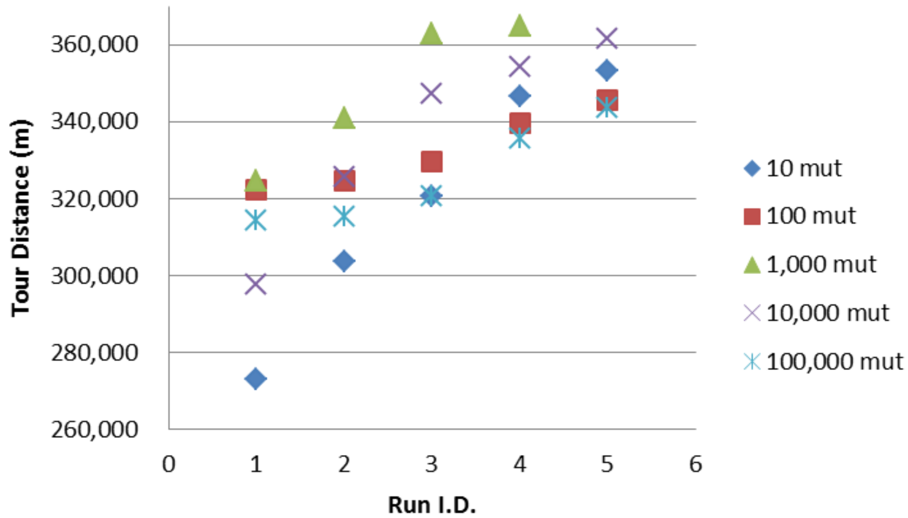


Figure 5.12 Validation for the quantity of mutations using a route comprising 30 destinations [Each Run I.D. represents a different starting point for each mutation scenario]

[12] Number of permutations (without repetition) = [n! ÷ (n-r)!], wherein all 30 (n = 30) destinations have to be selected once (r = 30) and the order in which they are selected is important Johnson, R. A. and G. K. Bhattacharyya (2001). Appendix A2: Rules for Counting. Statistics: Principles and Methods. Quebecor USA, John Wiley & Sons, Inc.: 660 - 662.

Therefore, with these findings, Figure 5.12, the algorithm was run with 10 mutations for each starting point (a randomly selected destination from the 30 destinations to be visited), which incidentally yielded the lowest average result (319,422 metres total round distance for the MCC to complete the deliveries to all 30 hospitals) during validation tests.

5.4.2 **Validation of Starting Points**

To test the appropriate number of starting points for the algorithm, simulations were run with 1000 randomly generated starting points, each mutating 10 times, Figure 5.13. Results from this process indicated that a result close to the most optimal route (shortest overall route) returned may be achieved in 8 out of 10 simulations.

However, closer analysis of the results, Figure 5.13 (inset), indicated a 134,860 VKm difference between the beginning of the plateau at run 180, Figure 5.13, and the most optimal result achieved (272,420 VKm). Further break down of these results indicated that:

- 4.8% of the results provide a solution below 300,000 VKm; and,
- 57.9% of the runs produce a solution below 400,000 VKm.

Therefore, for the purposes of this analysis a model comprising 1,000 starting points and 25 mutations is used to maximise the chances of identifying the most optimal solution achieved in tests.

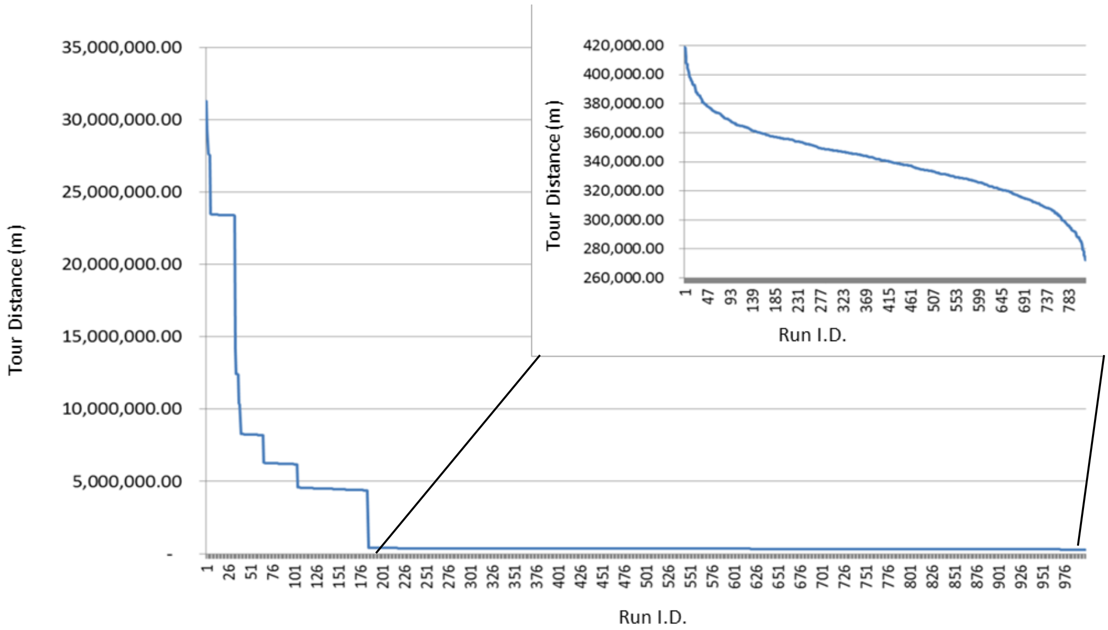


Figure 5.13 Validation for the quantity of starting points against the total tour distance, running 1,000 different simulations (each comprising 10 mutations, beginning from randomised starting points

5.5 Results

5.5.1 Feasibility Testing for the Proposed MCC Unit

Results from the cage survey, Table 5.4, indicated that a maximum of 30 cages (measuring 83 x 167 x 72 cm, [L x H x W]) were filled on any given day. Extrapolation of these results to an annual profile suggested 42.6 cages will be filled during the busiest day of the year, Figure 5.14. Further analysis shows that the busiest day of the year coincides with the busiest week of the year, with a total of 128.41 cages being filled during the week.

These results indicated that the daily maximum exceeds the capacity of a single proposed trailer. However, if demand smoothing practices (equal distribution of weekly demand across 5 days), used in vendor managed inventory partnerships and as part of NHS Supply Chain procurement strategies (Angulo et al. 2004; Pipe-Wolferstan 2013), were implemented to maximise fill-rates and evenly distribute the weekly total of cages across 5 days, the daily demand for the busiest week is reduced to 25.68 cages per day, thereby making the operation of the concept within a single unit feasible.

Table 5.4 Results indicating the number of cages of goods delivered to each department at GOSH during a 5-day week

	CBL,Cardiac Wing	**Southwood Blg**	**York House**	**Main Nurses Home**	**VCB Wards Frontage Blg**	**VCB Theatres**	**Octav Botnar Wing**	**Morgan Stanley Clinical Building**	**Total**
Monday	1.5	1	0	0	4.5	1.5	0.5	0	9
Tuesday	3	5	3.5	1	5.5	7	1.5	5.5	32
Wednesday	2	3	2	1.5	2	1	2	2	15.5
Thursday	3	3	2.5	1.5	3	4.5	1	5.5	24
Friday	3	1	1.5	1.5	4	1	2.5	1.5	16
Total	12.5	13	9.5	5.5	19	15	7.5	14.5	96.5
Average	2.5	2.6	1.9	1.1	3.8	3	1.5	2.9	

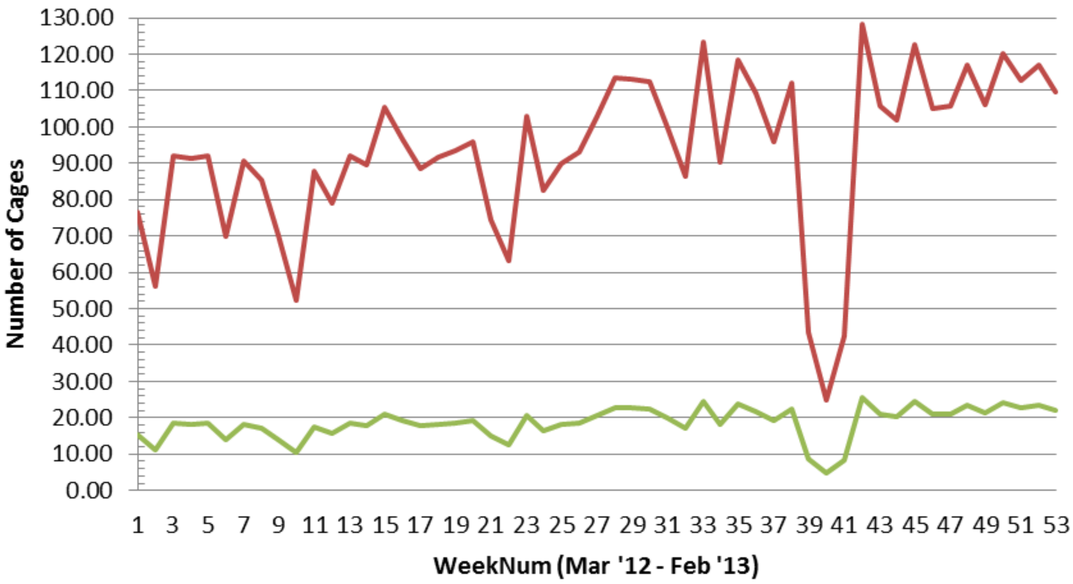


Figure 5.14 Relationship between the variation in cage numbers according to week of the year [weekly total demand (red), weekly daily average (green)]. Number of cages are uplifted from the 5-day survey according to an annual record of weekly orders by volume

5.5.2 **Siting the Mobile Consolidation Centre**

Analysis of the gravity model using the 775 suppliers for GOSH, Figure 5.15 indicated the 'ideal' location for the MCC being situated near junction 21 of the M25(A). Distances for each location in relation to GOSH are provided in Table 5.5.

An assessment of the hospitals with large parking facilities within the M25 near the 'ideal' locations for the MCC, indicated that Watford General (B) and Barnet and Chase Farm Hospital (C) present potentially suitable northern locations for the MCC. The Park Royal Industrial Estate (D) situated in north-west London, which represents one of the major logistics hubs for the current NHS Supply Chain operations, was identified as a suitable dedicated logistics facility.

Additional western, eastern and southern locations for hospital and dedicated logistics facilities assessments were also selected, to test a range of scenarios from one to four site models of operation:

- West: Grant Way, Syon Lane (E), West Middlesex University Hospital (F);
- East: Beckton Triangle Retail Park (H), Queen Elizabeth Hospital (I); and,
- South: St Georges Hospital (J) and Beddington Cross Industrial Area (K).

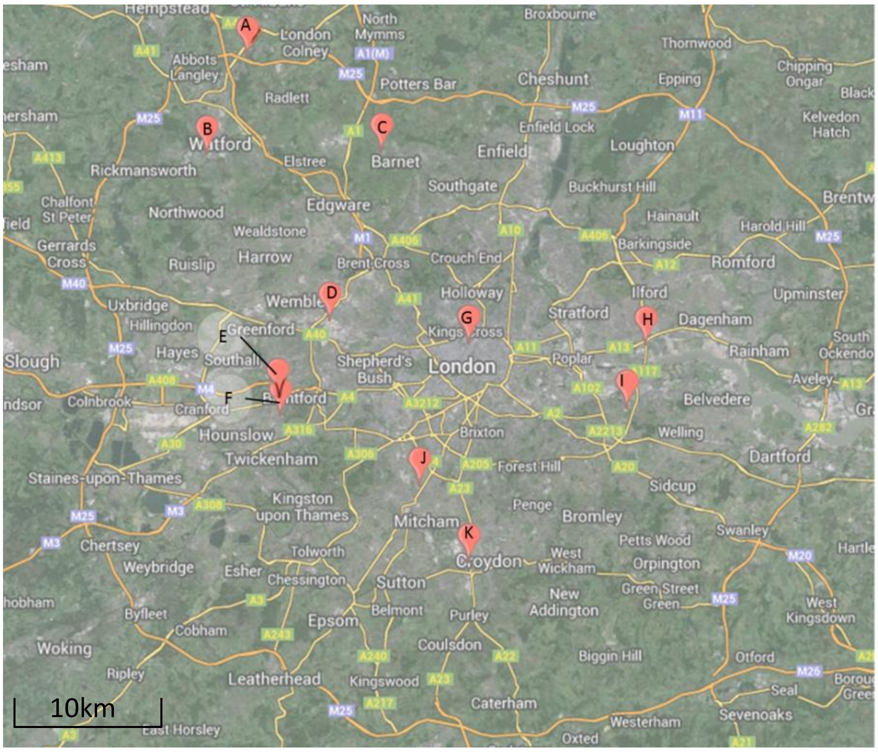


Figure 5.15 Suggested locations for the MCC [GOSH = G]

Table 5.5 Distances of prospective consolidation sites to GOSH

Consolidation Site	Distance to GOSH (km)
Watford General hospital (B)	27.57
Barnet and Chase Farm hospital (C)	18.06
DHL Park Royal (D)	13.27
Beckton Triangle Retail Park (H)	14.84
Queen Elizabeth Hospital (I)	14.76
West Middlesex University Hospital (F)	16.23
Grant Way, Syon Lane, Isleworth (E)	16.41
St Georges Hospital (J)	12.53
Beddington Cross Industrial Area (K)	18.00

5.5.3 **Performance Analysis for a GOSH Dedicated MCC Unit**

Results of the Depot Selection Assessment

Assessment of the proposed MCC sites indicated that for a supply chain where deliveries are made direct from the supplier to the MCC unit, the following locations provide the greatest total VKm and journey time savings for each region, in ascending order, Table 5.6:

- North London, Watford General;
- West London, Grant Way, Syon Lane, Isleworth;
- South London, St Georges Hospital; and,
- East London, Beckton Triangle Retail Park.

Table 5.6 MCC site selection analysis according to the least VKms generated by MCC depot locations

Geographical Region	MCC Location	VKms travelled	Journey Time (hrs)
North London	Watford General	15,689	344.80
	Barnet and Chase Hospital	15,793	336.34
	Park Royal	16,047	342.84
South London	St Georges Hospital	17,319	345.60
	Beddington Cross Industrial Area	18,285	372.38
East London	Beckton Triangle Retail Park	17,854	349.50
	Queen Elizabeth Hospital	18,082	356.90
West London	West Middlesex University Hospital	16,418	340.53
	Grant Way, Syon Lane, Isleworth	16,389	338.94

The order of each geographical location reflects the distribution of suppliers, whereby the proposed location providing the greatest VKm travelled and journey time savings is located within north-west London; followed by a western, southern and then eastern location. These results were used to inform the remainder of the analysis, whereby a:

- 1 site MCC scenario operated from Watford General;
- 2 site MCC scenario operated from Watford General and Isleworth;
- 3 site MCC scenario operated from Watford General, Isleworth and St Georges Hospital; and,
- 4 site MCC scenario operated from Watford General, Isleworth, St Georges Hospital and Beckton Triangle Retail Park.

Results for the GOSH Dedicated MCC Performance Analysis

Results for the assessment identifying the impacts of GOSH on the performance of the existing supply chain (Table 5.7) indicated a minimal reduction of 2%, 1% and 3% in total VKm, Journey time and emissions, respectively, when GOSH is removed from the supply chain. Thereby suggesting that the diversion required for deliveries to GOSH between the previous drop and next drop locations are minimal. Therefore, assuming that only goods for GOSH are consolidated, an increase in the overall total VKm, journey time and emissions generated by the remaining supply chain activities (Base without GOSH) and the new consolidated supply chain for GOSH, may be observed.

Assessment for the consolidation scenarios (1–4 sites), Figure 5.16, indicated significant decreases in the total VKm, journey time hours and emissions are achieved, with further decreases observed with an increase in the number of consolidation centre sites.

A 40% decrease in the total number of VKms is observed between the Base with GOSH and the single site operating scenario. The greatest decrease in VKms between the four operating scenarios is observed between the single site and two site scenarios where an additional 7% decrease is achieved. Observations for the two site scenario against the three and four site scenarios indicated a further 2% reduction in VKms with each the addition of each subsequent consolidation centre site.

Table 5.7 Results for the GOSH only MCC scenario assessment

Scenario	Assessment Route[13]	Total Distance (km)	Total Time (hrs)	CO_2e (tonnes)
Base with GOSH	Supplier to Courier to Previous Drop to Next Drop (Return)	26,262	526.55	5.38
Base without GOSH	Supplier to Courier to Previous Drop to GOSH to Next Drop (Return)	25,670	523.40	5.24
Single Site	Supplier to Consolidation Centre to GOSH (Return)	15,670.02	344.46	3.38
Two Site		14,607.42	345.02	3.15
Three Site		14,305.32	305.88	3.08
Four Site		14,088.63	301.50	3.05

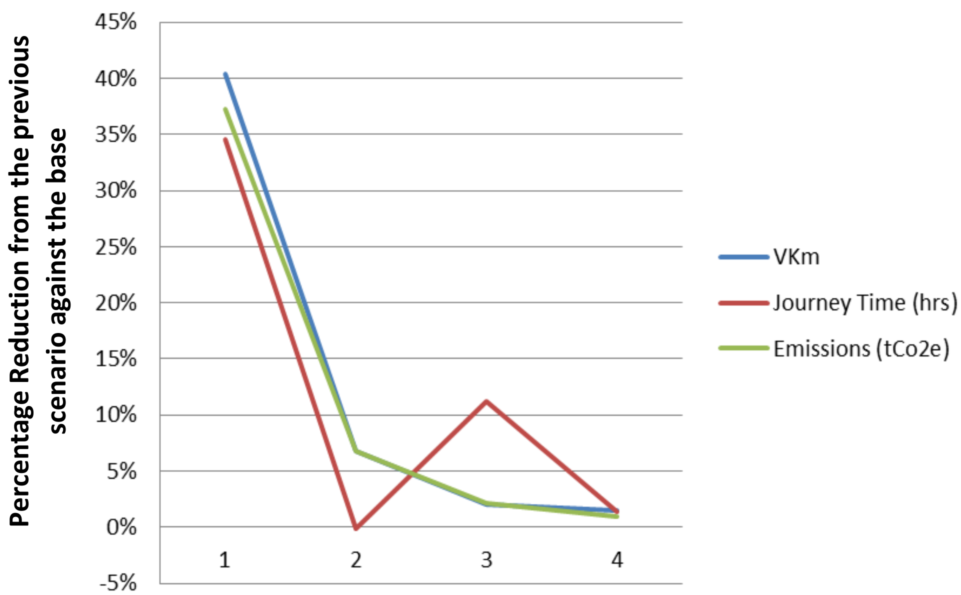


Figure 5.16 Assessment of multiple consolidation sites, against the previous scenario (i.e. x-axis denotes the number of MCC trailers implemented in the scenario)

[13] As explained in Figure 5.7

Significant reductions of 35% and 37% for journey time and emissions, respectively are achieved between the base with GOSH and a single site consolidation centre option. The decreases in emissions of 7%, 2% and 1% gained with the addition of each site are in accordance with the trends observed for reductions in VKms. This is to be expected as vehicle emissions are derived from the VKm accrued, multiplied by the kg of CO_2e generated per VKm-travelled.

Further analysis of journey time results indicated an increase in total journey time of 0.16% between the single and two site consolidation centre operating scenarios. Whilst this increase may be considered negligible, it may be attributed to insufficient gains in journey time savings for suppliers travelling to their nearest centres being achieved to offset the time required to move the MCC unit to a second location. Analysis of the three site operating scenario shows an additional 11% reduction in journey time hours against the single site scenario. The addition of a fourth site provides minimal additional reductions (1%) from the three site operating scenario.

The results for the consolidation of GOSH supply indicated that there could be reductions in VKm, journey time and emissions may be achieved for a single site operating scenario. However, it may be considered that implementation of more than two sites is unnecessary given the minimal reductions that may be achieved.

5.5.4 **Performance Analysis for a London Wide Implemented MCC Scenario**

Assessment of the base scenario, Table 5.8, indicated that for 29 Trusts, a total of 261,805 VKm, 4,807 Journey Time hours, and 226.08 tonnes of CO_2e are generated by 1,372 vehicle trips with an average gross vehicle weight of 7 tonnes, for the uplifted survey week from the 2011 Delivery and Servicing survey.

Analysis of the London-wide scenario, assuming the same suppliers for each hospital travel from the same point of origin and with MCC units allocated per hospital, Table 5.8, indicated reductions in VKm of 16% - 25% between the 1 site and 4 site scenarios, against the base; and, reductions in the total emissions (CO_2e) between 37% and 40%.

Whilst an overall decrease in emissions against the base is observed, Table 5.8, increases in emissions are observed for 2 to 4 site operations against the single site scenario. These observed increases may be ascribed to the movement of the MCC units to different locations, since the distance, time and emissions accrued by suppliers making deliveries to the MCC are likely to have decreased. This may be corroborated by the distribution of suppliers within London, Figure 5.9, which indicated a small number of suppliers, relative to the entire population being located closer to GOSH than one of the four proposed MCC sites.

Analysis of the total journey time hours for each of the four scenarios indicated a negligible increase from the base, for one and two site operations of .007% and .008% respectively; and, a decrease observed for three (10.7%) and four (12%) site operations. This increase may be attributed to insufficient time savings for supplier journeys to compensate for the additional time accrued by the movement of the MCC unit.

Table 5.8 London-Wide MCC assessment results

Scenario	Route	Total Distance (km)	Total Time (hrs)	CO_2e (tonnes)
London Wide Base	Supplier to Courier to Hospital (Return)	261,805.16	4,807.97	226.08
London Wide (MCC Per Hospital)				
1 Site	Supplier to Consolidation Centre to GOSH (Return)	220,294	4,841.81	135.25
2 Sites		205,390	4,848.28	142.95
3 Sites		200,780	4,292.37	140.00
4 Sites		197,601	4,228.11	137.67
London-Wide (MCC Per Supplier Group)				
4 Sites	Supplier to Consolidation Centre to GOSH (Return)	236,621.03	5,176.70	165.04

Assessment of the London-wide scenario with MCC units allocated to supplier groups, i.e. suppliers making deliveries to their nearest centres, indicated overall reductions of 10% and 27% in VKm, and Tonnes of CO_2e, respectively. However an increase of 9.2% is observed in the overall journey time accrued, against the base. Comparisons of the 4 site scenarios for an MCC unit per hospital, against MCC units allocated per supplier group, indicated a 22.4% increase in journey time, and a 19.7% and 19.9% increase in the total VKm and emissions accrued compared against the scenario whereby an MCC unit is assigned per hospital.

5.5.5 **Economic Impact**

An economic assessment of the proposed concept, Appendix E indicated the total annual costs of the GOSH only site to range between £95,342 and £99,391 for 1 site and 4 site operations, respectively. Analysis of the London-wide assessments operating across 4 sites indicated annual costs of £446,662 for the operation of MCC units per hospital, and £444,130 when MCC units are allocated per supplier group.

Whilst the operating costs of the existing model of operation cannot be accurately determined. The economic impact assessment conducted for the TNT Mobile Depot indicated that operation of the model accrued approximately twice the costs of the existing delivery operations by vans, owing to additional warehouse, infrastructure costs, depreciation and cleaning of the depot, as well as the rental cost for the parking location (Verlinde et al. 2014).

The capital costs of the trailer have not been included in this economic assessment given they may be considered highly variable ranging between several £10,000 to a couple £100,000, according to:

- Type / condition of materials e.g. using a second hand trailer / chassis to construct the unit;
- Layout of the unit, e.g. a standard trailer or one such as the TNT Mobile Depot which includes an office which meets health and safety requirements;
- The number of mobile centres; and,
- The size of the trailer

(Kok 2015).

5.5.6 **Qualitative Results**

Participants of the interview process, including representatives of: healthcare goods suppliers (Intersurgical, NHS Supply Chain and Bunzl), providers (GOSH and Guy's and St Thomas' NHS Foundation Trust), local authorities (TfL and Southampton City Council), and 3PL's (TNT, DHL and Meachers), were presented with a series of questions, Appendix D, addressing the technical feasibility of the concept and how it may impact internal and external supply chain operations and processes, as well as policy issues which may affect the implementation of the proposed concept. The results of these questions are provided below.

General Feedback

Feedback from suppliers indicated the potential loss of contact with customers to be a negative characteristic of participation in a consolidation concept, since they can gain additional business from hospitals through driver interactions with hospital supply chain personnel. Conversely, hospitals suggested that the reduced contact with suppliers would act to reduce otherwise uncontrolled additional business generated by such practices, thereby improving the scope to manage procurement activities.

Technical Feasibility

The main concerns raised by participants were towards liabilities of items being delivered into the MCC, i.e. who was responsible for the items and at what point the responsibility was transferred to another party. Whilst it was proposed that the transfer of liabilities would occur at the point of electronic proof of delivery once an item had been scanned and deposited, hospital representatives queried the lack of quality assurance (QA) for the condition of the items as a result of the unattended delivery process. Typically, hospitals perform random checks of items being delivered to confirm the contents and condition, with some hospitals comprehensively checking all items being processed through the receipts and distribution department. However, due to the automation of the proposed MCC, no such checks can take place at the point of transfer. This may lead to an increase in the number of items unfit for purpose arriving at ward level, which could potentially lead to critical stock-out scenarios.

Whilst this issue is particularly pertinent with regards to patient care, it raises significant issues with regards to the return of damaged items and the ability to confirm the point at which it became damaged. Such issues would require policy agreements and legislation to be established regarding the condition of items when delivered to the MCC. It is common practice amongst logistics providers to employ agency drivers to cover periods during which full-time staff members are on sick/annual- leave. Therefore, during such periods, agency drivers making deliveries to the MCC may be unfamiliar with the unit and the processes of depositing items, leading to the deposit of items into the incorrect locations. Further concerns were raised by suppliers regarding the deposit of items into the correct location, and the accommodation of mis-picked / short-picked orders (fewer items delivered than ordered due to low stock at supplier warehouses). However, whilst there are no formal records of mis-picked and short-picked items at GOSH, their occurrence is considered to be minimal by supply chain staff at the Trust (Fry et al. 2012). In addition to this, when picks for items in consignments are being made at suppliers warehouses, it is recognised that the incorrect item may be picked, or that the order quantity may not be fulfilled. Under such circumstances the weight of the items being deposited may not match up against what the unit is expecting, thereby leading to an unconfirmed delivery of a consignment that has been delivered. Should such issues occur, owing to the automation of the concept, they may go unnoticed until the items arrive at the ward, or under a multiple hospital operating scenario, the incorrect hospital Trust. This would result in a complex process of relocating items to their correct destination / placing queries with suppliers to rectify mis-picks / short-picks.

Such issues may be mitigated by the use of advanced delivery notices to be scanned to inform the systems on the trailer of mis-picks / short-picks. Across the interviewees, there was a general consensus that quality assurance checks would be important and that it would be more appropriate to staff the facility.

All participants commented on the variability of products packaging according to the demand within the healthcare supply chain, for example the volume and size of goods can differ significantly between one and two lorry loads with regards to bulk items such as gloves, bandages and pulp moulded bowls (e.g. kidney dishes). Such variation would likely put the MCC over-capacity from a single delivery. Furthermore, due to the bulk of some orders (e.g. a pallet of polythene medical aprons may weigh in excess of 500kg, and sharps bins, bins for depositing used needles and syringes, may be delivered in boxes of 30, on pallets) direct delivery to the hospital where they can be receipted and broken down into separate consignments for each ward is considered more appropriate. Therefore, participants agreed that the trailer would be better suited to product based MCCs to which specific smaller, high value medical consumables are delivered, which it was suggested may also mitigate the need for back-hauling larger bulk items back up the supply chain through the MCC.

Finally, all participants queried the practicality of occupying hospital parking spaces for a unit located within the grounds of a hospital, owing to the loss of parking revenue and unwanted increases in traffic volumes to hospital sites. Therefore, the situation of the MCC within a dedicated logistics / stabling facility may be considered more appropriate.

Operational Feasibility

The MCC was perceived to deliver positive benefits to the internal distribution of goods within hospitals with, the direct shipping of items to wards from the lorry expected to reduce the time spent processing receipts, as well as the opportunity for items to become lost / delayed within the hospital. In order to accommodate the alteration in delivery time a small negative impact was expected with regards to the impact of increased delivery volumes on night time support work, potentially requiring additional materials management staff / night porters to be employed. However, the shift in delivery patterns from day-time to night-time are not expected to have an adverse effect on clinical services within wards since their demand is planned in advance, therefore their product requirements should be met by the previous night's deliveries.
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Both hospitals and suppliers expressed concerns over the integration of supplier and hospital systems with the concept. From the supplier perspective this focussed on the issue that some suppliers do not capture volumetric data for their products, required to use the MCC, therefore resulting in a hidden cost to participation in the scheme.

Suppliers highlighted issues regarding the education of drivers for participation in a variable location depot i.e. where the depot will be located at a given time should their delivery route change or be delayed, which would likely make the operation of booked delivery windows at the unit impractical; therefore necessitating an open window policy. Further to this, whilst demand smoothing is an accepted practice within the logistics and distribution industry, suppliers and 3PLs suggested that owing to the mobile nature of the concept, ensuring flat demand at the unit may be complicated, potentially leading to deliveries exceeding the capacity of the unit, thereby making an automated system of operations impracticable. This issue may be resolved by a delivery booking system, similar to that of the temporal loading bay measures in Barcelona (Álvarez and de la Calle 2011).

Suppliers raised concerns regarding the extended dwell time (time spent making the delivery) for a driver required to deposit deliveries comprising many separate consignments for separate wards, suggesting that the dwell time for the driver whilst checking and depositing each product is perceived to potentially greatly outweigh the benefits of pre-sorting items for suppliers. This particular element of the concept is perceived to result in hospitals yielding greater savings than suppliers. Furthermore, suppliers suggested that in such circumstances it may be considered more prudent to allow suppliers to make such deliveries direct to the hospital to prevent otherwise time consuming and unnecessary duplication of services. These findings suggest that the operation of the MCC in conjunction with the existing NHS SC (which largely services bulk deliveries) may be preferable.

Finally feedback from a 3PL company indicated that the dual site operations of the MCC unit, assuming time variable locations would not be feasible for parcel carriers operating express or next day services as they are organised according to items being sent to different depots. Therefore, if an item destined for the northern depot location became delayed, it would require shipment between the 3PL depots to be transferred onto a service which would travel to e.g. the southern depot location in the afternoon, accruing additional costs to the customer through courier Trunking operations, Figure 5.17. Furthermore, they highlighted that savings would only be achieved for logistics services operating as same-day carriers since charges for such services are calculated according to vehicle miles travelled; whereas parcel carriers typically operate services whereby they have a vehicle located within each postcode, irrespective of demand levels. Therefore emissions savings delivered by consolidation for city centres may not reflect those expected by the estimated reductions. Such practices highlight a need for market-based and / or regulatory practices to be implemented in tandem to yield the full benefits of urban consolidation centres.

One of the most significant benefits of the MCC is the reductions in traffic on the local road network which suffers from congestion exacerbated by on-street unloading activities for the hospital. Furthermore, the reductions in freight vehicle numbers to the Trust is expected to reduce the pressures on the limited space within the hospital delivery yard, by reducing standing vehicle times.

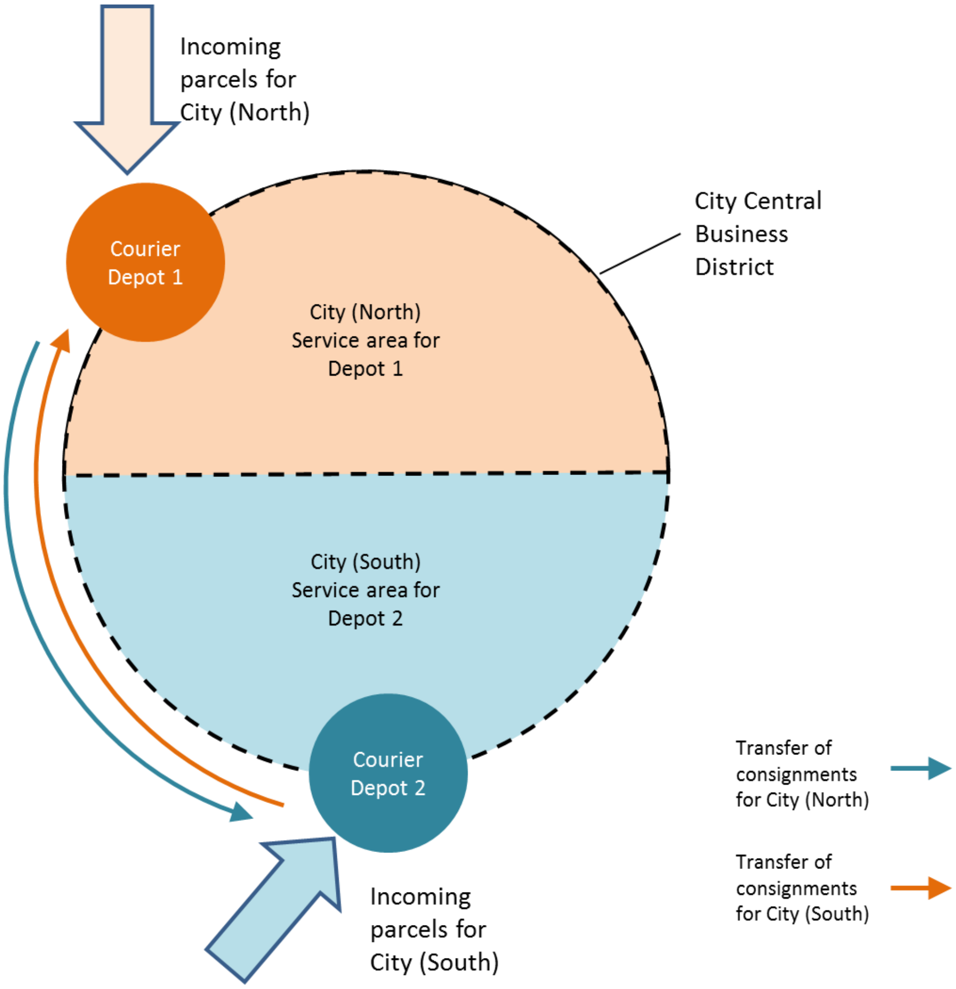


Figure 5.17 Illustration of courier trunking operations. (Incoming parcels to Courier Depot 1 are bound for City (North), however should the driver from Courier Depot 1 miss the delivery window for Depot 1, the consignment has to be transferred to Courier Depot 2 so that it may be delivered to Depot 2)

Policy Views

Whilst environmental legislation and regulation does have an impact on supplier's activities, many of the additional costs accrued by suppliers and logistics providers are often recovered through service price adjustments (Danielis et al. 2012). Feedback from suppliers indicated that the financial benefit of avoiding low emissions zones and congestion charging zones are negligible. However, legislation affecting fuel pricing are of significant concern to businesses, with some suppliers spending approximately £1 million per annum on fuel for a vehicle fleet. The most significant influence on delivery practices are considered to be customer demands. Therefore, if hospital Trusts imposed mandatory participation in the MCC, they would do so.

This suggests that a dominant factor in the participation of consolidation centre schemes may be the cost of participation and who the costs are passed on to.

Feedback from local authorities indicated that implementation of the MCC would be beneficial with respect to a call for safer roads for cyclists in central London, along with lower emissions. Hospital representatives indicated that the concept lends itself to a joint procurement framework, whereby all central London Trusts instruct small suppliers to make bulk deliveries of items for a range of hospitals to the same trailer, thereby consolidating large numbers of journeys, whilst also leveraging greater buyer power through bulk buying discounts. Furthermore, it was suggested that for the concept to succeed participation amongst numerous London hospital Trusts would be required to yield a significant impact.

5.6 Summary

A mobile consolidation concept intended to make consolidation more attractive to suppliers was assessed in two scenarios: GOSH only and London-wide.

The feasibility of the concept for GOSH was tested according to the maximum number of cages filled during the busiest day and week of the year, informed by a week's survey of the receipts and distribution department at GOSH, and a one year historical order volume record for the 2012-13 financial year. The results from this assessment indicated that the concept for GOSH can be accommodated within a single unit provided demand smoothing practices are employed, to average the capacity requirements to 30 cages per day.

Quantification of the impact of GOSH on the supply chain indicated minimal impacts, of 2%, 1% and 3% in total VKm, Journey time (hours) and emissions (CO_2e), respectively.

Consolidation for GOSH using the MCC concept indicated savings of between:

- 10,591 VKm (1 site) and 12,173 VKm per week(4 site);
- 181.53 – 225.05 journey time (hours) for the 2 site and 4 site operations, respectively; and,
- 2 – 2.33 tonnes of CO_2e between 1 site and 4 site operations.

Assessment of a London-wide scenario indicated a total of 261,805 VKm, 4,807 journey time hours, and 226.08 tonnes CO_2e are generated for 29 Trusts citywide. Comparisons of two scenarios, MCC units allocated per hospital; and MCC units allocated to geographical regions for specific supplier groups indicated:

- Reductions in VKm of 16% - 25% (1 – 4 site scenarios) against the base;
- Reductions in total emissions (CO_2e) between 37% and 40% for 1 – 4 site scenarios, against the base, with the greatest reduction being achieved for the 1 site scenario; and,
- Increases in Journey Time hours for 1 site and 2 site operations of 33.84 and 40.31, respectively; whereas, a reduction in total journey time hours of 579.86 were observed for 3 site and 4 site scenarios, respectively.

The MCC was perceived to deliver positive benefits to the internal distribution of goods within hospitals, with the direct shipping of items to wards from the loading bay reducing the time spent processing receipts, as well as the opportunity for items to become lost / delayed within the hospital. However, concerns were raised by participants towards the transfer of ownership for items being delivered to the MCC and further concerns regarding the integration of the new delivery approaches with existing industry systems and working practices. Specifically regarding the employment of agency drivers to make deliveries who may be unfamiliar with the system generating misplaced deliveries at the unit. Further concerns were also raised regarding the practicality of making deliveries to a unit which may change location during the day. Overall hospitals and local authorities perceived the concept to be beneficial, whilst suppliers and third party logistics providers suggested that there would be little benefit yielded from the implementation of the concept with regards to environmental and economic savings owing to the additional delivery and sorting responsibilities which would be assumed by those making deliveries. Overall findings from the qualitative assessment indicated the concept may be better suited towards a staffed model of operation tailored towards specific small volume high value consignments.

Chapter 6: Unattended Delivery for Urgent and Time Critical Items

6.1 Introduction

As demonstrated in Chapters 2 and 3, the mixing of urgent and non-urgent items within the medical supply chain leads to the loss or delay of urgent items amongst non-urgent goods (Poulin 2003; Dembiríska-Cyran 2005); and, engenders sub-optimal freight operations with poor fill-rates (McKone-Sweet et al. 2005).

Unattended delivery solutions such as electronic locker banks provide a potential solution to the delivery of urgent items to hospitals, facilitating night-time deliveries, providing a separate, dedicated route of supply for urgent items, and a means to disintermediate the internal supply chain, thereby expediting the delivery of urgent items to their final destination within hospitals. This chapter proposes the concept of an unattended electronic locker bank for the receipt of urgent items into the hospital, and collection by clinicians for use. The aim of this study is to quantify the feasibility of unattended electronic locker banks within the context of urgent healthcare supply.

6.2 Description of the Proposed Locker Bank Concept

The proposed locker bank concept is based on the traditional system operated in the field services sector, Figure 6.1, 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 separate urgent goods deliveries into hospitals and, enable a more human-centric supply chain by informing the recipient of the arrival of urgent orders for personal / delegated (by an available member of clinical or support teams) collection of the item for immediate use. In this research, it was assumed that the system would function in a similar way to that operated by a leading UK-based unattended delivery system (ByBox 2012).

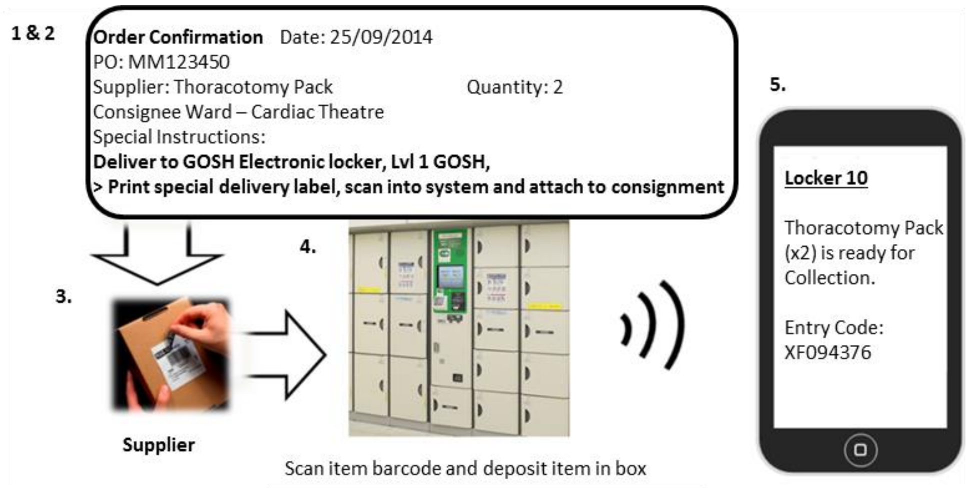


Figure 6.1 Illustration of the proposed locker bank concept

1) A clinical practitioner places a request for an order with the Ward Sister, who is in control of 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 or porters, available to perform the task.

6.2.1 **Dataset**

The model was informed by the November 2011 survey data which captured ad-hoc deliveries [n=403] and identified the product description, supplier name, manufacturer name and consignee department for recorded deliveries. These product listings were presented to the Head Nurse[14], who identified 38 product lines considered to be urgent goods Appendix F, 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 to provide a means with which to assess the physical space requirements for each package. Package dimensions were established by identifying the supplier for each respective urgent item order number and product code provided by the procurement department at GOSH. Following this, each supplier was contacted via email requesting the packaging dimensions for each consignment sent to GOSH during the survey week.

To enable a full assessment of the dataset an assumed package size was generated for the remaining 37% according to the weighted average of all the acquired box sizes. This approach provided the dimensional information necessary to establish

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

the compatibility of consignments into partitions for the 'Test for Survival' outlined in Section 4.3.1.

These results revealed that orders were delivered within standardized packaging used by suppliers to send out batches of items, returning 8 actual cardboard box sizes in which items are delivered, and 1 generated box size, Table 6.1.

Table 6.1 Eight box sizes and frequencies yielded from 63% of 426 urgent orders, with one generated box size (I.D. 9) using a weighted average of all acquired box sizes

I.D.	Box Dimensions (L x W x H) [cm]	Quantity	% of Population
1	22.5 x 15.2 x 2.7	33	8%
2	27 x 14 x 130	10	2%
3	28 x 42 x 94	13	3%
4	30 x 37 x 17	20	5%
5	32 x 16.5 x 6.3	9	2%
6	37 x 30 x 17	126	30%
7	38 x 27 x 19.8	15	4%
8	57 x 37 x 25.5	57	13%
9	44.7 x 32.4 x 28.9 [Generated]	143	34%

The qualitative assessment was conducted using one-to-one interviews with key members of staff involved in the ordering, management and supply of medical inventory to wards: 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, each participant was presented with the unattended locker bank concept, Appendix G demonstrating the new process of ordering and delivery for urgent items to the Trust, Figure 6.1. Owing to the growing presence of unattended electronic locker banks being made available for online consumers, some participants (62%) were familiar with the underlying concept. Each participant was then asked to provide feedback on the following subjects, to help gain further insight into the perceived uses, benefits, operational and technical feasibilities and practicalities of the concept:

- Next-day delivery, to address the urgency of items;
- Faulty and incomplete item scenarios, such as an incomplete theatre procedure pack (pre-packaged kits comprising a specific set of items required to perform a certain type of surgical procedure), as identified by the head nurse as a potential issue;
- The deposit and collection of lab samples (couriered from healthcare institutions worldwide to the hospital for testing by hospital specialists), identified as a burden on the receipts and distribution service within the hospital;
- Inter-departmental transfers of items such as suction catheters (used to remove respiratory secretions from airways), to address the issue of correct charging for items between departments;
- Out-of-hours deliveries, to determine the impact of moving goods to night-time delivery which would have a positive impact on day-time traffic volumes and provide more efficient driving behaviours;
- Stock-critical items, such as high value and controlled items (e.g. cochlear implants), to increase the security of such items using smart technology storage; and,
- The improved recording of urgent items and the potential reduction in staff time for managing urgent items, identified as a potential issue by the Head Nurse.

6.3 Methodology

As previously mentioned, space in hospitals is at a premium with most unutilized / underutilized space being allocated to primary hospital functions such as ward space and treatment rooms. Therefore, it is important for any proposed locker bank within the hospital to utilize as little space as possible, in order to do so one needs to understand exactly how many partitions are required given the observed flow of packages. Hence this is the focus of the analysis to help understand the viability of such a concept.

6.3.1 **Locker Bank 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. 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, three modeling approaches (Restricted, Semi-Restricted and Unrestricted "Autonomous") were adopted to test the feasibility of the concept and provide a means to quantify the value of more advanced methods, by comparison of each approach, in establishing locker partition formulations:

This assessment begins with a 'Restricted' approach for which the specification of 4 locker bank partition is pre-determined and the only variable in design is the combination of lockers used. Following this, a 'Semi-Restricted' approach assesses the performance of 4 hard-coded partitions, each of which reflects the dimensional requirements of 4 groups of parcels within the demand, as practiced by ByBox.

The purpose of the first two modelling methods is to test the impact on overall performance (i.e. required locker bank length) beginning with a locker bank whereby the specifications of each partition are arbitrary, compared to the requirements of the demand, progressing to an approach whereby each of the four available partition sizes reflect the requirements of the demand.

The third ‘Unrestricted’ “Autonomous” approach adopts a more continuous approach to partition sizes, presenting a list of all 13,600 permutations of possible partition sizes beginning at 0.01 metres, and increasing the height and width of the partition by a centimetre each time, up to a limit of 1.70m high, and 0.8m wide. Width restrictions were determined according to the practical width of a door and the space required to open (i.e. an 80cm wide door requires approximately $2m^2$ to open it). The maximum locker dimensions were agreed during discussions with ByBox and hospitals officials deciding the overall limits of the largest possible locker size to closely resemble the dimensions of a hospital cage (167 x 83 x 72 cm [h x w x d]). This was agreed to ensure the maximum size of a consignment delivered to the lockers does not exceed the means available within the hospital to transport it. The purpose of the Unrestricted model is to determine the spatial requirements of a locker bank which comprises locker partitions whereby the size and combination are dictated by the demand.

The depth of the partitions for all modeling scenarios is fixed to (80cm) deep to restrict the amount of space (e.g. corridor width) the locker bank occupies within hospital corridors and areas.

Restricted Approach

The first 'Restricted' method comprises partition sizes measuring full-height, half-height, quarter-height and eighth-height partition sizes, for the locker bank, as follows:

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.

Semi-Restricted Approach

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 packing model (Equation 1) which identified 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 linear packing model (Equation 1) assumes 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 2D 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 2D footprint multiplied by the total number of footprints required to accommodate all the boxes within the consignment (nV).

$$L_{pi} = nV \times l_{bi} \qquad \text{Eq. 1}$$

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 the 80cm width restriction, the consignment was divided into equal parts (i.e. halves or thirds). 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)

For both methods, a 5th partition "E" is allocated with zero dimensions. This is used to allow the hill climbing algorithm to achieve optimal results when testing lower coverage scenarios which will not require the maximum 11 required partitions.

Unrestricted Approach

The Unrestricted model attempted to pack each consignment into each of the aforementioned 13,600 partitions, using Equation 1, to generate a list of compatible partitions for each consignment. This list informed the model as to whether a consignment can be accommodated within a locker bank comprising a set of randomly selected partitions.

6.3.2 Locker Bank Unit Model

A genetic optimization algorithm is used to search for the optimal locker partition combination. The locker Bank model takes the listing of consignments received on each day, sub-divided into the pre-sized partitions A, B, C and D or 1 to 13,600. The aim of the model is to establish the optimal combination of partitions that allow a maximum number of orders to be stored within the smallest space. The algorithm performs a search for the optimal locker bank partition arrangement, adjusting the arrangement for each iteration and then determining whether the change improves the fitness (overall length of the locker bank required to accommodate a given proportion of consignments). Once an improvement can no longer be found, the remaining combination is considered optimal. Figure 4.6 in Section 4.4 illustrates the process of simulation, described in detail below.

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” or “10-100-1,000-10,000”. Each gene allele is selected at random from the available partition sizes. The initial candidate pool is tested for fitness and survival in order to determine the best candidate, Figure 6.2. 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.

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. Once the fittest individual has been determined, it is selected for mutation.

The First Fit Decreasing Height strip packing algorithm is predicated upon a bin packing problem. It assumes that all the packages to be packed into a single space and their dimensions are known. The algorithm orders the items by decreasing size (in this instance by height), and then proceeds to select the largest parcel packing it into a newly created Bin, (‘Bin 1’). It then selects the next largest parcel and attempts to pack it into ‘Bin 1’, if it does not fit within the residual space of ‘Bin 1’ a second Bin (‘Bin 2’) is created into which the item is packed. The algorithm then selects the next largest parcel (parcel 3) and attempt to pack it into the residual space in ‘Bin 1’, if it fits it will then be packed into ‘Bin 1’, if not then it will attempt to fit it into the residual space within ‘Bin 2’. If the parcel doesn’t fit in ‘Bin 2’ it will create 3rd Bin (‘Bin 3’) for the parcel to be packed into.

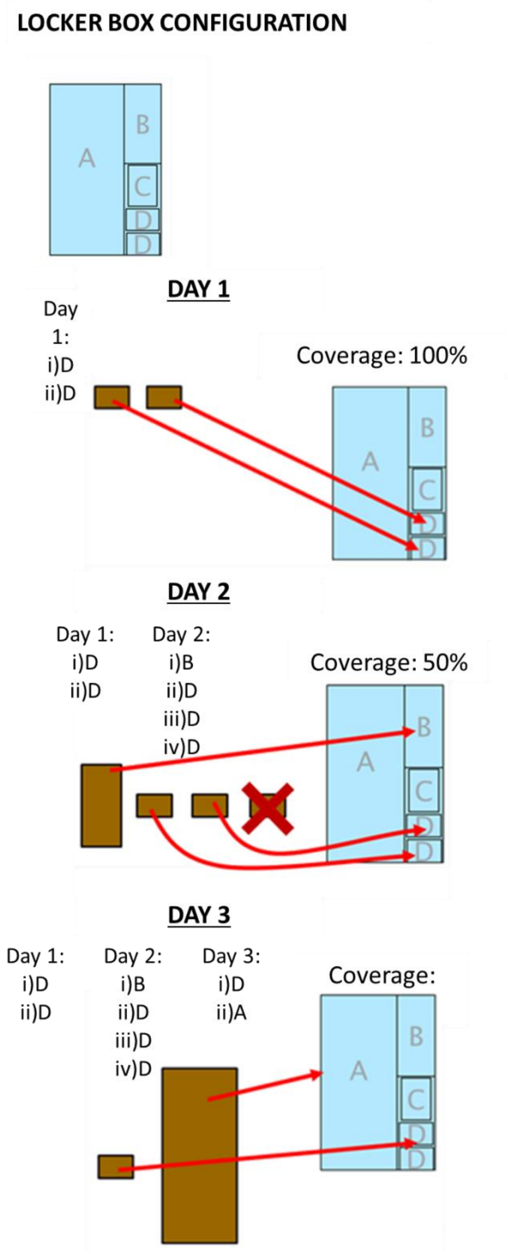


Figure 6.2 Process of the test for coverage - All consignments are fit into an available partition in the locker bank, once a partition is occupied it can no longer be used. This process is repeated for all items during each day. If the bank cannot accommodate any single item during a day, then that day is marked as 'unaccommodated', therefore the percentage of days the locker bank "works" (i.e. the coverage) is reduced.

The algorithm continues to work through the remaining parcels packing them into the residual space of the existing bins working from ‘Bin 1’ onwards’. The output of this process is the overall required length for the bounding locker bank, used as the fitness value for combinations to be compared against.

The process of mutation takes the fittest candidates partition sequence and randomly selects one of the partitions, swapping it for another randomly selected partition from the available partitions list. It reruns the survival value (%) and test of fitness sequences (comprising locker partitions and required length to accommodate them).

If the newly mutated candidate is fitter than its parent candidate, its sequence overwrites the parent. This process of mutation is repeated until a newly mutated candidate with a higher fitness than its parent can no longer be found.

Both tests were performed with varying degrees of minimum coverage, ranging from 100% of all deliveries to 80% 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. However, the addition of partition “E” with zero dimensions was necessary to enable the algorithm to achieve optimal partition combinations for lower coverage scenarios by omitting instances of ‘busiest day’ consignment numbers.

6.4 Validation of the Locker Bank Model

As stated in Section 4.2 and Section 5.4, genetic algorithms such as hill climbing algorithms can become ‘trapped’ within local optima. However, this issue may be overcome using the same method used in Section 5.4, by varying the number of random starting points, in this case beginning locker bank partition formulations, and the number of mutations performed.

Validation of the algorithm is conducted simulating a 100% coverage scenario as it incorporates the full range of demand and therefore all partition sizes [n=13,600] and potential combinations and permutations, thereby validating the maximum set of parameters.

The standard equation for calculating the size of combinatorial problems (i.e. the number of possible combinations), Equation 2, is used to establish the number of potential combinations in accordance with guidance from Johnson and Bhattacharyya (2001): Assuming a maximum sequence length (r) of 20 partitions for a single locker bank, and repetition of the same partition from a total of 13,600 available partitions (*n*) is allowed, there are 1.95307086 x 10^{64} potential solutions.

$$Number\ of\ Combinations\ (with\ repetition) = \frac{(n+r-1)!}{r!\,(n-r)!} \qquad \text{Eq.2}$$

6.4.1 **Validation of Mutations**

Due to the simplicity of the approach for the mutation of solutions in the Locker bank model, whereby a single partition is swapped out and the sequence tested, Section 4.3.2, the appropriate number of mutations can be established by running the algorithm from a single random starting location with an 'infinite' number of mutations. Once the algorithm reaches a point at which every subsequent mutation produces the same result, it can be assumed that no further mutations are required past the point at which the repeated result was initially 'found'. This process was performed for the locker bank model, Figure 6.3, revealing a plateau occurring after 25 mutations. Therefore it can be assumed that the optimal solution using mutations may be achieved within 25 iterations.

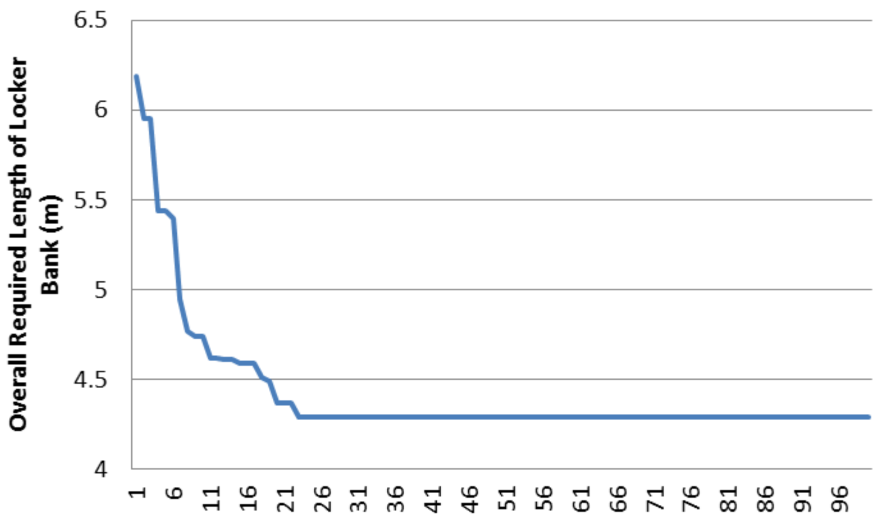


Figure 6.3 Validation of locker bank model mutations. The model was run with an endless number of mutations testing a locker bank capable of accommodating 100% of order demand. Once no improvement is achieved (i.e. the overall required length of locker bank doesn't reduce further), the best result has been achieved

6.4.2 **Validation of Starting Points**

Once an appropriate number of mutations has been established, the same test can be conducted for the appropriate number of starting points for the algorithm, to maximise the chances of achieving the most optimally achievable result.

Owing to the time required to simulate a single starting point comprising 25 mutations and project time constraints, it was not possible to run large numbers of starting points. However, the results in Figure 6.4 indicated that within 25 'starting point' simulations a result for the required length of the locker bank below 4 metres is achieved within 16% of the simulations. Therefore, 25 simulations comprising 25 starting points may be considered sufficient.

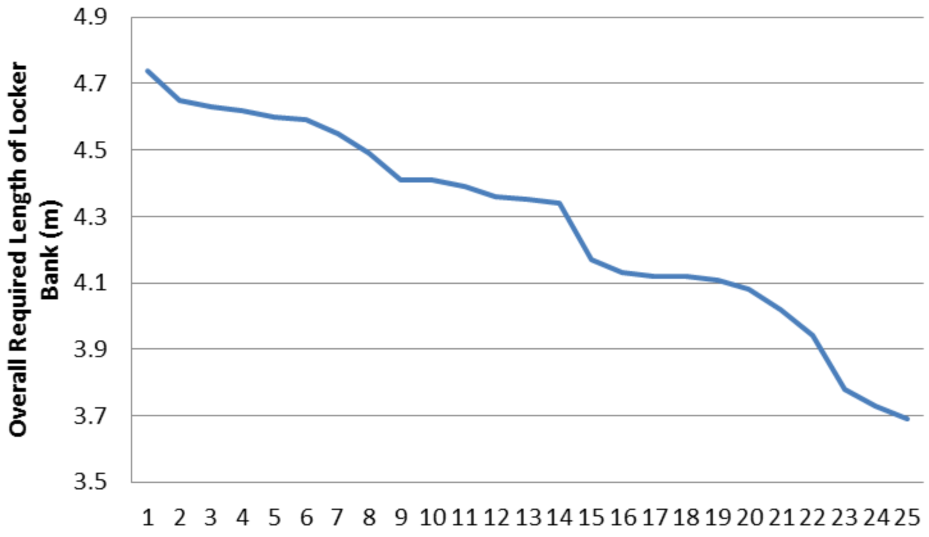


Figure 6.4 Validation of starting points for the locker bank model, running the model with 25 mutations for 25 separate random starting combinations

6.5 Quantitative Results

6.5.1 User Analysis for the Proposed Locker Bank

Assessment of the annual urgent order population into the hospital indicated that XMR / Interventional Radiology may have the most to benefit from using lockers to receive their inventory, with a total of 143 urgent orders over the year, averaging at 3 orders per week, each comprising 2 items. Subsequent orders by department are significantly fewer with 59, 43, 38 and 31 urgent items delivered to Perfusionist Theatres, Cardiac Theatres, Cochlear Implant Building and Haemodialysis, respectively. Full user analysis is provided in Appendix H.

6.5.2 **Restricted Model Results**

The results for the Restricted Model (Table 6.2, Figure 6.5 and Figure 6.6) indicated that a locker bank of 4m in length would accommodate 98% to 100% of all consignments for the year. Between 403 and 412 consignments would fit within a locker bank measuring 3.2m, suggesting that between 2% and 5% of the days deliveries are received the locker bank will not be able to accommodate all packages delivered owing to clashes in the requirement for specific locker sizes available in the locker bank. The required length of the locker bank does not change between 80% and 90% coverage.

Table 6.2 Restricted and Semi-Restricted model results utilizing four different partition types [25 starting points and 25 mutations]

Coverage (%)	Consignments Accommodated (max = 425)	Restricted Model		Semi-Restricted Model		Efficiency Savings (%)[b]
		Length [m]	Partition Combination	Length [m]	Partition Combination	
100	425	4.0	A,A,A,B,B,C,C,D,D,D,D	3.63	A,A,A,A,B,C,C,C,C,C	9
99	420	4.0	A,A,A,B,B,C,C,C,D,D	3.33	A,A,A,A,C,C,D,D,D,D	16
98	416	4.0	A,A,A,B,B,C,D,D,D	2.96	A,A,A,B,B,B,D,D,D,D	26
97	412	3.2	A,A,A,C,C,D,D,D	2.22	A,A,B,C,C,C,D,D,D,D,D	30
96	408	3.2	A,A,A,C,D,D,D,D	2.15	A,A,B,B,C,C,C,C	32
95	403	3.2	A,A,A,C,D,D,D	2.15	A,A,B,B,C,C,C	32
90	382	2.4	A,A,C,C,D,D,D	1.41	A,C,C,C,C,C,D,D,D,D	41
80(81%)[a]	340	2.4	A,B,B,C,D	1.11	B,B,B,C,C,C,C,D,D	46

[a] 81% minimum coverage was returned for the 'stated' minimum coverage of 80%. Coverage values are rounded down to the nearest whole percentage.

[b] efficiency savings represent the percentage of space saved by the length outputs from the semi-restricted model, compared against those from the restricted model.

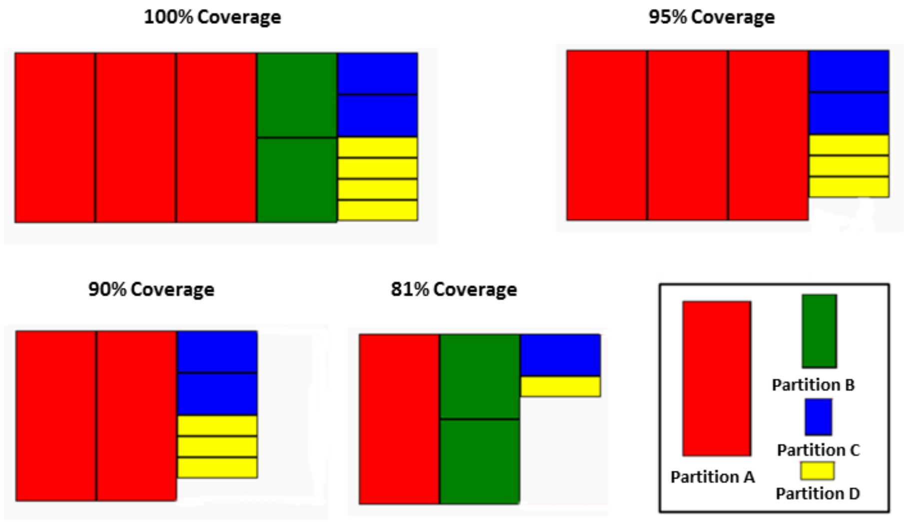


Figure 6.5 Visual results for the Restricted model, indicating the arrangement of the locker partitions within the space of the bounding locker bank

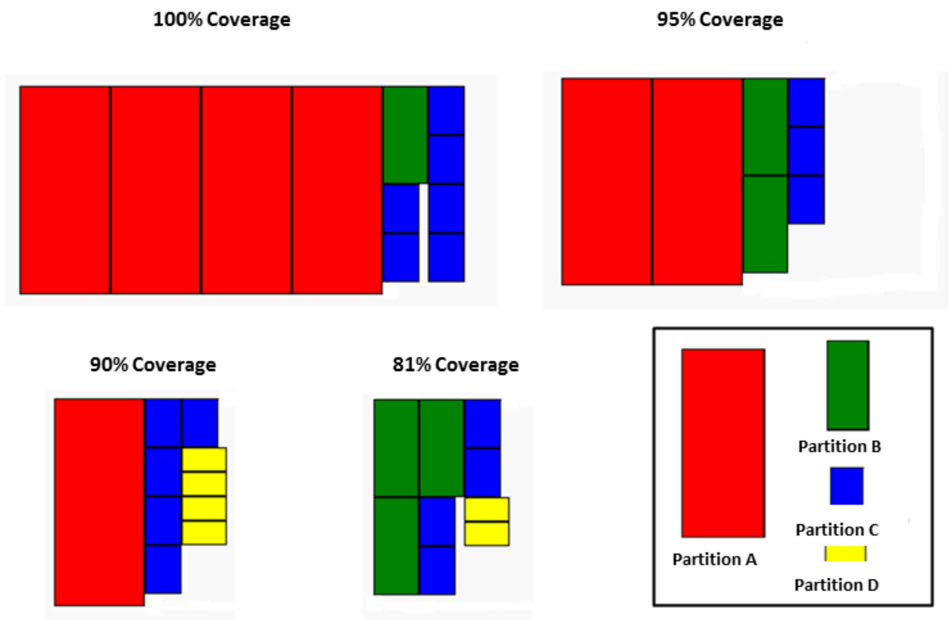


Figure 6.6 Visual results for the Semi-restricted model, indicating the arrangement of the locker partitions within the space of the bounding locker bank

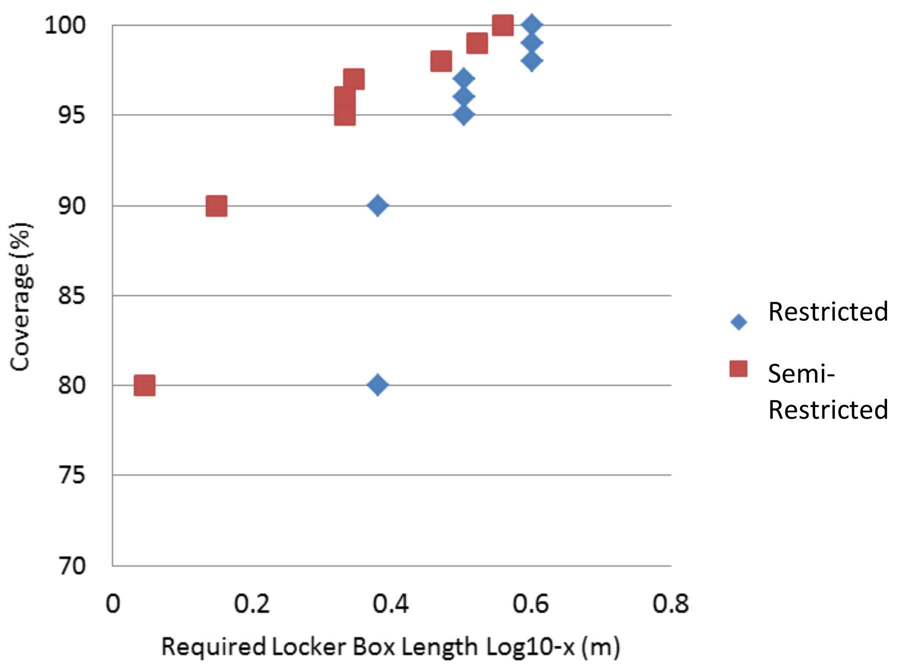


Figure 6.7 Graphical representation of restricted and semi-restricted results, indicating the coverage achieved at various locker bank lengths (m)

6.5.3 **Semi-Restricted Model Results**

Results from the Semi-Restricted Model, Table 6.2, indicated more optimal (i.e. shorter) locker bank configurations are achieved for each coverage value, yielding a maximum required length of 3.63m to accommodate 100% of consignments, as opposed to the 4m specified by the Restricted Model. This is reflected in all stages of the modelling process, Figure 6.7.

Direct comparison of the results from the two models in Figure 6.7 shows that the Semi-Restricted Model returns required locker bank lengths ranging from 10% (100% coverage) to 116% (80% coverage) more optimal than those specified by the Restricted Model. The results in Figure 6.7 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 6.7, indicated that more detailed modelling methods 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 results in Figure 6.5 and Figure 6.6 indicated that more optimal partition allocations and configurations are achieved with the Restricted 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 Semi-Restricted 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.

6.5.4 **Unrestricted Model Results**

Comparison of the results from the three modelling approaches, Table 6.3 and Figure 6.8 indicated that for the maximum demand scenario the Semi-Restricted model achieves more optimal results with a required length of 3.63 metres, against the required length of 3.69 metres for the Unrestricted model. This trend is observed for the lower demand scenarios with the model yielding between 1% (100% Coverage) and 80% (90% Coverage) less optimal results against the semi-restricted approach, Figure 6.8.

Table 6.3 Unrestricted "Autonomous" locker bank model results utilising 13,600 potential partition types [25 starting points and 25 mutations]

Coverage (%)	Consignments Accommodated (max = 425)	Required Length (m)			Number of Partitions for Unrestricted Model
		Restricted Model	Semi Restricted Model	Unrestricted Model	
100	425	4.0	3.63	3.69	19
95	403	3.2	2.15	3.11	13
90	382	2.4	1.41	2.54	13
80	340	2.4	1.11	1.44	7

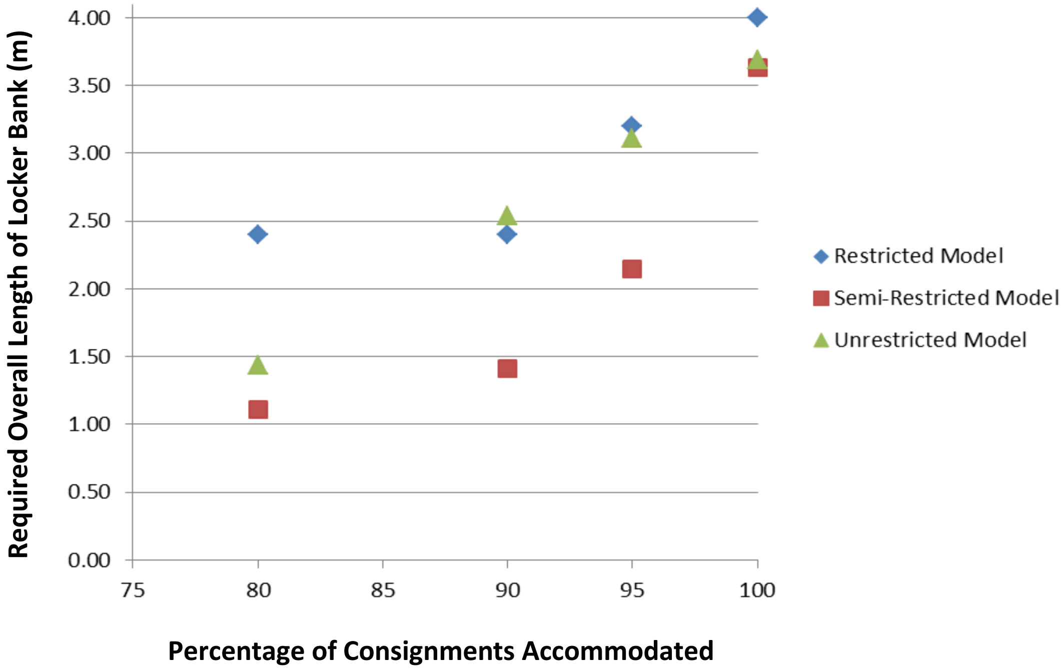


Figure 6.8 Comparison of Restricted, Semi-Restricted and Unrestricted model results, indicating the percentage of consignments accommodated for locker banks of various lengths (m)

Owing to the process of optimisation, should an increase in demand occur, the locker bank may fail, since the combination of locker partition sizes within the bank are tailored to the order population derived from historical data. However, a sensitivity assessment of the locker bank's performance during demand uplift scenarios was conducted, using the data showing the number of days a given number of consignments were received, Figure 6.9; and, assuming that the combinations of parcels arriving during the days fit within the available locker partitions.

Owing to the restriction of 11 locker partitions imposed on the restricted and semi-restricted locker bank modelling scenarios, which reflect the number of individual consignments arriving during the busiest day, the prescribed locker bank for the 100% demand scenario will fail 1% (1 day) of the time. However, owing to the higher number of locker partitions for the 100% scenario (19) specified by the Unrestricted modelling approach, the locker bank may only fail once a demand increase of 70% is reached.

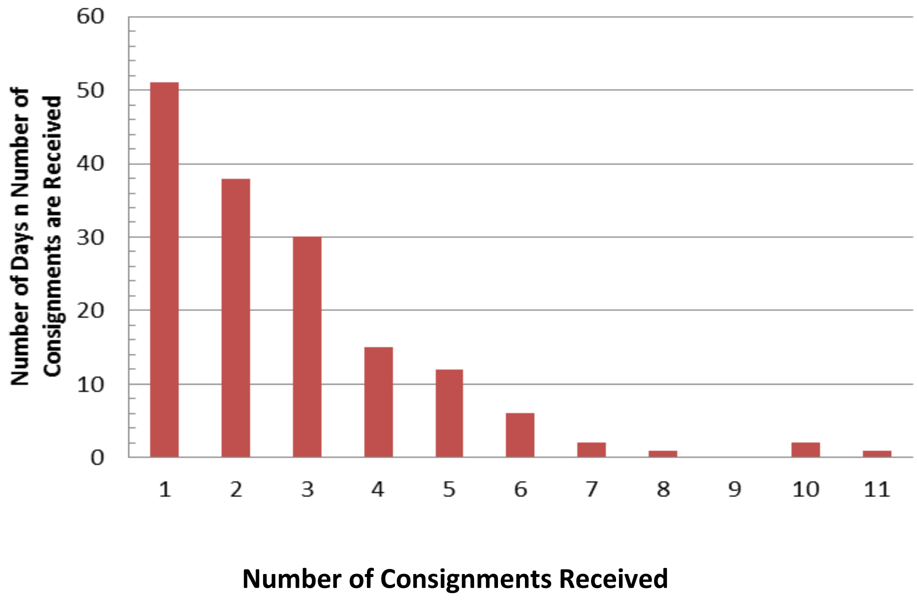


Figure 6.9 Urgent order demand profile according to the number of days

6.6 Qualitative Results

Interviews with clinical and non-clinical members of staff provided insight into the contextual uses for a locker bank system within GOSH. Full interviewee responses are provided in Appendix G.

6.6.1 Operational Uses for the Locker Bank

Next-Day Delivery

An unattended locker bank unit would 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 perceived this system to be of use predominantly for laboratories in the event of unpredictable patient demand. 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.

6.6.2 Contextual Scenarios for the Locker Bank

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. Participants identified that under such circumstances, a locker bank 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 focusing 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 bank 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 bank 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

Support staff identified that samples sent to the on-site laboratories occasionally require further testing to be conducted at local NHS Trusts. Currently, samples are collected either through the receipts area or direct from the departments. A dedicated locker bank 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.

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 occurrence of stock-outs on wards which in turn create difficulties with regards to the management of the appropriate / required size of inventories and individual ward / departmental budgets. However, staff feedback on this application indicated that 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.

6.6.3 **Wider Implications of the Concept**

Out-of-Hours Deliveries

As highlighted in Chapter 2, potentially one of the greatest benefits the unattended locker bank system offers is out-of-hours deliveries of critically urgent items, providing improved in staff utilization, operational efficiencies, and transport, associated with reduced CO_2 emissions.

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

Studies by Song et al. (2009), Edwards et al. (2009) and 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 bank 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 2012a) or when it needs to be held securely in a high security environment (Franklin et al. 2010; Pharmaceutical Journal Online 2012b).

6.7 Summary

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 3 modelling approaches (restricted, semi-restricted and unrestricted) predicated by a hill-climbing optimisation model.

The results from each modelling approach indicated that a locker bank limited in height (1.7m) and depth (0.8m) able to accommodate 100% of all urgent consignments passing into the hospital during a typical week, has a required length of 4m, 3.63m and 3.69m for a restricted, semi-restricted and unrestricted modelling approach, respectively.

The difference in the results between the three models indicated that there is some value in adopting a more detailed modelling approach for locker bank partition allocation, yielding a 10% space saving between restricted and unrestricted approaches. However, less optimal results achieved by the unrestricted approach suggest that 'autonomous' approaches whereby the locker bank demand dictate the formulations of the locker bank entirely do not necessarily yield better results. However, it is important to note that if the model were afforded a longer runtime it may achieve more optimal results.

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.

Results from the qualitative analysis suggested:

- The next day supply functions of the locker bank concept are unattractive from a supply perspective as managerial staff encourage forward planning, so the availability of faster delivery times may encourage unwanted ordering habits;
- The locker bank provides significant potential for the return of items and provides an appropriate location for the consolidation of items which may be sourced from multiple origins (hospitals and local care institutions) in the event of a stock out;

- The locker bank demonstrated potential for the delivery and collection of laboratory samples, whilst also providing added tracking and monitoring;
- Use of the concept for interdepartmental transfers received negative feedback as the increased track and trace afforded by use of the lockers were not considered to outweigh the speed of person to person transactions. However, use of the locker banks for the holding of controlled items and goods within the hospital for night time access pose some use and benefits; and,
- The lockers provide the potential for out-of-hours deliveries, enabling for more efficient driving behaviours and the timely delivery of items. In addition to this they may also be used to eliminate the unwanted traffic generated by personal deliveries within the R&D department.

Staff perceptions of the locker bank 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.

Chapter 7: Understanding the opportunities for more sustainable Laboratory Courier Services at GOSH

7.1 Introduction

Findings in Chapters 2 and 3 indicated that current hospital and courier service provider practices centred on collecting items as and when they arrived for outward journeys at the hospital. Whilst the traffic and emissions impact of such practices are largely unquantified, findings from the laboratories courier survey (Chapter 3) indicated the contributions of laboratory courier services may be large.

Analysis of courier services at GOSH indicated an average of 10 samples and / or equipment to be couriered per day, from 47 days within a 3 month period, with a significant number of courier services being commissioned by the Clinical Transplantation Laboratory, Figure 7.1.

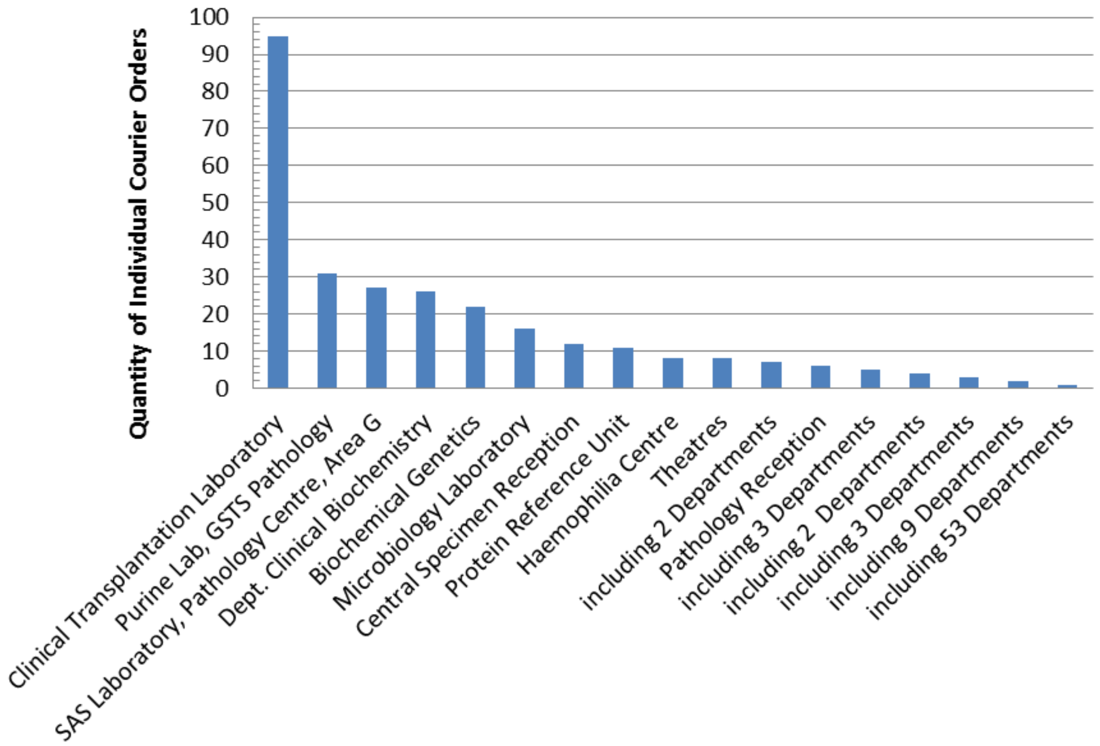


Figure 7.1 Analysis of the quantity of courier orders by hospital department

Courier services at GOSH are requested by members of staff from each department independently of one another, therefore the arrival of packages at the receipts and distribution department where items are sent to be booked onto courier services is unpredictable for those ordering services. Owing to the lack of coordination in courier service bookings items are commonly couriered separately however, should two or more items for couriering arrive at the same time they may be booked onto the same vehicle. This highlights an underutilised element of courier services which may be a promising area for collaborative thinking to reduce logistical impacts.

As highlighted in Chapter 3, 81% of samples couriered represent either a test for a patient or organisation (e.g. water samples). These samples may be sent from GOSH to other hospital Trusts for analysis or returns of samples and test results to healthcare institutions worldwide. However, in all cases samples are provided with an expected turnaround time for analysis, ranging from a couple of days to a week. These time periods are defined by whether an item is: marked as urgent (which in the case of the dataset assessed, 9 are considered urgent); or non-urgent. In consideration of this, the data suggests that of the 476 courier services ordered over the 3 month period in 2014, 467 are suitable for consolidation.

Assessment of the literature indicated that little has been done to examine the environmental and congestion impacts of courier services, with the majority of research focussing on economic efficiency (Revere 2004; Revere and Roberts 2004). Using data from the survey presented in Chapter 3, this study evaluated the impacts of temporal consolidation such as the planned delay of non-urgent (items which are not perishable and are not subject to strict time constraints for their return) hospital laboratory samples and equipment until a given time or number of items is met for couriering to people and healthcare institutions worldwide; using a hill climbing genetic algorithm with integrated travelling salesperson optimisation function to determine the optimal configuration of vehicles in which to consolidate items, and the optimal route for each vehicle.

7.2 Courier Consolidation

As described in Chapter 2, temporal consolidation is typically predicated on the intentional delay of goods to a single customer until a pre-established threshold is achieved. However, temporal consolidation may also be conducted according to the delay of items until a pre-established time of day or, amount of time has elapsed (e.g. since the first arrival of an item).

The appraisal of temporal consolidation for courier services in this context is assessed according to the optimal number of time periods (i.e. length of time with which to delay items) required to yield a reduction in courier related emissions.

7.2.1 **Dataset**

This study used quantitative (modelling) methods to determine the optimal period of time and optimal combinations of vehicles with which items should be temporally consolidated to deliver the greatest reductions in emissions. As detailed in Section 4.5, time periods were assessed using a hill climbing algorithm with an integrated travelling salesperson function, developed specifically for this assessment, to consolidate samples within a given time period, and optimise vehicle packing and delivery routes for all outward bound laboratory samples.

The models were informed by 476 courier records from a three month sample of historic operations at GOSH. The dataset was scrutinised, selecting records providing the information necessary for modelling: product description[15], number of items to be couriered, date to be collected, the time the order was booked into the courier system, contents, destination, approximate weight [kg] and dimensions [cm or m]. This process resulted in 332 useable records. A further 9 records, marked as items for urgent delivery, were omitted as it is assumed these cannot be delayed, resulting in 323 records which are compatible for consolidation with one another. Analysis of the data set indicated that 'Sub Category B' (perishable items requiring dry ice for transit), was the most common parcel type to be couriered, accounting for 34% of the items delivered, followed by blood samples (25%), and journeys for the collection / delivery of blood pressure monitors (10%) from / to patient addresses.

Each record was transformed to give the date and time the item was first booked in to the hospital shipping department, the package type, Table 7.1, the smallest vehicle it can be transported in, and its destination (items bound for international destinations, including Belfast (2% of record population), have a re-assigned destination to the courier companies international shipping depot located in East London).

[15] Blood samples, Blood pressure monitor and cuff, CD & Memory Stick, DNA Sample, Documents, Glass Slides, Graft, Heart Conduit, Hydrotherapy Sample, Medicines, Miscellaneous, Patient Samples, Sub Category B (perishable items requiring dry ice for transit), supplies / equipment, transplant cooler box and unspecified.

Table 7.1 Parcel types characteristics and their frequencies in the total 3 month order population

	Parcel Specifications		**Number of Parcel Type in Records**
	Dimensions [cm] (L x W x H)	**Maximum weight [kg]**	
1.	42 x 29 x 10	3	120
2.	20 x 20 x 20	5	192
3.	150 x 100 x 120	600	11

Since no records were available to indicate the vehicles used for each individual trip for the base case, vehicles were assigned to each record according to the smallest vehicle the consignment can fit within. This was determined using a linear packing function (Equation 3), where: l_v, w_v and h_v are the length, width and height of the vehicle, respectively; and, l_b, w_b and h_b represent the length, width and height of the box being packed, respectively.

$$\Sigma parcels = \frac{l_v}{l_b} \times \frac{w_v}{w_b} \times \frac{h_v}{h_b}$$

Eq. 3

The calculations assumed each package is stored up right, restricting its rotation by 90-degrees on the x-axis. The package is 'packed' into the vehicle twice varying the rotation of the package each time to determine the optimal packing configuration. The packing function determines how many of each parcel type can fit within the horizontal footprint of the vehicle, Table 7.2.

This number is subsequently multiplied by the number of times the height of a parcel can be divided into the height of the vehicle. If the number of parcels which can fit in the vehicle exceed the number in a consignment the vehicle was added to the list of vehicles compatible for a given courier record. Analysis of the data presented in Table 7.1, indicated parcel type 2 to be the most common in the record population. Comparison of the physical dimensions for each parcel type against the relative load space dimensions for each vehicle suggested that 63% (Type 2 and 3 parcels) of all the items couriered are not compatible with bicycle couriers. Of this 63%, 11 (3%) (Type 3 parcels) are not compatible with any vehicle below a Small Van.

Table 7.2 Vehicle specifications for each available vehicle type performing courier services for Pathology laboratories at GOSH

	Vehicle Specifications[a]			
Vehicle	**Load Space Dimensions [cm] (L x W x H)**	**Payload [kg]**	**Emissions [g / km]**	**Fuel Consumption [km / litre][c]**
Bicycle[d]	42 x 29 x 10	3	16[b]	26.78
Motorcycle[d]	42 x 29 x 26	5	120	15.49
Small Van	1.7 x 1.49 x 1.2	400	179	15.49
Transit SWB Van	2.4 x 1.7 x 1.4	800	230	15.49
Transit LWB Van	3.4 x 1.7 x 1.7	1200	258	15.49
Transit XLWB Van	4.1 x 1.7 x 1.8	1500	258	15.49

a. Vehicle dimensions, payload and emissions are in accordance with the vehicles provided by the hospital courier company.

b. Emissions factor assigned to a bicycle, derived from the daily kilocalorie intake of a rider (3466), and the food has an impact of 1.83 tons CO2e per year per person, putting the kilocalories at 1.44g CO2e. Therefore the ‘fuel’ of the cyclist can be estimated at 16 grams CO2e/km (ECF 2011).

c. Fuel consumption for each vehicle is based on figures provided by DEFRA, UK (Defra et al. 2013).

d. Figures denote the size and weight of the package a cyclist / motorcyclist can carry.

However, in addition to size limits, the destination of parcels was considered when allocating the bicycle to a parcels ‘compatible’ mode of transport. Guidelines provided by the courier company limited the range of a bicycle delivery to within a range of postcodes, Figure 7.2. As reviewed in Sections 2.4.6 and 2.4.9, such limits are widely practiced, with longer-range parcels being shipped by motorised vehicle (Basterfield 2012). This is done to minimise the cumulative mileage performed by a single bicycle courier and maximise the efficiency of the services they provide, such as fast, short-distance journeys through congested areas of cities (Hedditch 2014).

Analysis of the entire record population [476] indicated a large number (67%) of courier services are commissioned within London, Figure 7.3, the majority of which (300) are to hospitals or organisations.

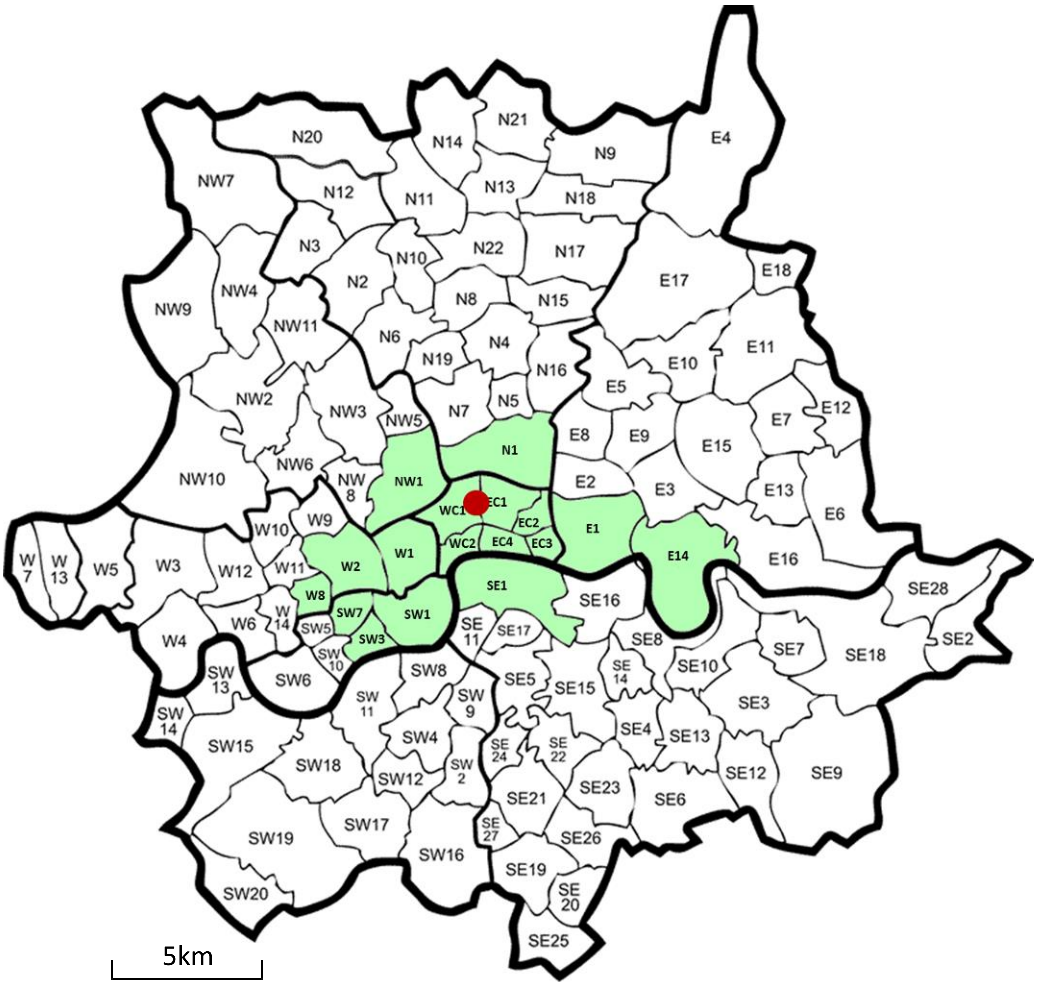


Figure 7.2 Map of bicycle courier postcodes indicating the restrictions of bicycle courier services for GOSH [red dot = GOSH]

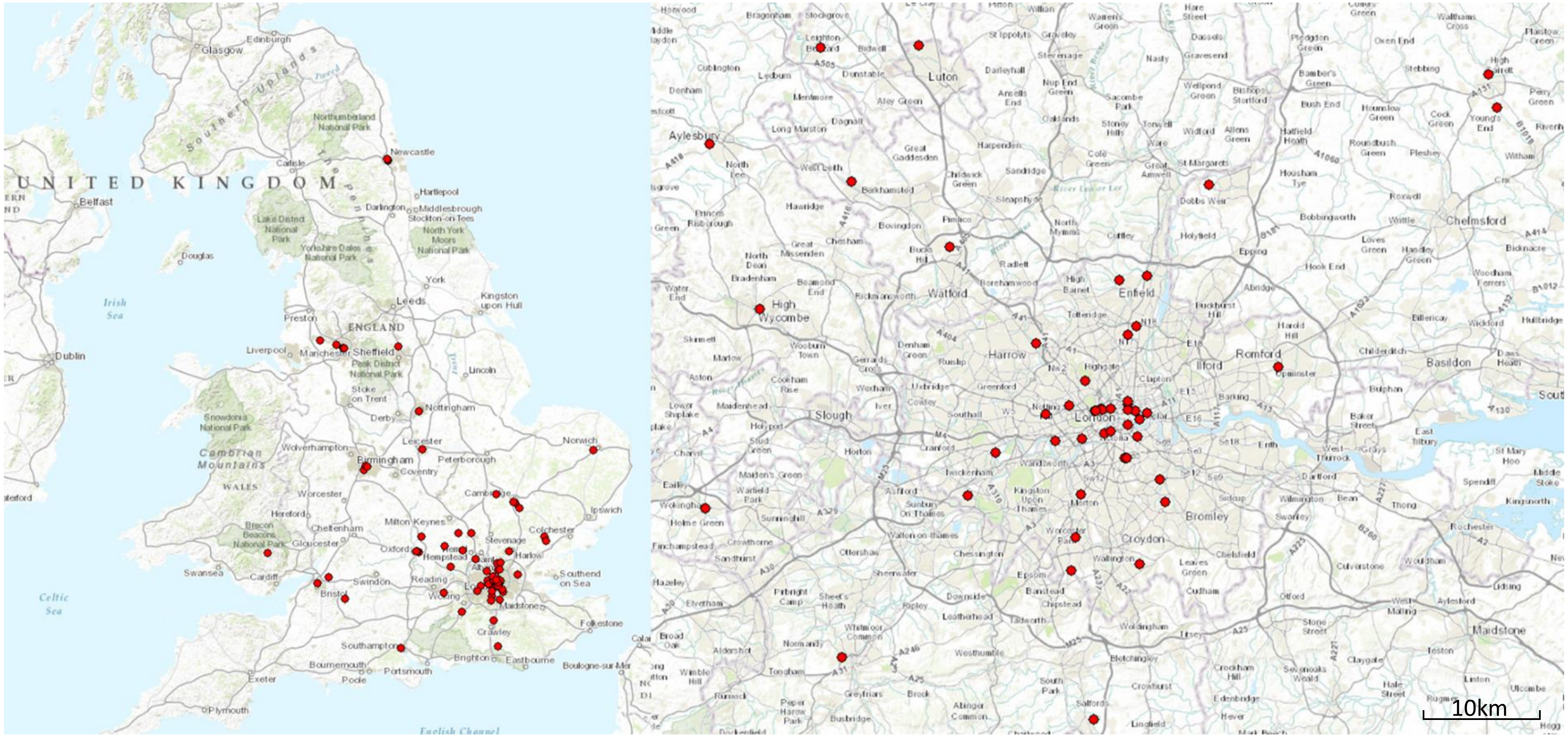


Figure 7.3 Nationwide distribution of courier destinations for courier services making deliveries for GOSH

7.3 Methodology

7.3.1 **Journey Distance Analysis**

Journey distance was assessed using the shortest journey options, calculated using ArcGIS Network Analysis Tool. Journey origins and destinations were represented by the Easting and Northing for all supply chain nodes, obtained using postcode data, compared against Ordnance Survey 'Code-Point' data.

7.3.2 **Scenario Testing**

The base case was modelled according to the current method of practice, whereby each record is couriered in a dedicated individual vehicle trip, to mirror the current practices. As previously stated, no records were available to indicate the vehicles used for each individual trip therefore vehicles were assigned to each record according to the smallest vehicle the consignment can fit within. The emissions for each trip were calculated by multiplying the emissions factor, Table 7.2, for a given vehicle against the distance of the journey.

The temporal consolidation of courier samples was conducted using a hill climbing optimisation algorithm, with an integrated travelling salesperson function to determine the shortest delivery route for each vehicle trip, detailed in Section 4.5. As stated in Chapter 4, heuristic approaches are typically applied to such problems whereby a solution close to, or at the global optimum to the problem may be found in less time than would be required to search exhaustively through each possible solution. This approach was selected owing to the potentially high number of combinations items may be packed into. For example, in accordance with guidance from Johnson and Bhattacharyya (2001), on the busiest day there is a maximum of 15 (*r*) parcels which may be consolidated into a single time period, assuming all items may be packed into all 6 possible vehicle types (*n*), there are 4.70185 x 10^{11} possible combinations to choose from (Equation 4).

$$Number\ of\ Permutations\ (with\ repetition) = n^r \qquad \text{Eq.4}$$

However, in reality the potential number of combinations for this problem is reduced owing to the constraints of items being compatible with a given vehicle type. Further to this, the problem is complicated by the subsequent reduction in vehicle capacity once a vehicle contains a parcel.

The temporal consolidation of services was assessed dividing a standard 10-hour day at GOSH into time intervals. An initial test was performed to assess the impact on the total distance (Km) and vehicle emissions (tCO_2) from a change in the number of time intervals, indicating that an decrease of 5 intervals was sufficient, Table 7.3. Additional scenarios of 4, 3, 2 and 1, were also added to the assessment to determine the impacts of time intervals as their duration is extended to encompass a single day.

Table 7.3 Time intervals for courier consolidation

Time Interval	**Duration (Minutes)**
20	30
15	40
10	60
5	120
4	150
3	200
2	300
1	600

7.3.3 **Courier Consolidation Model**

The model creates a set number of time periods over a 10 hour day (07:00 – 17:00), according to a pre-set length for each period, varying between 30 minutes (i.e. 20 time intervals per day) and 600 minutes (1 time interval per day). It allocates each order on a given day to the correct time period according to the time it was booked in, thereby creating a demand for each time interval.

For each time period, the model begins by randomly selecting a vehicle type (numbered 1 – 6), Table 7.2. It proceeds to pack each item for the time period into the vehicles, using a comparable approach to a First Fit Decreasing Height strip packing algorithm (Lodi et al. 2002), whereby items are packed into the first vehicle they will fit in. If an item is packed, the destination for that item is added to the vehicle's delivery route, and the residual capacity of the vehicle is decreased. If an item is not packed, the model adds another random vehicle type to the list of available delivery vehicles (vehicle sequence) and attempts to pack the consignments again. This process is repeated until all items are packed. If the number of vehicles required to accommodate all the items in the time period exceeds the total number of items to be couriered, the empty vehicles are discarded as they will not accrue any vehicle-kms and therefore will not generate any emissions contributing to the overall performance of the solution.

Once a starting sequence is established, Figure 7.4, it is tested for fitness, assessing the VKm generated by the required delivery route and emissions generated by each vehicle to complete their respective delivery rounds. This provides a metric against which alternative vehicle sequences for each time interval may be compared. From this point, the vehicle sequence is mutated by means of randomly selecting a vehicle within the sequence and changing it for another randomly selected vehicle. The process of packing the items is repeated until all items are packed, at which point the 'test for fitness' (Section 4.5.2) is also repeated. This process is repeated until no further improvement can be found.

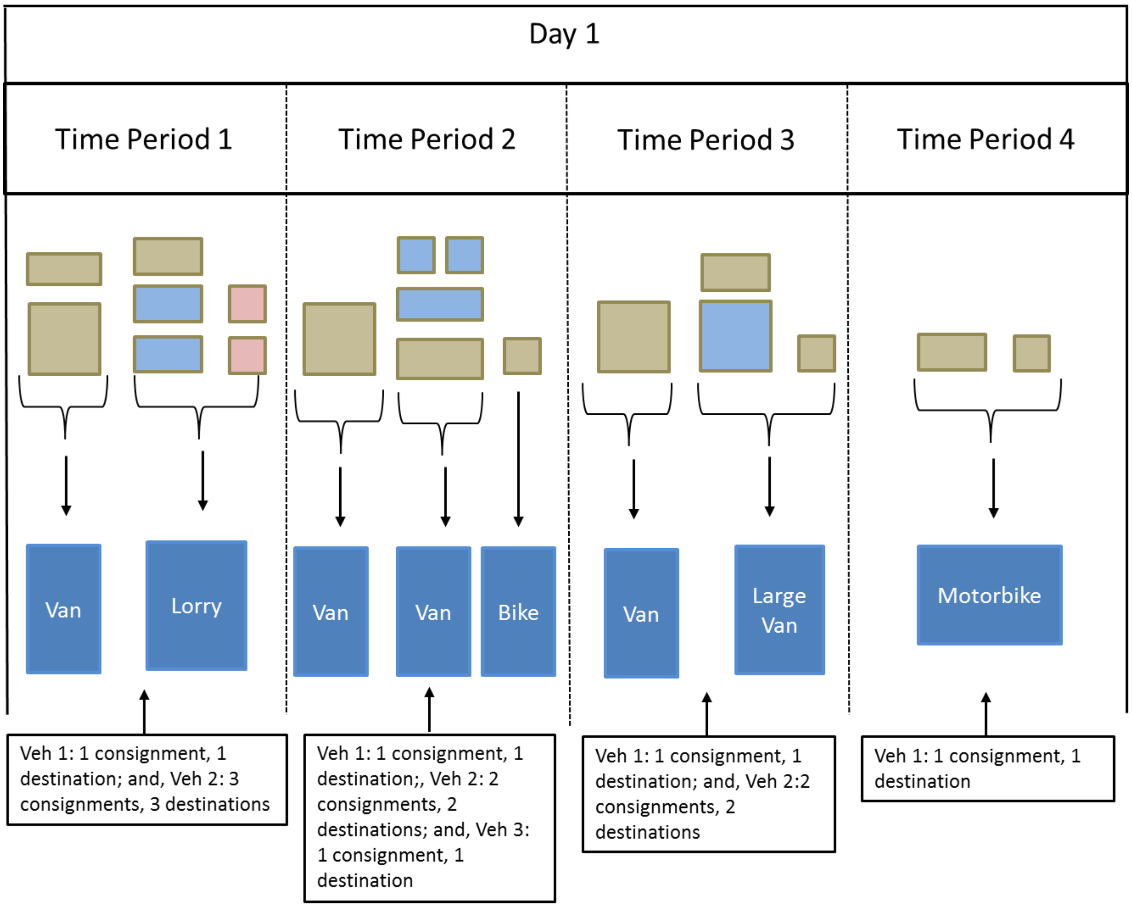


Figure 7.4 Process of consolidation for items delayed within a given time period

7.4 Validation of the Courier Consolidation Model

The courier consolidation model incorporated two heuristic approaches: a hill climbing algorithm and a travelling salesperson function.

The hill climbing algorithm for this approach is validated using the same approaches used in Section 5.4 and 6.4, simulating the highest demand scenario of items consolidated into a single time period (n=15) to be packed into vehicles, of which there are 6 to choose.

7.4.1 Validation of the TSP Model

Since the maximum possible number of destinations in a delivery route [n=15], as determined by the highest demand scenario whereby 15 items are couriered in a single day (1 time period), is less than the number of destinations used in the validation approach for the MCC TSP, Section 5.4, the same parameters, i.e. 1,000 starting points and 10 mutations, were used for the simulation of the integrated TSP model.

7.4.2 Validation of Mutations for the Hill Climber

Owing to the nature of the model whereby part of the solution is destroyed each time, the results of this analysis do not indicate a threshold of mutations at which an optimal result will be achieved. Therefore the same number of mutations [n=10] that are used for the MCC model (Section 5.4.2) were used for each courier consolidation scenario.

7.4.3 Validation of Starting Points for the Hill Climber

Simulation of 100 starting points comprising 10 mutations, Figure 7.5, indicated that total vehicle emissions less than 1.6 tCO_2e and 1.7 tCO_2e are achieved within 3%, and 22% of simulations, respectively. Therefore, in approximately 3 runs out of 100 the most optimal result achievable will be found, and a further 19 runs out of 100 a result within 6% of the most optimal result will be achieved. These results indicated a higher probability of achieving a result close to the most optimal vehicle emissions achieved by the model within 100 starting points.

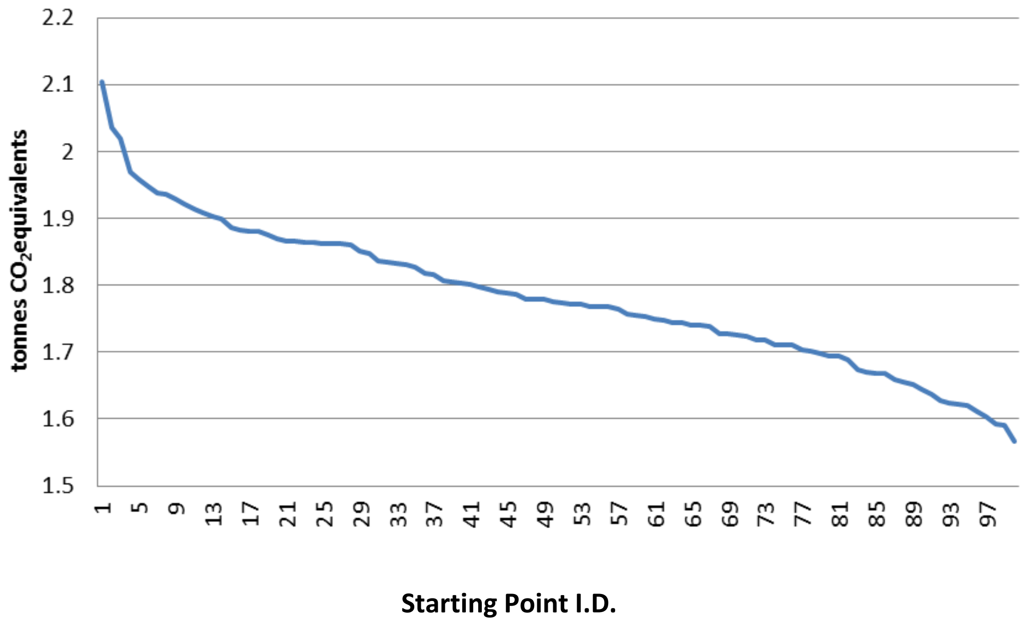


Figure 7.5 Validation of the end results (emissions) for 100 starting points each comprising 10 mutations – reduction of the overall emissions for each starting point indicates an optimum has not been achieved, however model runs of 100 starting points will yield the best result achievable within the time constraints of the project

7.5 Results

Comparison of the results for the consolidation of all 323 courier services against the base scenario across the whole database, Table 7.4, indicated reductions of between 337 VKm (30 minute time periods) and 3,744 VKm (daily consolidation), however the total emissions associated with the consolidated journeys indicated an increase (between 0.42 and 0.83, for the 1 time period and 20 time period tests, respectively) in the cumulative tonnes of CO_2 equivalents emitted. Further to this, the fuel consumption observed for the consolidated scenarios is significantly greater, with increases of between 226.74 litres (1 time period) and 559.05 litres (20 time periods). Assessment of the vehicle composition for each consolidation scenario, Table 7.5 and Figure 7.6, indicated that the elevated vehicle emissions and fuel consumption observed in the consolidated scenarios may be ascribed to the lower utilisation of bicycle transport (which is used significantly more in the base scenario) and higher utilisation of larger vehicles which are inherently required to transport consolidated loads.

Table 7.4 Courier consolidation model results for each temporal delay scenario [100 starting points each comprising 10 mutations]

	Performance Metrics		
Scenario	**Total Distance [VKm]**	**Total Emissions [tCO_2][a]**	**Fuel Consumption [Litres]**
Base	11,311	1.16	149.38
20 (30 min) time periods	10,974.54	1.99	708.43
15 (40 min) time periods	11,043.84	2.00	712.90
10 (1 hour) time periods	10,722.50	1.96	692.16
5 (2 hour) time periods	10,723.90	1.96	569.55
4 (2 hour 30 min) time periods	10,699.49	2.00	690.67
3 (3 hour 20 min) time periods	10,082.48	1.96	614.46
2 (5 hour) time periods	9,628.43	1.90	553.38
1 (10 hour) time period	7,567.60	1.58	376.12

a. Metric tons of Carbon Dioxide.

As previously mentioned, the selection of vehicles for couriering samples is largely based on the minimum space and weight requirements of an item and the proximity of ‘compatible’ vehicles to the hospital. Therefore, the base scenario whereby the smallest vehicle is allocated to an item may be considered an improvement of the ‘real-world’ scenario. However, full assessment of the ‘real-world’ scenario is complicated as, with the exception of low capacity vehicles such as bicycles and motorcycles, courier vehicles are seldom dedicated solely to a single customer’s item often transporting items for numerous customers at the same time. Therefore the distance, emissions and fuel consumption accrued by a vehicle is shared between many customers.

Table 7.5 Number of vehicles for each vehicle type required for each time interval

		Consolidated Time Periods							
Vehicle	**Base**	**20**	**15**	**10**	**5**	**4**	**3**	**2**	**1**
Bicycle	65	1	2	0	1	2	7	4	2
Motorcycle	247	37	41	24	22	24	12	9	2
Small Van	11	144	145	132	113	96	78	56	38
Transit SWB Van	0	16	10	15	13	13	18	14	12
Transit LWB Van	0	2	4	1	4	1	6	12	7
Transit XLWB Van	0	3	0	1	4	9	4	6	7
Total	**323**	**203**	**202**	**173**	**157**	**145**	**125**	**101**	**68**

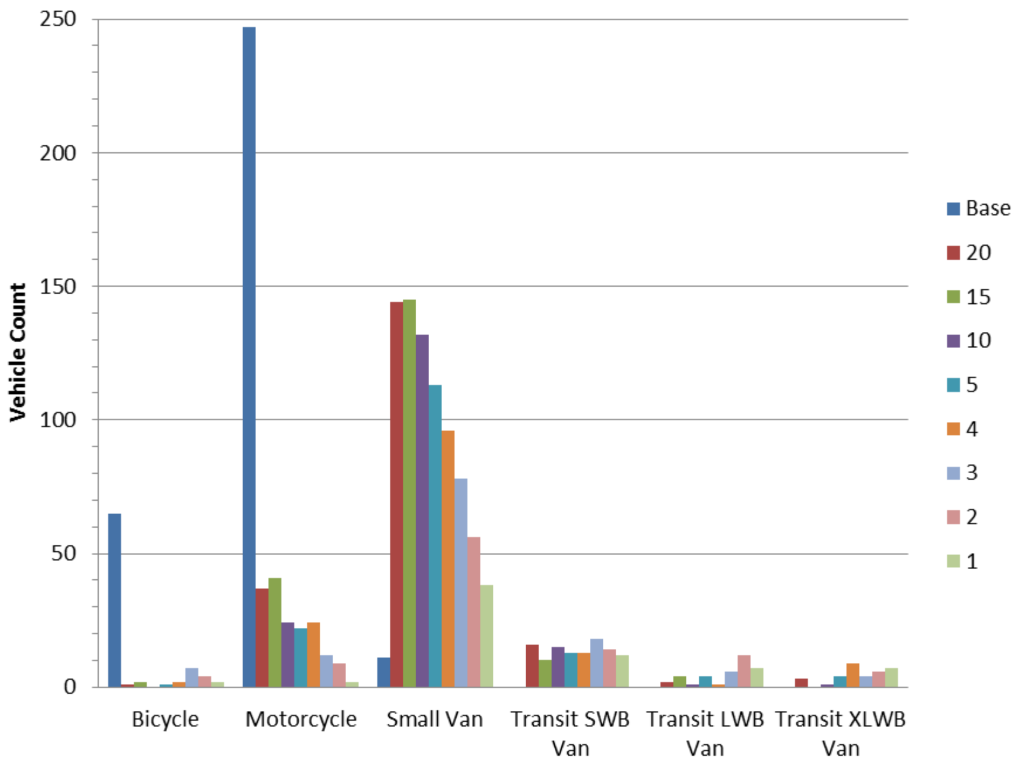


Figure 7.6 Comparison of vehicles composition (i.e. the proportion of vehicles used from each type) by consolidation scenario

Assessment of the results, Figure 7.6 indicated a higher weighting towards utilisation of small vans for all consolidated scenarios, compared to the base where greater use of motorcycles is observed. This modal shift represents an increase of 59 grams of CO_2 emissions per kilometre for every journey made.

Comparison of the total number of vehicles used for each consolidation scenario, Figure 7.7 indicated a 37% reduction in traffic volumes is achieved between the base and temporal consolidation in 30 minute periods. Further consolidation of courier trips by 15 periods indicated negligible gains are achieved. Additional gains of between 8% and 14% are yielded for each subsequent increase in the duration of consolidated periods, up to 3 time periods. Further consolidation of items yielded additional gains of 19% and 33%, for 2 time periods and 1 time period, respectively, on previous temporally consolidated time periods. These observed gains indicated an overall range of 42% reductions in vehicle numbers between the consolidation of items into 30 minute periods and 1 day.

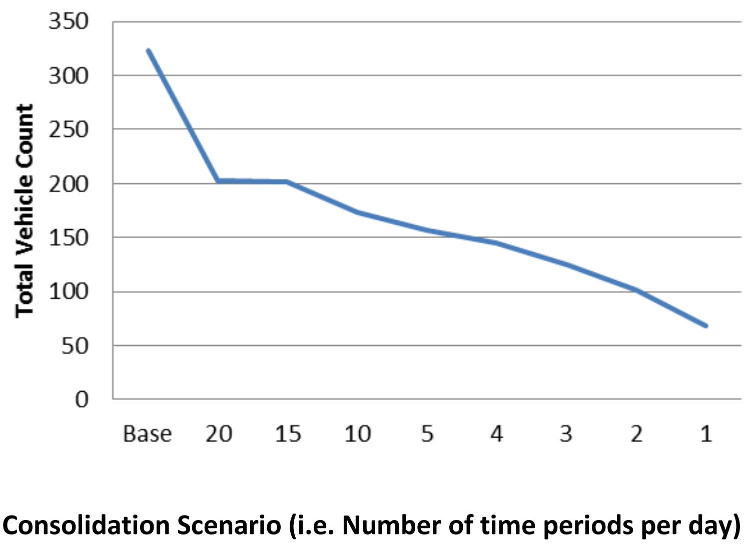


Figure 7.7 Comparison of total vehicle numbers for temporal consolidation

According to the assessed models of operation customers and service providers are posed with the decision of safeguarding road network capacity through the consolidation of courier services which indicate a greater negative environmental impact; or aiming for more environmentally efficient services which engender higher traffic volumes on freight networks.

In light of this finding, an additional set of model simulations (for 1, 5, 10, 15 and 20 time period scenarios) were performed to determine the required vehicle emission savings achieved by cleaner fuels and locomotive methods, to make consolidated services more environmentally attractive, Table 7.6.

The results, Table 7.6 indicated that savings against the base (Table 7.4) are achieved with 30% reductions in vehicle emissions for the 1 time period scenario. However reductions below the base are not achieved for the remaining time period scenarios until reductions of 40% vehicle emissions are reached. Whilst these savings may be achieved with the use of low carbon or zero carbon technologies, by way for fair comparison between the consolidated and base scenarios, the efficiency savings applied to consolidated scenarios would also be applied to the base case. This would likely result in the base case yielding lower carbon emissions.

Table 7.6 Low emissions courier consolidation model results [100 starting points, each comprising 10 mutations] – testing the emissions generated for each temporal consolidation scenario according to 10% increases in vehicle efficiency (i.e. reductions in vehicle emissions tCOe)

	1 Time Period		**5 Time Periods**		**10 Time Periods**		**15 Time Periods**		**20 Time Periods**	
Vehicle Efficiency	***Emissions (tCO_2e)***	***Distance (km)***	***Emissions (tCO_2e)***	***Distance (km)***	***Emissions (tCO_2e)***	***Distance (km)***	***Emissions (tCO_2e)***	***Distance (km)***	***Emissions (tCO_2e)***	***Distance (km)***
60%	0.64	7,331.17	0.84	10,782.36	0.83	10,674.90	0.86	11,105.58	0.85	11,021.85
70%	1.12	7,853.30	1.38	10,700.67	1.38	11,333.78	1.42	11,059.69	1.41	11,016
80%	1.19	7,261.45	1.57	10,703.62	1.58	10,998.75	1.62	11,060.42	1.61	11,008.79
90%	1.39	7,596.62	1.78	10,751.68	1.77	10,986.79	1.82	11,067.62	1.80	10,991.77

7.6 Summary

The current model of operation for laboratory sample courier services within healthcare is perceived to be unsustainable. With high numbers of vehicles performing individual or dedicated trips for customers. However, this research indicated that the current model of operation for hospital laboratory samples is more optimal from an environmental perspective, saving between 0.42 and 0.84 tCO_2 over a three month period, compared against a number of temporally consolidated scenarios. It should be noted that the base case scenario is representative of the best operational scenario should items be couriered individually, with all 65 samples compatible with bicycles couriered as such. However, consolidated scenarios were found to provide VKm savings between 336.46 (20 time periods per day) and 3,743.4 (1 time period per day) against the base. Conversely, consolidated courier journeys for the same period indicated significant reductions in the total number of vehicles required to complete all deliveries. Consequently, the key decision for courier companies and customers to make is whether to adopt environmentally efficient operations, or whether to safeguard the existing urban road network capacity through consolidated courier practices, which may also act to reduce the number of freight related traffic accidents within urban areas.

Therefore, it may be postulated that the benefits of reduced vehicles, vehicle-kilometres and emissions may only be achieved through the use of vehicles powered by greener fuel technologies such as electric assisted bicycles and electric vehicles, which enable for the consolidation of items with reduced levels of emissions.

Whilst it is recognised that the speed of sample analysis and turn around are likely to have an impact on the extent to which items may be consolidated, the data required to include such analysis did not exist at the Trust. However, it may be assumed that should dedicated couriering windows be established it may act to drive the analysis of samples within certain time frames to meet specific delivery windows.

Chapter 8: Discussion and Conclusions

This study aimed to understand the requirements of hospitals and their impacts on healthcare supply chain efficiency with a view to investigate the past, current and future developments in healthcare and wider supply chain literature. The intended outcome of which was to develop a number of solutions to improve the environmental performance of healthcare supply chains without compromising service quality. This chapter discusses the overall findings and resultant implications of this research in more detail.

8.1 Healthcare Supply Chain Management – Understanding hospital requirements and the impacts on the healthcare supply chain

The requirements of healthcare supply chains are inherently inefficient, with much of the literature citing agile supply and incomplete / incoherent demand information as the primary causes of economically and environmentally unsustainable freight practices.

The review of healthcare supply chain literature, Chapter 2, highlighted that widespread inefficiencies, such as high vehicle frequencies, sub-optimal load factors and stock-out scenarios are documented worldwide throughout public and private healthcare sectors. Such inefficiencies are ascribed to unpredictable and highly variable inventory requirements owing to the broad spectrum of illnesses and ailments, and variations in patient response to treatment, which affect the type, level and duration of care required by each patient. Research indicated that these characteristics of hospital demand are typically managed using a parallel supply chain structure, comprising:

- A primary multi-echelon (consolidated) supply chain to ensure the continuous replenishment of key inventories and common use bulk items such as gowns, gloves etc.; and,
- A secondary single-echelon (agile) supply chain to provide the delivery of specialist items and manage unplanned inventory requirements with direct shipping from supplier to hospital.

This supply chain model is implemented extensively throughout the public and private healthcare sectors. However, the effective utilisation of the model has been found to differ between public and private healthcare markets, with lower supplier participation in the primary supply chain documented amongst public sector healthcare institutions (c. 30% at GOSH). Much of the literature postulates that higher rates of subscription to consolidated routes of supply under privatised markets may be attributed to complimentary cost-driven market mechanisms, which can also be observed in the wider consolidation supply chain literature, stipulating that UCCs are not feasible under liberal markets outside of the construction sector or without a single landlord imposing mandatory use (Regué and Bristow 2013).

Given agile forms of supply have been found to engender high delivery frequencies and sub-optimal load factors (McKone-Sweet et al. 2005), the high volume of deliveries observed at GOSH during the 5-day DSP survey (n = 403) may be considered symptomatic of the high proportion of goods procured via the secondary agile supply chain route. Conversely, despite high numbers of private sector healthcare institutions and their suppliers subscribing to consolidated medical supply, sub-optimal supply chain practices and operations continue to be experienced, therefore indicating that the characteristics of agile supply are not the only reasons for the observed inefficiencies.

Much of the healthcare supply chain literature suggests that the inefficiencies observed in healthcare supply chains may be managed by supply chain management best practice such as CPFR (McKone-Sweet et al. 2005; Aronsson et al. 2011; de Vries and Huijsman 2012). However, the successful implementation of such solutions is perceived to be blocked by poor visibility and monitoring of hospital inventory, and a lack of capital to develop ICT supply support structures (Burns 2002; McKone-Sweet et al. 2005).

Comprehensive and coherent generation and communication of demand specific information is a key requirement for any supply chain to cater for the needs of the end-consumer. Such information is necessary for all nodes (i.e. manufacturers and suppliers) to coordinate their operations to ensure that product orders and manufacturing can be met on-time and in-full. However, poor visibility and monitoring of inventorying is a recurring theme within healthcare supply chain literature, with many operational and technological solutions focussing on methods to improve the monitoring and communication of inventory levels and consumption.

As discussed in Chapter 2, the direct / stockless inventory approach attempted to increase the visibility and monitoring of hospital inventories for suppliers by consolidating the total number of suppliers, and disintermediating the supply chain by granting them greater autonomy over the management of stock at ward level. Whilst this model mitigated against stock-outs within hospitals, improved the overall utilisation of stock and increased vehicle fill-rates, it resulted in an increase of delivery frequencies to hospitals. This suggests that in order for the requirements of a hospital to be met in full, inefficient freight patterns are required. However, despite this approach optimising supplier operations, perceptions of greater benefits gained by hospitals resulted in the stockless inventory approach being abandoned by suppliers. Further analysis of this approach in the context of specialist care institutions, such as GOSH also renders the concept impracticable, owing to high numbers of suppliers for specialist items which would prevent the consolidation of the total supplier population.

8.2 Technological Advances in Healthcare Supply Chain Management – Investigating the current and future developments in healthcare logistics technologies and their potential impacts

Technological solutions such as intelligent storage and item tracking (e.g. RFID) demonstrate significant gains to be made in the management and utilisation of stock within hospitals, thereby helping to improve the generation of demand information for suppliers to enable more sustainable freight practices.

The greater level of monitoring achieved by such solutions has been shown to generate comprehensive and detailed demand data which can be passed onto suppliers electronically to facilitate a CPFR framework. If such solutions were implemented within each ward store in a hospital, it may yield the same level of visibility for inventory levels afforded by the stockless inventory approach. In addition to this, it is argued that the enhanced awareness of inventory held within each location of the hospital would enable inter-departmental sharing of inventory, thereby decreasing the dependence on externally sourced agile supply when a ward stocks-out of an item. Further to this, as demonstrated by Mun et al. (2007), increased locational awareness of assets within hospitals can improve asset utilisation and highlight areas in which reductions of surplus equipment and inventory may be made.

However, real-world implementation of such solutions at a hospital-wide level typically represents a significant capital outlay, rendering such solutions unaffordable for public healthcare institutions. Therefore, intelligent storage and tracking systems are typically implemented within theatre areas which use large volumes of high value items and equipment. Furthermore, studies have found that the practicalities of tagging the lowest denominations of each inventory item and the potential destruction of tags present significant barriers to the practical application of technologies which require RFID and 2D-code tagging.

In addition to this, comparisons of the outcomes for the implementation of intelligent storage solutions within two major London NHS Trusts highlighted institutional barriers such as staff willingness to change, to hamper the successful implementation of ICT inventory managing technologies. Despite recognised benefits to both staff and patients, in the form of reduced administrative inventory tasks for staff, it was found that without the comprehensive policing of the system by a member of staff, users of the cabinets may not adhere to the required operational practices of the system required to deliver the intended benefits.

Interviews with supply chain staff at GOSH indicated a perception of staff fearing surveillance within hospitals to be one of the main reasons for resistance of such ICT solutions. This is in part substantiated by the practice of inventory hording, widely recognised within UK NHS Trusts, whereby staff who perceive stock-outs of horded items to be a common occurrence, habitually stock pile them in ‘hidden’ areas for use. Such practices would not be possible under highly managed inventory systems, potentially leading to staff resistance.

Wider assessment of attitudes within hospitals and amongst healthcare suppliers from the results of qualitative assessments with staff (Chapters 5, 6 & 7) indicated that a lack of willingness towards change and the financial burden of wide-scale implementation of new technologies and working practices presents one of the most significant barriers to the successful implementation of sustainable supply chain measures. This has also been observed in the wider sustainable urban logistics literature, most prominently pertaining to urban consolidation.

The value of future technologies such as Smart pills and body sensor networks arguably provide the greatest potential benefits to the healthcare supply chain. Monitoring the health of people and patients outside hospitals would enable for the accurate prediction of inventory requirements, thereby facilitating increased levels of freight planning, which may enable for improved vehicle fill-rates and greater supplier collaboration. However, the actual implementation of such technologies appears to be a long way from any practical implementation owing to the required establishment of legal legislation and guidance detailing the liabilities and privacy agreements relevant to the technologies.

The success of many advances in healthcare supply chain management is hinged on the deployment of technologies and solutions industry-wide throughout all hospitals and amongst the majority of healthcare inventory suppliers. However, as demonstrated by the UK, U.S. and Chinese initiatives to encourage the wide-scale deployment of Electronic Data Interchange, achieving large-scale change is a slow process. It has become apparent that for healthcare supply chains to become sustainable, significant amounts of organisational change are required for long-term solutions to be achieved. Without the presence of complimentary market measures, institutional barriers prevent the fast deployment of sustainable long-term solutions. Therefore, it may be deduced that whilst addressing the root cause of unsustainable healthcare supply inherent within the internal supply chain may provide a long-term solution, in the short-term, in the interest of meeting the 2011 White Paper goal to achieve essentially CO_2-free cities by 2030, sustainable external supply chain strategies are required to accommodate the needs of the internal chain, whilst positively addressing the external issues.

8.3 Application of Sustainable Urban Logistics for Healthcare – Evaluating the range of sustainable urban logistics solutions and how they may be implemented in healthcare

Consolidated and night-time freight operations may provide sustainable solutions which accommodate the current operating practices of hospitals whilst achieving reductions in freight traffic volumes and emissions within city centres associated with inner-city hospitals and healthcare institutions.

A review of sustainable urban logistics literature outlined six key measures: market-based, regulatory, supplier collaboration, urban consolidation, out-of-hours deliveries and sustainable courier transportation initiatives.

Assessment of market-based and regulatory measures in relation to healthcare indicated that whilst their implementation in isolation has been found to deliver reductions in urban freight numbers and the disruptions caused by unloading and loading activities. The benefits they provide can be limited owing to suppliers and parcel carriers continuing freight activities and accruing charges which are subsequently passed onto customers. In the context of healthcare these solutions present less of an impact as in some of the reviewed cases healthcare suppliers are granted exemption from charges and restrictions owing to the essential services they provide. However, such solutions have been found to yield significant benefits when implemented in tandem with one, or a combination of the remaining four sustainable urban logistics measures.

An assessment of collaboration indicated that there is some scope for collaborative procurement of goods between hospitals within a single geographical region, as demonstrated by the collaborative alliances formed in Singapore (Pan and Pokharel 2007). However, such alliances are typically formed as a cost-saving measure. A review of the London Procurement Partnership (LPP), which represents a collaborative alliance between a number London NHS Trusts demonstrates that collaborative sustainable urban logistics measures are feasible in the UK NHS context. However, much like the Singapore alliance, the LPP represents an economically driven initiative intended to provide an alternative means of consolidated supply to the current NHS Supply Chain. The success of this initiative has been hampered by issues pertaining to the allocation of charges for the service, with the NHS requesting a zero on-cost to the organisation resulting in suppliers electing to provide goods by other means. Therefore, the success of collaborative measures between hospitals is found to be hampered by the avoidance of capital charges.

Supplier to supplier collaboration has been found to yield significant benefits between partners and competitors within the same industries. However, such forms of collaboration require a comprehensive database (Bhakoo and Singh 2012) to predict and identify the slack capacity available within vehicles for shared loads. Therefore, given the unpredictability of demand and the lack of comprehensive demand information available in the healthcare industry, supplier collaboration may be considered unattainable.

Despite poor participation in current consolidated healthcare supply, urban consolidation presents one of the most promising methods of freight volume reduction whilst also accommodating hospital service requirements. Interviews with members of supply chain staff at GOSH and a review of the literature identified the erosion of supplier profits, loss of control and visibility of goods travelling to end-consumers, and the sub-optimisation of suppliers current operations to be significant barriers to the success of consolidation schemes. Previous attempts to overcome such barriers typically focussed on the monetary incentivising of suppliers to use freight consolidation services in order to achieve the necessary economies of scale which provide attractive returns, such as reduced operating costs to suppliers. However, as indicated by the literature, approximately 80% of urban consolidation schemes fail without the presence of continued financial subsidies or measures making use of the services mandatory. Further assessment of the literature identified that little appears to have been done to redesign the current model of consolidation attempting to: offset the costs of schemes against cost-savings to the end-consumer; and reduce the negative impacts on suppliers thereby making participation more attractive. This research attempted to address this gap in knowledge with the appraisal of a novel mobile consolidation concept for healthcare. However, in consideration of the presence of urgent and non-urgent items within the supply chain, it was considered necessary that an alternative delivery method was provided for the receipt of urgent items to the Trust, in the form of unattended electronic delivery.

Assessment of the out-of-hours deliveries literature showed that night-time deliveries of freight can provide significant environmental and operational benefits to organisations as a result of faster and more reliable journey times. However, implementation of out-of-hours activities requires the employment of additional staff, which accrues higher costs than day-time staff owing to unsociable working hours and extended business insurance. Integration of night-time receipt of NHS Supply Chain deliveries into GOSH demonstrates that out-of-hours deliveries are feasible in the context of healthcare. However, out-of-hours deliveries at the Trust are afforded by the large amount of space available within the loading bay to which deliveries may be made and securely stored. Whilst the holding of inventory within an overnight lock-up eliminates the need to employ additional staff to receipt items, in order to ensure the security of the delivered items, use of the out-of-hours delivery facilities at the Trust are limited to a single supplier. In addition to this, as found during the survey of the Trust, and as identified in the literature, hospital loading bays often suffer from insufficient physical space to accommodate traffic volumes. Therefore, the provision of night-time storage such as a secure lockable cage or compound may be considered untenable in many cases.

However, implementation of unattended electronic delivery solutions presents potential for resolution of the issues pertaining to out-of-hours deliveries, enabling for receipt of items at any-time of the day, into a secure facility without the need for additional staff or insurance. Furthermore, owing to their size they do not provide a solution for large volumes of goods. Therefore, unattended electronic delivery solutions were found to present significant potential for their use in the delivery of specialist and urgent items to hospitals. In this context they provide a solution to the issues surrounding the mixing of urgent items in the supply chain and their potential subsequent delay within internal hospital distribution networks. This research identified such application of unattended electronic delivery solutions as a gap in the healthcare supply chain literature, and attempted to fill it by testing the concepts feasibility.

As highlighted by the literature, laboratory courier services are pervasive within healthcare. The presence of CEP services within urban areas are a widely recognised problem, contributing significantly to urban congestion and city-wide vehicle emissions. Wider CEP literature identifies such services as a necessary requirement in urban environments suggesting their impact can be largely mitigated by the use of bicycles to complete journeys. However, upon assessment of the requirements of items typically couriered from hospitals, such as an item's: urgency, size, temperature control and journey distance, a large number of items are not compatible with bicycles. This research identified that whilst most CEP literature focusses on sustainable services from the perspective of cost and achieving more sustainable operations by modal shift, little has been done to assess the effects of temporal consolidation. In recognition of this and the requirements of couriered laboratory samples, this research focussed on testing the feasibility of temporal consolidation of laboratory courier samples and its impacts on the traffic volumes and emissions.

8.4 Understanding the benefits of Mobile Consolidation, Unattended Delivery and Sustainable Laboratory Courier Services for Healthcare, in the context of GOSH

8.4.1 Mobile Consolidation

Analysis of the mobile consolidation concept (MCC) was focussed on quantifying the practical feasibility and environmental impact of the concept, in the context of a single hospital (GOSH) and London-wide implementation (incorporating 29 NHS Trusts) under various operational scenarios comprising numerous MCC unit locations. The following findings were derived from the analysis of the results.

GOSH-Only MCC Assessments

Implementation of a Mobile Consolidation Centre for GOSH could deliver significant reductions upwards of 40%, 35% and 37% for VKm, journey times and emissions, respectively, for the hospital and local road network. However, in the citywide context these reductions may be perceived to be negligible (i.e. maximum reductions of 2.33 tonnes of CO_2 emissions).

The assessment of the MCC for the consolidation of non-urgent goods to GOSH indicated the concept to be feasible implemented as a 19-tonne trailer unit, provided demand smoothing practices, as executed for the NHS Supply Chain were used. An analysis of potential consolidation centre locations indicated a northerly located site to deliver generate the smallest VKms travelled (15,689) and Journey Time hours (344.80), followed by western, southern and eastern locations. This trend was found to reflect the national distribution and concentrations of suppliers to GOSH.

Results from the assessment of the base supply chain scenario against the base supply chain excluding GOSH indicated that the inclusion of GOSH within the existing supply chain has minimal impacts on the performance of the supply chain, with 2%, 1% and 3% increases in total VKm, Journey time and emissions, respectively. This indicated that the full redirection of goods to GOSH via a consolidated route may result in an overall increase in traffic and emission within the city.

Assessment of the consolidated results for the consolidation scenarios (1 – 4 sites) indicated significant reductions in:

- VKms between 10,592 (1 site) and 12,174 (4 site);
- Journey time hours ranging from 182.09 (1 site) to 225.05 (4 site); and,
- Tonnes of CO_2 equivalents emitted, between 2 (1 site) and 2.33 (4 site), compared against the base.

Analysis of these results indicated the most significant reductions in all three metrics to be achieved for single site consolidation against the base, with additional small reductions (c. 6%) yielded for the addition of a second site. However, an increase in journey time hours was observed between the single site and two site operations. This was largely attributed to insufficient reductions in journey time gained by suppliers to offset the additional journey performed by the MCC unit to transfer to the second site. Observations of the MCC indicated that with the exception of journey time savings for the 3 site scenario (achieving a further 11% reduction in journey time against the 2 site model) minimal additional reductions were gained for the addition of a third and fourth location, across all metrics. Therefore it may be considered that the operation of the MCC service beyond a two site model is unnecessary.

The results for the GOSH-only consolidation model indicated that whilst the traffic and emissions impacts present significant benefits to GOSH with respect to: reduced pressures on the loading bay which has been identified as operating over-capacity; and, potentially significant impacts on the local road network as a result of reductions in vehicle numbers and unauthorised loading and unloading activities.

London-wide MCC Assessments

The provision of MCC units for 29 NHS Hospitals throughout Central London may provide significant reductions in freight related vehicle kilometres, journey time and emissions up to 24.5%, 12% and 39.1% respectively (yielded from implementation of the concept for each hospital over 4 sites).

Two models of operation for the London-wide scenario were tested:

1. MCC units allocated to individual hospitals or NHS Foundation Trusts; and,
2. MCC units allocated to supplier groups, allocated according to the shortest journey for suppliers to make deliveries.

The purpose of these assessments was to quantify the impact of the concept in the context of London-wide VKms-travelled, journey time hours and emissions. Assessment of the London-wide scenario required the modelling of a London-wide base scenario, comprising 29 NHS Trusts. Data from the GOSH-only base model was used to inform the model, uplifting the vehicle requirements and associated emissions according to factors derived from comparisons between annual NHS Supply Chain order volumes for GOSH and the remaining 28 Trusts.

This generated a base scenario whereby a total of 261,805 VKm, 4,807 Journey Time hours, and 226.08 tonnes of CO_2 are accrued by 1,372 vehicle trips for the hospitals.

Extrapolation of the concept to a London-wide context indicated an estimated 36 trailers would be required to accommodate the expected delivery volumes for all 29 Trusts. Such numbers of MCC units poses a significant issue with regards to the siting of each centre, staffing requirements, and the potential traffic generation associated with their relocation between the four proposed sites.

Whilst both London-wide concepts have been found to delivery significant reductions in VKm (between 25,184 and 64,204), journey time hours (579.86) and related carbon emissions (61.04 – 88.41 tonnes CO_2 equivalents), economic analysis of the concept implemented at a London-wide scale over 4 sites was estimated between: £444,130 for units allocated by supplier group;

and, £446,662 for units allocated per hospital. This suggests that on a London-wide scale a warehousing model may be preferable as rental costs for such sites may the similar (Schulz 2014).

MCC Units per Hospital or NHS Foundation Trust

Analysis of the consolidated model indicated reductions in VKm between 16% and 25% from 1 site to 4 site scenarios, against the base; and reductions in total emissions (tCO_2e) between 37% and 40%.

As previously stated, the large number of MCC units was expected to potentially diminish the environmental savings yielded by the concept. This 'mechanism' was observed for London-wide journey time hours. Whilst an overall decrease in emissions against the base was observed, an increase in the emissions observed for 2 to 4 site scenarios against the single site scenario were recorded. It is expected that this increase may be in accordance with the increase in journey time hours observed between the 1 and 2 site operating model for GOSH-only freight. However, the negative effects of significantly increased numbers of MCC units may be found to have a greater impact, thereby affecting higher quantities of consolidation sites.

MCC Units per Supplier Group

Analysis of MCC units for each supplier group, fixing the location of equal numbers of trailers in each of the four geographical regions yielded reductions of 25,184.13 VKm, and 61.04 tonnes of CO_2 equivalents; and an increase of 368.73 journey time hours, against the base. However, comparison of the model for MCC units per hospital / NHS Foundation Trust comprising 4 sites against the model assessing MCC units per supplier group indicated that allocation of MCC units per hospital / NHS Foundation Trust yield between 17.5% and 17.7% greater reductions in VKm and associated emissions. Conversely, the model for MCC units allocated by supplier groups indicated an overall increase in journey time hours (22.4% increase on the overall journey time hours accrued by 4 site consolidation per hospital).

Comparison of the two London-wide models therefore indicates that one or two site operation of a model whereby MCC units are allocated to each hospital would be more beneficial. However, implementation of the model whereby MCC units are allocated per hospital / NHS

Foundation Trust represent a practical issue with the scheduling for the transfer of the required 36 MCC units for the concept.

Industry Feedback

Feedback from interviews with healthcare providers, suppliers, 3PLs and local authorities indicated that all participants perceived an increase in the visibility of their items and their final destination, compared against existing consolidation services.

Representatives of healthcare institutions identified the expedited delivery afforded by pre-sorting cages to be of a significant benefit. However, concerns regarding the secure storage of cages during night-time hours were raised. The agreed solution for which was to store the cages within a secure area of the hospital, such as the Receipts and Distribution department.

All participants raised concerns regarding the quality assurance, legal liabilities and responsibilities for items delivered to and held within the MCC. Whilst the issues of legal liabilities and responsibilities were addressed by the electronic receipting of items into units, concerns were raised by members of healthcare providers regarding the extensive quality assurance practices many Trusts implement to ensure the condition and accuracy of what is delivered against invoices. This highlights a key flaw in the implementation of automated systems, which may increase the potential of items which are unfit for use arriving at ward level and going un-identified until they are required. Such circumstances may be potentially fatal and also lead to a greater volume of urgent orders being made by Trusts. In light of this, staffing of the unit is considered the only viable outcome to overcome this issue, which also allays fears of security for the unit and its contents. However, staffing of the unit would represent a cost which is perceived to be more than the costs associated with the staffing of traditional consolidation concepts, owing to the ability for consolidation centre service providers to spread the costs of such services between multiple users.

3PL participants of the industry feedback process indicated few expected reductions in actual VKm and emissions to be achieved with any consolidation concept within London. They highlighted that it is common practice amongst parcel carriers to make provisions for a single delivery vehicle allocated to each postcode within London. Therefore, in spite of healthcare supplies being delivered to- and consolidated in- an out of city location, it may be likely that, as identified by the analysis of the GOSH only base scenario including and excluding GOSH in the supply chain, increases in inner-city vehicle numbers would be observed. Identification of such trends indicates that for urban areas to yield the full benefits from consolidation, market-based and regulatory measures are required to encourage more sustainable logistics planning amongst suppliers and 3PLs. However, as identified by the literature extensive models of consolidation available to all organisations within inner city locations is required to maximise adherence to market-based and regulatory measures.

Suppliers and 3PL companies indicated that with respect to the delivery of large consignments, a greater number of benefits to hospitals may be yielded by the implementation of the proposed MCC concept with regards to the additional time required to deliver of items into partitions of the unit, thereby pre-sorting items for delivery to Trusts. Further to this, it was suggested that where large consignments are being delivered it may be more prudent for suppliers to make deliveries direct to the hospital to prevent otherwise time consuming and unnecessary duplication of services.

The overall outcomes of the quantitative and industry feedback assessments concluded that whilst the proposed concept presents significant reductions in VKm, journey time hours, emissions and vehicle numbers; alongside numerous operational benefits, the concept may be better suited to implementation in tandem with the existing NHS Supply Chain, receiving delivery of the numerous small, high value items delivered to hospitals. Limitation of the concept to such deliveries would be expected to reduce the physical requirements of the concept, thereby reducing the number of trailers required for a London-wide operating scenario.

8.4.2 **Unattended Delivery for Urgent Goods Supply**

Unattended delivery for the receipt of urgent goods into hospitals is both technically and practically feasible indicating a maximum locker bank length of 3.69m required to accommodate 100% of all urgent deliveries; and, with hospital staff perceiving numerous benefits to the system with regards to the monitoring, security and speed of delivery for time-critical product orders.

This research tested the feasibility of unattended delivery for the receipt of urgent items into Trusts, as a means to improve the visibility, monitoring, speed and reliability for the delivery of time critical items to their intended recipient, whilst also separating urgent and non-urgent items within the supply chain, thereby facilitating more sustainable supply chain practices amongst non-urgent stock. In addition to this, various levels of modelling practices were tested to determine the optimal method with which to formulate the required specification of locker banks.

Results from the quantitative assessment found the delivery of urgent items to GOSH via an unattended electronic locker bank to be feasible. Model results indicated that a locker bank measuring a maximum of 4m long, by 1.7m high, by 80cm deep, to be adequate in accommodating 100% of all urgent goods demand to the hospital. The expected benefits of the proposed system was the removal of an average 8 urgent deliveries from the daily average number of ad-hoc deliveries to the Trust (n=81).

Feedback from staff and potential users of the system indicated that the implementation of the proposed system would provide many benefits with regards to the consolidation of critically urgent items sourced from numerous locations, the traceability of urgent items receipted into the Trust and reduction of stock shrinkage.

Hospital staff and 3PLs identified potential abuse of the system whereby orders of non-urgent items are indicated as urgent resulting in the artificial increase in urgent demand. Such practices may result in a locker bank operating above the available capacity, leading to the delivery of actual urgent items via traditional hospital distribution channels. However, this issue may be overcome by imposing restrictions on the use of the system, allocating approved users and / or approved items for the system.

Assessments of Modelling Approaches

Analysis of the different levels of modelling approach varying from: basic locker bank formulation using 4-hard coded partition types determined independent of demand characteristics; to, autonomously designed and allocated partitions according to demand, indicated that more optimal formulations of locker partitions for locker banks may be achieved with increased levels of influence from the characteristics of demand. Comparison of the modelling approaches assessing the requirements to accommodate 100% of all consignments indicated that semi-restricted modelling approaches (using 4-hard coded partitions specified for 4 ranges of box size) achieved 10% more optimal results (i.e. shorter overall required locker bank to accommodate 100% of urgent demand) against the restricted model, whereby partitions were specified irrespective of demand. Results from the unrestricted model, indicated 8% reductions in the required length for a locker bank. Whist these results indicated that semi-restricted modelling approaches yield better results than unrestricted models, it may be possible that the unrestricted model did not achieve a more optimal result owing to time constraints restricting the number of simulations which could be run. In the context of this research, the results of the modelling approach assessments indicated that given time constraints less sophisticated levels of modelling may produce more optimal results.

8.4.3 **Sustainable Courier Services for Healthcare**

Consolidation of courier services for hospitals could result in reductions in related traffic volumes (between 120 and 255 vehicles), with a potential increase in overall emissions being observed (ranging from 0.42 to 0.84 tonnes of CO_2).

This study attempted to quantify the value of temporal consolidation of courier services. As identified in the literature consolidation of courier services is considered to be difficult owing to the urgency and unpredictability of orders (Menge and Hebes 2011). In recognition of this, this research identified the number of deliveries listed as urgent (9) which cannot be consolidated, identifying 323 couriered items for the study.

Using a hill climbing algorithm with an integrated Travelling Salesperson fitness function, the courier demand was consolidated into optimal vehicle numbers and formulations for 8 time period scenarios. Results from the assessment indicated reductions between 337 VKm (30 minute time periods) and 3,744 VKm (daily consolidation). However, increases in the total emissions against the base were observed between 0.42 and 0.83 tonnes of CO_2 equivalents for the 1 time period and 20 time period tests, respectively. Further to this, the fuel consumption observed for the consolidated scenarios was significantly greater with increases between 226.74 litres (1 time period) and 559.05 litres (20 time periods), suggesting that consolidation of laboratory courier samples accumulates greater emissions and associated economic costs in fuel. Despite overall reductions in total VKm are observed for all consolidation scenarios an increase in the total VKm is observed for the 15 time period scenario against 20 time periods. This increase is also observed for tCO_2e and fuel consumption between the two scenarios.

Assessment of the total number of vehicles for each scenario indicated a significant reduction (between 38.2% and 79% for 20 time periods and 1 time period, respectively) in the number of vehicles required to complete all courier journeys. However, this reduction is achieved by an increase in small vans used for consolidation. Assessment of the vehicle profiles for temporal consolidation indicated that for the base 247 of the 323 items to be couriered were conveyed by motorcycle. Whereas analysis of consolidated scenarios showed a preference towards the use of small vans to transport items representing between 144 journeys (20 time periods) and 38 journeys (1 time period).

Assessment of the results across all consolidated scenarios indicated few additional gains achieved between the 20 time period and 15 time period scenarios. However, assessment of all subsequent consolidation scenarios indicated gains of between 8% and 14% for each additional decrease in the number of intervals in to which items are grouped.

The results of this study indicated that individual dedicated trips of the smallest possible vehicles for courier items suggests that the current base scenario is more environmentally sustainable and consumes less fuel, compared against consolidated scenarios. However, consolidated scenarios yielded significant reductions in VKm and the volume of traffic associated with courier services. Therefore, courier service providers and users are posed with the decision of selecting cheaper environmentally efficient service which generate larger numbers of traffic; or, less environmental, more expensive services with a smaller traffic impact.

Additional analysis of the consolidated scenarios, incrementally reducing the tailpipe emissions for each vehicle, indicated that global reductions of between 60% and 70% for each vehicle yields reductions in emissions whilst also reducing vehicle numbers and VKm-travelled. Such reductions may be considered feasible with the implementation of ultra-low emissions vehicle (ULEV) technologies such as electric locomotion. Statistics from OLEV (2013), estimates potential tailpipe emissions of less than 75 grams CO_2 per km to be achievable with new ULEV technologies. Comparing these emissions against the emissions for small vans, Table 7.2, emissions of 75 gCO_2 per km represents a 58% decrease in vehicle emissions. Further consideration of ULEV emissions indicated reductions of 72% are achievable (OLEV 2013). These figures suggest that the emissions reductions required to make temporal consolidation of courier services environmentally sustainable are practicably feasible.

8.5 Relevance in the Wider Healthcare Context

The homogenous nature of hospital supply operations within the UK suggests that the benefits of the three logistics solutions assessed by this research may deliver similar operational gains, whilst also achieving reductions in road network traffic and vehicle emissions.

The data used in this these to inform the assessments for each of the three main research themes is specific to GOSH. Therefore, the results from this thesis may be considered isolated to the specific set of requirements, and operational circumstances at the Trust. In recognition of this, an internal review of the supply chain at University Hospital Southampton (UHS), a peri-urban NHS Trust, situated towards the outskirts of the city, Figure 8.1, was performed to assess the relevance of the findings for this Thesis in the wider NHS context.

Assessment of hospital spend reports at UHS indicated that 25 – 30% of inventory is procured via the NHS Supply Chain with the remainder being acquired via direct ad-hoc orders from suppliers. These figures are found to be in accordance with those observed at GOSH. Assessment of delivery notes for a 5-day period (2nd – 6th December, 2013) indicated 909 separate consignments were delivered to the Trust. However, it should be noted that this is not necessarily indicative of the exact volumes of delivery traffic to the hospital, as multiple consignments, with separate delivery notes, may be made by a single supplier / courier.

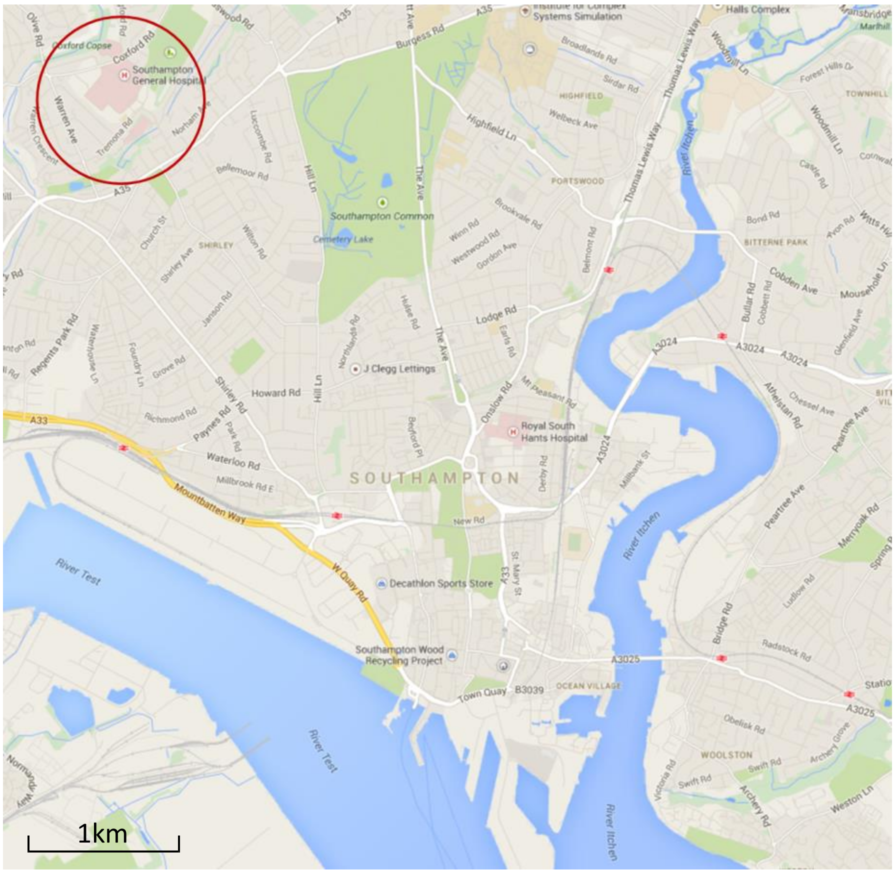


Figure 8.1 Location of University Hospital Southampton (Southampton General)

Comparisons of the internal stock management processes between GOSH and UHS indicated large similarities in the approaches and methods used to manage inventory at ward levels. As was observed at GOSH, the supply chain at UHS is predicated on a parallel external supply chain, comprising a multi-echelon (NHS Supply Chain) route, and a single-echelon (direct, ad-hoc) route. Internal supply is also modelled on the same semi-direct structure observed at GOSH.

Assessment of the goods-in facilities at the Trust highlighted the issue of insufficient loading bay space available for the delivery and receipt of inventory, owing to use of the area by multiple users (namely goods-in traffic and laboratory courier services). As was identified at GOSH, the provision of space for ward stores was also observed at UHS, with multiple users of the stores further exacerbating the situation.

In light of these findings, it may be deduced that there may be similar opportunities for the implementation of all three solutions assessed in this research. However, it becomes apparent that the size of the city, number of hospitals within the city limits, their location and size affects the overall traffic impact and emissions reductions yielded by each solution.

Transferability of the each proposed solution is significantly affected by the size of hospitals, and the geographical location and spatial characteristics of cities (i.e. city shape and size).

As demonstrated by the London wide analysis for the MCC a maximum hospital size limit may be considered with regards to the implementation of the concept over a traditional warehouse based consolidation service. Broadly speaking implementation of the concept in the context of larger hospitals which require more than one trailer to service them is likely to make the concept operationally and financially unattractive. Therefore, the trailer may be considered more attractive in scenarios wherein small volumes of goods are involved. In this context, due to the scalability of the concept down to smaller vehicles the concept may not have a minimum hospital size.

Application of the MCC concept in the context of other cities indicated greater restrictions, as highlighted by the Southampton case study. The proposed model for London was predicated on the situation of units at four compass points around the city, with a bias of positioning in the north west of the city owing to the dominance of supplier origins in the Midlands and North of the UK. Therefore the geographical location and shape of a city in relation to the supplier base would affect the location of the MCC which is determined by land availability. For example, in the context of Southampton which is located on the south coast of England and has three main points of access for freight traffic, any proposed MCC concept would require multiple trailer units situated within the same location. Under such circumstances more traditional consolidation concepts may be seen to be more attractive.

With regards to the proposed locker bank and courier consolidation solutions, each concept may be scaled according to the demand requirements of any institution. Therefore, they may be considered equally applicable within cities and organisations of varying size.

In the context of smaller hospitals it may be the case that each of the concepts, with the exception of courier consolidation for which the expected gains would be smaller owing to the likelihood of smaller laboratory services, may provide greater gains compared to larger hospitals. Since larger hospitals generate greater inventory demands they are more often able to achieve greater economies of scale amongst suppliers thereby enabling for larger consolidated ordering; whereas the smaller inventory requirements of small institutions are less likely to have the capacity to store larger inventories and therefore require smaller, more frequent deliveries.

Irrespective of the context in which each of the concepts are implemented the expected benefits from each solution would be similar to the GOSH case, yielding: reduced pressures on loading bays, increased visibility and tracking of urgent stock and decreased courier related traffic inside the grounds of the Trust, to UHS as are delivered to GOSH.

Each of the three initiatives are equally transferrable to other sites, authorities and sectors.

Given the transferability of each solution in the context of different cities and hospitals of varying size it may be assumed that each of the solutions may be applied to different institutional sites and organisations in which there are commonalities in ordering patterns, demand and the goods being procured.

With reference to unattended delivery and courier consolidation which may be considered generic solutions able to be tailored to a specific scenario or customer according to the organisation of their services, they may be considered applicable to any organisational / institutional structure. For unattended delivery solutions such as locker banks this is widely demonstrated by the diverse range of applications they are used for in the business to consumer and business to business market sectors. For example, in the context of offices such as the TfL Palestra building (situated in Southwark, London) which received a large number of online purchases for employee’s personal consumption to the business, implementation of the unattended locker bank provides a means to redirect non-business post on-site to an automated service thereby reducing pressures on the primary functions of the R&D department, whilst also avoiding failed first time deliveries.

Additional application of the unattended delivery solutions are evident in amongst the smaller scale healthcare institutions such as GP surgeries and pharmacies which receive night time secure deliveries via the NHS SC.

Application of the courier consolidation concept may arguably be applied to any business generating a high number of outgoing courier items each day which are categorised as non-urgent. This may service businesses such as financial services institutions and local authorities located in smaller cities or towns, which need to courier items to head office in other parts of the country.

The proposed MCC concept in relation to other industries presents opportunities for joint procurement of common use consumables for groups of organisations within the same sector, such as schools and large municipals, as well as companies within the same geographical region. Application of this concept may facilitate local agreements between organisations for the procurement of stationary etc.

8.6 Assessment of the Healthcare Supply Chain with the Implementation of the Three Proposed Solutions

The implementation of each of the three solutions to optimise the three sub-systems (non-urgent supply, urgent supply and laboratory courier samples) collectively achieve optimisation of the whole system.

As highlighted in Chapter 1, this research focussed on the three main movements of goods in / out of GOSH: urgent goods in, non-urgent goods in, and outgoing courier services, Figure 8.2.

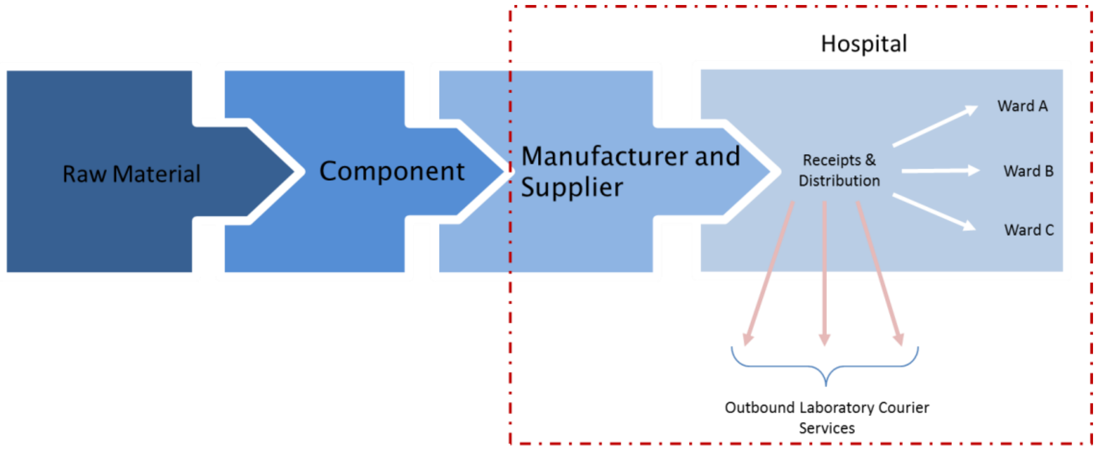


Figure 8.2 Illustration of the study area within the medical supply chain which is the focus within this research (surrounded in the red box)

It was identified in the literature that the healthcare supply chain is inefficient owing to a lack generated demand related data, and communication of such data throughout the supply chain. Without such issues being addressed, effective implementation of more sustainable supply chain best practice such as greater hospital-supplier collaboration is difficult to achieve. Therefore the focus of this research was to optimise the current “state-of-play” in the hospital supply chain.

The MCC and unattended delivery solutions arguably provide the most significant improvements to the healthcare supply chain as a result of expediting deliveries through the internal supply chain as a result of the disintermediation of supply chain agents; and the increases in the visibility of hospital demand data to suppliers. Importantly the two solutions are complimentary of one another, with the implementation of the unattended delivery solution enabling for the MCC to become a viable measure to optimise the delivery of non-urgent goods. Furthermore, the retiming of urgent freight to out-of-hours times which cannot be altered in volume / frequency helps to: reduce the impacts of the related freight vehicles by enabling for more efficient driving cycles to be achieved; and, improve the speed and reliability of reliable deliveries to hospitals owing to lower network congestion during off-hour periods.

Much like the end result of the MCC, the consolidation of courier services for hospitals attempts to optimise the number of courier service deliveries from hospitals by encouraging more sustainable practices by means of consolidating the number of vehicles required to perform rounds.

The combination of the three proposed solutions optimises and reduces the number of vehicles travelling to and from hospitals, thereby reducing their impacts on the local road network and air quality.

8.7 Research Barriers

During the course of this research the following issues (listed according to their importance, i.e. most important first) were identified:

8.7.1 **Time constraints, affecting the amount of time available to run model simulations**

As discussed in Chapter 4, the modelling approaches used to evaluate each of the three proposed solutions are based on heuristic approaches. Whilst measures were implemented to increase the likelihood of achieving a result close to the global optimum, the only methods which guarantee the best solution to combinatorial optimisation problems are exact search methods, Section 4.2, which require significant amounts of computational time.

8.7.2 **Lack of comparative data**

There was a lack of comparative data enabling for the scrutinisation of each of the three proposed solutions in relation to the wider context of the healthcare industry, geographical locations and alternative sectors. Therefore, many of the comparisons were performed using data and insight from qualitative interviews. Greater volumes of both quantitative and qualitative data may have provided greater clarity in the application of the three solutions in the wider context.

8.7.3 **Deficiencies in London-wide data for the assessment of each research theme in a larger context**

The lack of cage fill data with which to assess the number of MCC units required to service the hospitals in the London-wide context inhibited the accuracy of the feasibility assessment. Furthermore, the estimation for the number of vehicles travelling to each of the other London Trusts may be considered inaccurate, since the size of a Trust does not indicatively mean there will be a proportional increase or decrease in the number of deliveries / vehicles to a Trust relative to the parameters observed at GOSH.

Chapter 9: Contribution of the research and recommendations

9.1 Contribution of the research and conclusions

In carrying out this research, this Thesis has established answers to the research questions stated at the outset (see Section 1.4), making a number of unique contributions to the academic record.

9.1.1 **Effectiveness of sustainable supply chain solutions in Healthcare**

The study provided a comprehensive review of the healthcare supply chain literature and an analysis of numerous sustainable urban logistics solutions. The purpose of this review was to ascertain what the main traffic generators for the procurement of goods into hospitals were, and identify previous and current methods of managing them. The outcome of this process highlighted: the mixing of urgent and non-urgent goods within the same supply chain, lack of tracking and visibility of items within hospitals, specialist inventory requirements from multiple suppliers and high volumes of laboratory courier services as perpetuators of unsustainable logistics practices to hospitals.

9.1.2 **To what extent can innovative sustainable logistics provide environmental transport solutions for hospital supply?**

Results for each of the three proposed solutions indicated that whilst they provide environmental benefits to the hospitals at which they are implemented. Their city-wide impact is relatively minimal, requiring scaling up of the concepts to numerous healthcare institutions to yield a substantial impact on city wide emissions. Whilst it may be considered that unattended electronic delivery solutions and temporally consolidated courier services may be easily implemented at a city wide scale since the two solutions require coordination on an individual Trust basis. Implementation of the MCC concept at a city wide scale presents numerous complications owing to the number of units required to service multiple Trusts, therefore requiring large amounts of coordination between suppliers and hospitals to minimise the negative impacts of the concept.

Results from the sustainable courier services study highlighted that sustainable logistics solutions do not necessarily yield environmental benefits, identifying a need for technological improvements such as low emissions vehicle technologies to provide and increase potential environmental gains.

9.1.3 What are the most appropriate combinations of approaches to adopt to maximise efficiency across the external internal supply chains?

The combination of consolidated and unattended electronic delivery for hospitals has been found to deliver potentially significant reductions in emissions (between 2 tCO_2 for a single site operation and 2.33 tCO_2 for four site operations) by enabling consolidation of non-urgent items and improvements to supply chain operations. However, as identified by the research for sustainable laboratory courier services, current courier services operations present more environmentally sustainable solutions compared against proposed consolidated scenarios (increases between 0.42 tCO_2 to 0.84 tCO_2). This research identified a need for lower emissions vehicle technologies to provide sufficient reductions in emissions to make temporal consolidation of courier services environmentally viable. However, for a network traffic perspective, courier consolidation presented significant benefits.

9.1.4 How can these solutions be effectively implemented and managed across different hospital structures?

Discussion of each of the solutions in relation to wider NHS institutions indicated that whilst there may be an application for each of the solutions and a requirement for the benefits each provides, the external contextual situation, such as the geographical location and number of hospitals within cities are likely to greatly affect the overall positive effects at a city-wide level.

9.1.5 **Policy recommendations**

Policy changes are required at: individual organisational levels, industrial / sector levels and local / national government levels.

At an individual organisational level, internal policies are required to ensure the standardisation of stock management practices, and the comprehensive and coherent generation of stock and demand data throughout all silos. This may aid in improved inventory sharing throughout institutions, thereby reducing wastage and the need for urgent goods; and, the communication of vital demand related information to suppliers / distributors, enabling for more efficient freight planning to be implemented. Further to this, it may also be necessary to establish policies internally which restrict the use of 24 hour services which, as established in Chapters 1 and 2, perpetuate unsustainable delivery patterns and elevated levels of UFT.

At an industrial and sector level, there is already evidence to indicate the standardisation of data generation within the healthcare sector with the implementation of GS1 coding to standardise the barcoding of goods with a single type of labels compatible with current healthcare industry systems. Such standardisation will enable for better systems integration between healthcare institutions and suppliers, thereby improving the flow of information throughout the supply chain. In the context of the logistics, distribution and supply industries it may be appropriate to investigate the value of restricting the number of 24 hour services which are made available, to mitigate the unsustainable growth of 24 hour service patterns. However, implementation and enforcement of such policies may arguably be more effective if introduced and governed by local and national authorities.

The role of local and national government for each of the solutions developed and testing in this research are rooted in encouraging subscription to the solutions and wider behavioural change. In many cases the current landscape of freight is dictated by economic drivers such as operating costs and net profit for logistics providers. Therefore, if policies were implemented to change the ‘shape’ of the market place, from an economic perspective for suppliers and hauliers, in favour of consolidation, collaboration and night time freight greater gains towards network and environmental sustainability may be observed.

In this context, the powers afforded by local and national government arguably provide the greatest potential for governance and change towards sustainable supply chains within the healthcare and wider sectors.

9.2 Limitations

The key limitation of this research was the consistency of detail in the data used to inform each study, which resulted in the reduction of sample sizes. In addition to this the lack of economic data made available by hospitals and healthcare suppliers made it unfeasible to conduct a comprehensive Cost-Benefit Analysis for each of the concepts, thereby making a full assessments for the feasibility of each solution impracticable.

9.3 Further Work

The following topics were identified for additional research for the themes studied in this thesis:

- In order to establish policies and regulations which monitor and fine companies for lack of sustainable practices such as temporal consolidation of general freight and courier services it is necessary to establish the proportion of demand which is urgent and that which isn't. This would is necessary as it would be likely that implementation of policies restricting the use of 24 hours services for urgent consignments only would artificially increase the incidence of urgent shipments. In addition to this, such work in this field would help to identify whether there is scope to increase the amount of goods shipped under non-urgent conditions, thereby enabling for more sustainable freight practices to be implemented such as Full Truck Loads;

- Continuation of the assessment for the MCC concept requires the identification of small, high value items which may be deemed suitable for delivery through the proposed system. In parallel with this data, a full environmental impact assessment and Cost Benefit Analysis (COBA) would be required to determine the operational and financial practicality of the concept. Extension of these analyses to the implementation of the unattended delivery locker banks and courier consolidation concepts may also be considered prudent.

Appendices

Appendix A DSP Survey Sheet

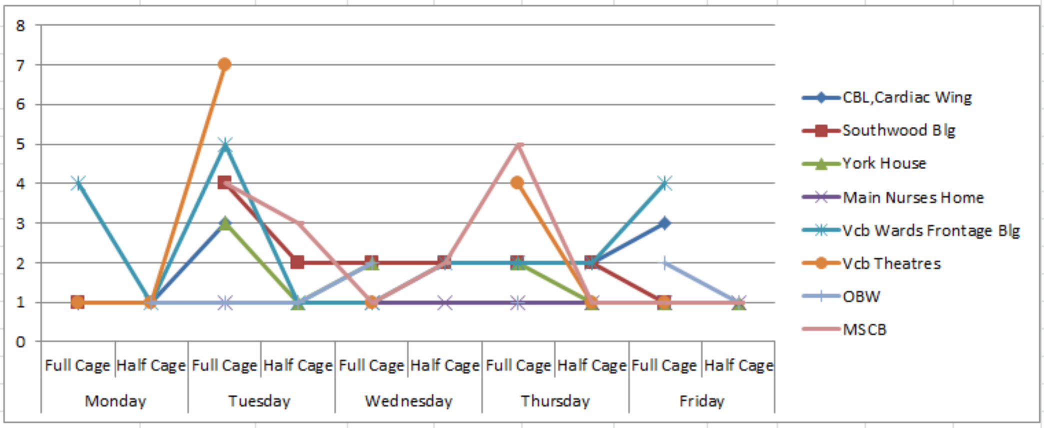
#	Time		Supplier	Courier	Veh Reg	Veh Type (A, B..)	Drop/Pick (D/P)	Hospital	Fill Rate	Containment (Quantity)					
	ARR	DEP						G / N	%	Loose	Cages	Dollies	Bags	Boxes	Other
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															

	Contents / Delivery Point (Ref over board)	Specialist (Refrig? Waste?)	Origin	# of deliveries in route	Previous Drop	Number GOSH is on route?	Next Drop	Final Destination
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Appendix B Cage Survey and Historic Demand Record

Cage Survey

One Week Data		GOSH									
	Cages QTY	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Total	
		CBL,Cardiac Wing	Southwood Blg	York House	Main Nurses Home	Vcb Wards Frontage Blg	Vcb Theatres	OBW	MSCB		
Monday	Full Cage	1	1			4	1			7	
	Half Cage	1				1	1	1		2	9
Tuesday	Full Cage	3	4	3	1	5	7	1	4	28	
	Half Cage		2	1		1		1	3	4	32
Wednesday	Full Cage	2	2	2	1	1	1	2	1	12	
	Half Cage		2		1	2			2	3.5	15.5
Thursday	Full Cage	2	2	2	1	2	4	1	5	19	
	Half Cage	2	2	1	1	2	1		1	5	24
Friday	Full Cage	3	1	1	1	4	1	2	1	14	
	Half Cage			1	1			1	1	2	16
								Cages Total		**96.5**	*96.5*



Historic Demand Record 2012 / 13

INDEX	Year	WeekNum	Number of Orders	Uplift Factor		
1	2012	14	498	0.791732909		
2	2012	15	366	0.581875994		
3	2012	16	601	0.955484897		
4	2012	17	595	0.945945946		
5	2012	18	600	0.953895072		
6	2012	19	455	0.723370429		
7	2012	20	592	0.941176471		
8	2012	21	556	0.883942766		
9	2012	22	459	0.72972973		
10	2012	23	340	0.540540541		
11	2012	24	572	0.909379968		
12	2012	25	515	0.818759936		
13	2012	26	601	0.955484897		
14	2012	27	584	0.92845787		
15	2012	28	688	1.093799682		
16	2012	29	629	1	Survey Week 15/07/2013	
17	2012	30	576	0.915739269		
18	2012	31	598	0.950715421		
19	2012	32	609	0.968203498		
20	2012	33	626	0.995230525		
21	2012	34	486	0.772655008		
22	2012	35	411	0.653418124		
23	2012	36	671	1.066772655		
24	2012	37	539	0.856915739		
25	2012	38	587	0.933227345		
26	2012	39	608	0.966613672		
27	2012	40	672	1.06836248		
28	2012	41	739	1.174880763		
29	2012	42	737	1.171701113		
30	2012	43	733	1.165341812		
31	2012	44	650	1.033386328		
32	2012	45	563	0.895071542		
33	2012	46	804	1.278219396		
34	2012	47	589	0.936406995		
35	2012	48	773	1.228934817		
36	2012	49	713	1.13354531		
37	2012	50	626	0.995230525		
38	2012	51	731	1.162162162		
39	2012	52	283	0.449920509		
40	2012	53	162	0.257551669		
41	2013	1	276	0.438791733		
42	2013	2	837	1.330683625		
43	2013	3	690	1.096979332		
44	2013	4	664	1.055643879		
45	2013	5	799	1.27027027		
46	2013	6	685	1.089030207		
47	2013	7	690	1.096979332		
48	2013	8	762	1.211446741		
49	2013	9	691	1.098569157		
50	2013	10	783	1.244833068		
51	2013	11	736	1.170111288		
52	2013	12	762	1.211446741		
53	2013	13	715	1.13672496		

Appendix C Uplift of Vehicles for London-wide Assessment

Hospital	Uplift By Orders	Required # of Trailers
Great Ormond Street Hospital	1	1.00
King's College Hospital NHS Foundation Trust	4	4.01
Saint Pancras Hospital (Camden & Islington)	1	1.00
University College Hospital	3	3.01
Guy's and St Thomas' NHS Foundation Trusts (incl. Evelina Childrens Hospital)	8	8.02
The Whittington Hospital (incl. NHS Islington and NHS Haringey)	1	1.00
Barts Health NHS (Mile End Hospital, Newham University Hospital, The London Chest Hospital, The Royal London Hospital, St Bartholomew's Hospital, Whipps Cross University Hospital)	5	5.01
Royal Free Hospital	2	2.00
Lewisham and Greenwich NHS Trust (incl. Lewisham and Queen Elizabeth Hospital)	2	2.00
Homerton University Hospital	1	1.00
Chelsea and Westminster Hospital	2	2.00
North Middlesex University Hospital	1	1.00
The North West London Hospitals NHS (Northwick Park, St Mark's, and Central Middlesex Hospitals)	2	2.00
Charing Cross Hospital, Hammersmith Hospital, Queen Charlotte's & Chelsea Hospital, St Mary's Hospital, Western Eye Hospital (now called "Imperial College)	3	3.01

Appendix D MCC Questions and Responses

<u>HOSPITAL RESPONSES</u>
Identifying Hospital Issues
Overstock in corridors often, as well as occasional issues with deliveries going missing.
TECHNICAL FEASIBILITY
Q. *What do you perceive to be the potential operational and practical stumbling blocks of this concept? i.e. Paperless receipting integration with current hospital operations, Night-time deliveries model affecting current operations, such as requirements for products the day of delivery (relates to lead times), Systems integration.*
Systems integration may be a challenge, but I think the key to this programme working is the involvement of all NHS Trusts across London in order to enable suppliers to usefully engage with the offering (and not need to double up on deliveries). From a logistics point of view this makes sense, but systems issues i.e. information is available on the box to enable deposit of items into the correct locations may be an issue. Change of delivery address issues. Some orders don't provide the supplier / delivery company with end locations, therefore delivery by department wouldn't be possible.
Q. *How do you perceive this concept may affect internal distribution within the hospital? E.g. disintermediation of the internal supply chain? Is there anything in the hospital which you perceive may be removed with the implementation of this concept, or would the hospital be required to take on additional staff, services and processes to accommodate the concept?*
No comment
Q. *What type / range of products do you perceive to be serviceable by this concept?*
High value, "just in time" deliveries (though there may be additional scope)
Q. *How do you perceive that the MCC may be received at the hospital? Do you foresee any issues with proof of delivery, returns, delivery time?*
This could put added work on the night shift to deliver the products, but I think overall the concept will be well received.

***Q.** Are there any services provided by the R&D department which you don't consider can be covered by the MCC? If so, how might this affect the downsizing of the R&D department?*
No comment
***Q.** What evidence based metrics would you require to appraise the model? i.e. KPI's, operational metrics, current and future?*
Rate of on-time delivery, volume of stock delivered through model compared to conventional deliveries.
***Q.** Are there any distance / locational issues not covered by the positioning of the MCC? i.e. proximity / accessibility to the hospitals it services?*
No comment
***Q.** Do you have facilities for out-of-hours deliveries?*
No comment
POLICY ISSUES
***Q.** What would have to be done, with regards to the proposed implementation of the concept that would make it attractive? i.e. under what circumstances could it be implemented?*
Understanding the true hidden costs in supply chain would be key, i.e. re-order items etc. If hospitals understood the true hidden costs this would be a no brainer.
***Q.** Who are the key decision makers you perceive would influence its implementation?*
Best vehicle for NHS Trusts to engage – Transport for London. Mayor's Office. London Procurement Partnership. Lobby at Chief Exec Level, NHS Southern England Office (London Student Health Authority). Can approach it with Sustainable Development Unit for Low Carbon. Involve ANHI, trade association. Get industry to collaborate. Contact LPP – politically they would be the most appropriate team to collaborate with. They manage procurement teams at each participating Trust.

***Q.** Are there any internal policies within the hospital and wider healthcare legislation which may make the pursuit of this concept viable? i.e. hospital operations procedures? future reception and handling of items? Fiscal drivers such as procurement?*
No comment
***Q.** Would you foresee any ownership issues for the concept? i.e. maintenance, operational ownership, liability ownership issues?*
No comment
LOOKING FORWARD
***Q.** How might care in the community impact on this model?*
It may enable nurses or clinicians to pick up from the MCC as well as receive deliveries centrally at the Trust.
EXTERNAL
***Q.** Sustainable logistics policies: White Paper policies - Essentially CO_2 free city logistics by 2030? How might this change hospital supply?*
It's likely that the hospital will need to move away from deliveries from HGVs, as there is a call for safer roads for cyclists in central London, as well as lower emissions. In light of this, it may be worth considering the concept of smaller van deliveries of the compartments from the MCC.
***Q.** How do the LEZ and Congestion Charge affect the cost of deliveries to your hospital?*
No comment
Additional Data
***Q.** Stock and non-stock procurement proportions?*
The Trust has worked with DHL on the consolidated procurement model, though this was not fully successful, as the lack of involvement of the whole NHS supply chain meant that there was little value to suppliers (they still had to go into London to deliver to non-participating Trusts).
***Q.** Any existing consolidation / sustainable logistics?*

No comment
Q. *Emissions targets for the hospital?*
The Trust has committed to a 34% carbon reduction by 2020 in line with the UK climate change act.
MISC
NHS SC to save £150 million (with cabinet office). For hospital, 80 – 90 cages per week. Non-NHS SC stock tends to be high value. Could provide a range of solutions with MCC: everything in one truck, and everything apart from NHS SC in one truck, and one picking up NHS SC and cross docking. One characteristic of NHS SC, overheads have ballooned. The number of people employed has mushroomed e.g. Rugby distribution centre has been opened to try and combat the increasing overheads.
<u>THIRD PARTY LOGISTICS PROVIDERS RESPONSES</u>
Identifying Hospital Issues
No Comment
TECHNICAL FEASIBILITY
Q. *What do you perceive to be the potential operational and practical stumbling blocks of this concept? i.e. Paperless receipting integration with current hospital operations, Night-time deliveries model affecting current operations, such as requirements for products the day of delivery (relates to lead times), Systems integration.*
Ensuring a flat demand over days. Issues of regulating the volume of deliveries taken. What is the plan if delivered with too much are received? Variable locations may be an issue with educating deliveries drivers. Difficulties in operating booked delivery windows. Have to operate open window policy. Ordering of urgent products may increase to bypass the concept, this would need to be policed. There are risks to getting access to a Trust system. Quality Assurance checks, e.g. for GOSH if they were to QA check 100% of goods would require 4 – 5 members of staff. QA checks would have to be limited to spot checks or no checks with one member of staff.

If taking deliveries from more than one hospital's goods at a single unit, then a risk of misplacing items into the incorrect Trust's deposit. Security issues – not being in a warehouse where the same level of security wouldn't be possible would be an issue. If it's a Trust run operation rather than contracted, then managing annual leave would be very difficult. Need a solution for no show at the site. What is contingency if staff member can't make it to the centre, would need an out of hours solution with scan and drop. Health and safety risks around one member of staff running the centre solo. Running from a mobile network – issues with Trust systems integration. – service access issues. Would need access to an N3 access network to make systems integration better as it differs per hospital. If using vehicles to do deliveries, what would happen if the vehicle broke down, no trunking system available to transfer items onto another truck. IT systems, people, locations, permissions. Ownership of stock? – If all stock is owned by the Trust once deposited, they would have to take insurance out to charge to customers or to the hospital. 3PL may operate, but more likely better for the Trust, thereby overcoming ownership and insurance issues.
Q. *How do you perceive this concept may affect internal distribution within the hospital? E.g. disintermediation of the internal supply chain? Is there anything in the hospital which you perceive may be removed with the implementation of this concept, or would the hospital be required to take on additional staff, services and processes to accommodate the concept?*
The concept will provide a positive effect on the internal distribution within the hospital. But when stuff is delivered to the ward, each ward needs to sign for items at carton level. All end-users need to confirm delivery at the hospital, ward and store level. If going in at night it would have to go into the R&D. Cages couldn't be dropped off at night and guaranteed to be there. Signature at department level at box level to ensure security would be required.
Q. *What type / range of products do you perceive to be serviceable by this concept?*
Some high end clinical products, often get asset tagged (individual tags are applied and then entered into the system) i.e. pacemaker kits are asset tagged, therefore you would need the staff and systems on the trailer to asset tag. Individual barcoding at box level. Becoming more common for patient level consumption data.
Q. *How do you perceive that the MCC may be received at the hospital? Do you foresee any issues with proof of delivery, returns, delivery time?*
No Comment

Q. *Are there any services provided by the R&D department which you don't consider can be covered by the MCC? If so, how might this affect the downsizing of the R&D department?*
No Comment
Q. *What evidence based metrics would you require to appraise the model? i.e. KPI's, operational metrics, current and future?*
Percentage of goods received and then transferred to the hospital, would be a small percentage of products receipted from the courier and then receipted into the Trust in the same day. Cut off would have to be 17:00. Percentage of spot checks to create a QA. Confirm that parcels are checked against a range of suppliers. Method of checking discrepancies raised for incorrect deliveries or damaged items. Management issues raised – issues files logging system. Trusts are concerned with the time it takes for resolution of issues. Most within 1 hour, 4 hours and some within 8 hours for issues resolved. Receipting – accuracy of receipting – e.g. 5% accuracy of I.T. receipt. Confirming that when goods are dropped off at night they arrive at the end user. Hand-over – need tracking for the last part of the supply chain to check they get the products. Need to check the lag from midnight delivery at the Trust to delivery at ward level (portering).
Q. *Are there any distance / locational issues not covered by the positioning of the MCC? i.e. proximity / accessibility to the hospitals it services?*
No Comment
Q. *Do you have facilities for out-of-hours deliveries?*
No Comment
POLICY ISSUES
Q. *What would have to be done, with regards to the proposed implementation of the concept that would make it attractive? i.e. under what circumstances could it be implemented?*
No Comment
Q. *Who are the key decision makers you perceive would influence its implementation?*
No Comment

Q. *Are there any internal policies within the hospital and wider healthcare legislation which may make the pursuit of this concept viable? i.e. hospital operations procedures? future reception and handling of items? Fiscal drivers such as procurement?*
No Comment
Q. *Would you foresee any ownership issues for the concept? i.e. maintenance, operational ownership, liability ownership issues?*
No Comment
LOOKING FORWARD
Q. *How might care in the community impact on this model?*
No Comment
EXTERNAL
Q. *Sustainable logistics policies: White Paper policies - Essentially CO_2 free city logistics by 2030? How might this change hospital supply?*
No Comment
Q. *How do the LEZ and Congestion Charge affect the cost of deliveries to your hospital?*
No Comment
Additional Data
Q. *Stock and non-stock procurement proportions?*
No Comment
Q. *Any existing consolidation / sustainable logistics?*
No Comment
Q. *Emissions targets for the hospital?*
No Comment

MISC
Couriers would benefit at multiple supplier level, courier network would claim the largest benefit. Can't unlock benefits from couriers and suppliers. Total cost is same / less but would be difficult to pass it onto the Trust. Justifying the cost against the intangible benefits, if demonstrated as cost neutral but can get non-cash releasing benefits. What is the cost to enter the market? ***Attractiveness*** – Need to be able to measure the carbon emissions reduction s- some Trusts haven't done. Any kind of savings they could achieve to cut out wholesalers. Differential savings they could achieve for local deals. Movement of high value, low volume goods (pacemakers and hearing aids) for hospitals. Would enable picking up key products for groups of Trusts to level bulk buying. Whether the technology would replace the error rate of manual handling of low band employees, i.e. scanning to create a record of deliveries. Biggest challenge would be how to get the benefit back, as the courier companies would benefit the most. Look at how Trusts have a large cost associated with mixed delivery of products (Ortho / Cardio) between £10,000 to £30,000 of next day delivery fees. If they had a later window for deliveries so that they don't have to pay such fees, could have a significant impact on the implementation of the model. Pre-9 o'Clock delivery costs – most Trusts would pay £150k to £500k per annum for deliveries. What proportion is unnecessary Pre-9? If they are a large trauma centre or an A&E therefore receive lots of urgent unplanned demand. So require faster supply, some specialist Trusts can't borrow inventory from local Trusts, so have to go direct to suppliers for goods.
<u>SUPPLIER 1 RESPONSES</u>
Identifying Hospital Issues
Are there any issues within the hospital re: visibility and monitoring of inventory?
TECHNICAL FEASIBILITY
Q. *What do you perceive to be the potential operational and practical stumbling blocks of this concept? i.e. Paperless receipting integration with current hospital operations, Night-time deliveries model affecting current operations, such as requirements for products the day of delivery (relates to lead times), Systems integration.*

What happens if an item is deposited into the wrong bin / hospital trailer, lack of track and trace. Liabilities? POD concept with mobile comms, driver could generate an electronic POD, by entering product type and quantity to overcome mispicks and changes to order volumes. Bank holidays produce large spikes in order quantities. In order to level ordering patterns switch to a 7-day operation. Concerns regarding volume issues – product orders can vary significantly between a single artic or two artics. Would the concept require volume data – some suppliers don't provide or have this information. No minimum spend in supply chain, which adds a level into the business. Packing of loose items because of supplier / consolidation providers such as Bunzl have to break bulk. Mixed boxes for 10 or 11 departments. Would the consolidation concept require suppliers to deposit 10 / 11 separate items rather than consolidating them into a single box. Timing of deliveries is a big issue within the NHS Supply chain. What is the audit trail. Who is responsible and at what point of the supply chain? Issues around agency drivers – how much detail or understanding do they need to use the mobile consolidation centre. For an automated concept would companies need to employ spare drivers rather than agency drivers? 10 drivers at a depot amounts to 50 weeks holiday which then amounts to 50 weeks of agency drivers who are less efficient and incur more accidents. Treatment of products by agency drivers is worse than company drivers. Risk of going to a consolidation centre, suppliers are losing contact with customers so they lose implicit market knowledge gained by visiting the customer and seeing the other business being provided to the hospital by competitors. Loss of visibility of activities at hospitals – not "touching the customer". One 3PL suggested back hauling for a competing 3PL and they refused based on "wanting to touch the customer on a regular basis". Changes of volume, no seasonal trends in healthcare, but see sharp peaks around bank holidays. It would be a good move for hospitals to move towards 7-day operations to smooth flows.
Q. *How do you perceive this concept may affect internal distribution within the hospital? E.g. disintermediation of the internal supply chain? Is there anything in the hospital which you perceive may be removed with the implementation of this concept, or would the hospital be required to take on additional staff, services and processes to accommodate the concept?*

For major accounts suppliers will pick down to ward level. They can sequence load the vehicle so that they go off the vehicle to the ward. 40% of bunzl days are sorting receipts. If items can be shipped straight to ward from the truck this reduces time spent in processing receipts.
Q. *What type / range of products do you perceive to be serviceable by this concept?*
Consumables and high value products. Difficulties come from low value high volume products, and potential weighty products (i.e. mixed pallet of aprons may weigh 500kg), handling issues with depositing such items into the trailer and then back at the hospital end. Sharps bins are difficult because they will be delivered in boxes of 30 on pallets, not practical to break into cages. Items which are damageable. Where does the ownership of the product change hand. From the POD point of view, who is receipting the product? Where do the monetary claims and damages claims transfer, i.e. to the consolidation centre operator or the supplier? At what point do suppliers stop ownership of the product. Problem from large deliveries, dwell time of driver whilst they are checking products. At what point does ownership switch to the hospital? And till what point can they claim on damage?
Q. *How do you perceive that the MCC may be received at the hospital? Do you foresee any issues with proof of delivery, returns, delivery time?*
No Comment
Q. *Are there any services provided by the R&D department which you don't consider can be covered by the MCC? If so, how might this affect the downsizing of the R&D department?*
Products can be checked at the R&D department, but can't be checked by automated systems. However, NHS is moving towards a no back-orders. Provided there is a move to no-back orders on purchase orders whereby there is a short supply on delivery which is made up later on, then there is no value added by R&D which can't be provided by the MCC. 0 back orders, if they don't have it, cancel it and raise a new purchase order.
Q. *What evidence based metrics would you require to appraise the model? i.e. KPI's, operational metrics, current and future?*
Fulfillment rate in terms of fulfilment to end-user. Next-day delivery, in terms of suppliers make deliveries of items which are intended for use the day after delivery. 99% fulfilment rate.

Q. *Are there any distance / locational issues not covered by the positioning of the MCC? i.e. proximity / accessibility to the hospitals it services?*
Depends on volumes used to fulfil the process. We don't operate any class 1 vehicles within the M25 due to access. So the centre would have to be operated within areas accessible by existing fleet. Frequency and volume of orders, we are filling an 18t lorry per day for St Georges alone. – risk is dwell time at the consolidation point (we are at St Georges 30-40 mins). So under the scenario where a single unit is allocated to a supplier, might as well provide the supplier with a single unit and instruct them to fill it up and bring it in. Consolidation of cages with our deliveries being consolidated into NHS SC cages so that only one cage is moved per ward rather than the duplication of an NHS SC and our cage for the same cage. For small non-stock suppliers, they may be compatible with the MCC being allocated per supplier. Would suppliers want to consolidate items at a single site or do they want to be going into London.
Q. *Do you have facilities for out-of-hours deliveries?*
Yes. It is a positive option which Bunzl are pushing. Currently operating a fleet with 10% operating at night. Can operate more guaranteed delivery times for the customer.
POLICY ISSUES
Q. *What would have to be done, with regards to the proposed implementation of the concept that would make it attractive? i.e. under what circumstances could it be implemented?*
Would have to sit with the board. One of the risks to our business is that they lose contact with the customer. Probably an issue for many suppliers. For us, key suppliers will receive key usage reports. Can generate extra business with direct contact with customer. Fewer vehicles don't necessarily guarantee lower emissions.
Q. *Who are the key decision makers you perceive would influence its implementation?*
Operations director and commercial sales director.
Q. *Are there any internal policies within the hospital and wider healthcare legislation which may make the pursuit of this concept viable? i.e. hospital operations procedures? future reception and handling of items? Fiscal drivers such as procurement?*

Not currently. White papers may make logistics have to think more about what they do. Fuel is the biggest variable cost which they have no control of. Bunzl healthcare spend just over £1m per annum on commercial fuel.
Q. *Would you foresee any ownership issues for the concept? i.e. maintenance, operational ownership, liability ownership issues?*
No. Commercial concept – who is the commercial driving force behind the concept. E.g. some suppliers don't want to get in bed with DHL. Logistics looks to be going the same way as banking with a handful of companies dominating the market. – the end user is not aware of the situation within the logistics industry due to shrinking of options within the market.
LOOKING FORWARD
Q. *How might care in the community impact on this model?*
No Comment
EXTERNAL
Q. *Sustainable logistics policies: White Paper policies - Essentially CO_2 free city logistics by 2030? How might this change hospital supply?*
No Comment
Q. *How do the LEZ and Congestion Charge affect the cost of deliveries to your hospital?*
Financially the avoidance of the LEZ and CC zone does not provide enough of an incentive. Wouldn't be a massive saving. Trucks have to go into central London anyway irrespective of participation. Driver would be more what the customer wants not legislation. i.e. customer wants deliveries in cages which costs Bunzl thousands due to un utilised space but they have to do it.
Additional Data
Q. *Stock and non-stock procurement proportions?*
No Comment
Q. *Any existing consolidation / sustainable logistics?*
We have looked at similar concepts for smaller hospital's, the benefits from an operational view are obvious.

Consolidation has a future, but need to understand the drivers behind it. Whether there will be consolidation for consumables, bulk and catering, or whether this will be done by supplier or hospital. Laundry and catering are becoming a product being brought in rather than something done on site.
Q. *Emissions targets for the hospital?*
No Comment
MISC
No Comment
<u>SUPPLIER 2 RESPONSES</u>
Identifying Hospital Issues
Cost savings delivered by concept for 'Supplier 2' may be harvested by nhs. No savings for freight for 'Supplier 2' because they outsource. 'Supplier 2' products are large and bulky and fill lorries well. Supply so much bulk into NHS SC. If 'Supplier 2' has to bring bulky items in house from NHS SC they would struggle with space which would incur additional costs. Would bulk products fit into the model? Sometimes sending pallet loads into hospitals, carton orders may be too big. Would items be turned away? – Could be resolved by booking the delivery day to the unit. If something needs to be turned away, couriers aren't empowered to take the items away to the supplier again. They would need a separate area to stock this until a place can be found for it. Unit values change at suppliers all the time. This would have to be updated whenever it happens and this can be quite common. Would they have to match minimum orders? Every order is different. Issues of returns. How would this be done? Would items be turned away? POD for 'Supplier 2' would be a signature. Once something is received into the container is the POD responsibility on the hospital or the supplier. – no further responsibility on supplier once it has been deposited. Weighted receipt. Like self-check outs. - What happens if there is a mispick / short pick? – What would happen? Would receipt still happen? Because 'Supplier 2' third party logistics, would have to discuss with carrier not 'Supplier 2'. Any booking in that is done is performed by carrier.

What happens with unexpected items? – would have to have a human intervention. Technical / practical issues – lots of issues from a suppliers: interfacing with new systems = problem, how main carriers would operate with this.
TECHNICAL FEASIBILITY
Q. *What do you perceive to be the potential operational and practical stumbling blocks of this concept? i.e. Paperless receipting integration with current hospital operations, Night-time deliveries model affecting current operations, such as requirements for products the day of delivery (relates to lead times), Systems integration.*
On paper the scheme is considered more attractive and logical. However, dealing with the NHS, fears of how the NHS would operate this and work with it. Would the NHS throw lots of human resources at it? 'Supplier 2' items are quite bulky so would they be able to be deposited into a hole or a hatch? 'Supplier 2' has two artic lorries a day picking items up. – need a person in there to sort and stack items within the depot. Would this depot have to be manned like TNT mobile depot? All barcode items would have to be fed into the system. – How would 'Supplier 2' info be fed into system? Would all EAN numbers, weights, volumes, pallets and quantities be fed into the system? If this went 'live' would it start with small items to gain ground? Issues of security with regards to pharma.
Q. *How do you perceive this concept may affect internal distribution within the hospital? E.g. disintermediation of the internal supply chain? Is there anything in the hospital which you perceive may be removed with the implementation of this concept, or would the hospital be required to take on additional staff, services and processes to accommodate the concept?*
For major accounts suppliers will pick down to ward level. They can sequence load the vehicle so that they go off the vehicle to the ward. 40% of 'Supplier 2' days are sorting receipts. If items can be shipped straight to ward from the truck this reduces time spent in processing receipts.
Q. *What type / range of products do you perceive to be serviceable by this concept?*
Could potentially be any 'Supplier 2' items however as a concept smaller pharmaceutical items would be considered more appropriate. Larger bulk items are more suited to lorries going straight to the hospital. Would need a very large bank just for 'Supplier 2' items.
Q. *How do you perceive that the MCC may be received at the hospital? Do you foresee any issues with proof of delivery, returns, delivery time?*

No Comment
Q. *Are there any services provided by the R&D department which you don't consider can be covered by the MCC? If so, how might this affect the downsizing of the R&D department?*
No Comment
Q. *What evidence based metrics would you require to appraise the model? i.e. KPI's, operational metrics, current and future?*
Examples of where other suppliers have used the unit before 'Supplier 2' take part. It is such a huge change from current operations. They would need assurance from NHS it was going to be implemented permanently. If all boxes were same size and weight then it would be more appealing. Would need lots of statistics for success and failure. Wouldn't want to pass any savings onto the NHS. GPO's in U.S. is the same as private healthcare in the UK where all hospitals group buy.
Q. *Are there any distance / locational issues not covered by the positioning of the MCC? i.e. proximity / accessibility to the hospitals it services?*
No Comment
Q. *Do you have facilities for out-of-hours deliveries?*
No Comment
POLICY ISSUES
Q. *What would have to be done, with regards to the proposed implementation of the concept that would make it attractive? i.e. under what circumstances could it be implemented?*
From a logistics perspective – if they didn't have to deal with DHL it would be preferable. Wouldn't have to employ another person for Blue diamond. It would remove middlemen within the supply chain, making it more preferable. If you take places like wales and Scotland, nhs operate supply chain, don't make profit and run the service better than DHL. Not obsessed with price such as other suppliers to reduce costs of units.
Q. *Who are the key decision makers you perceive would influence its implementation?*
The hospital Trust would be key decision makers. If they dictate it would have to be used, they would use it. 'Supplier 2' wouldn't usually use 3PLs but customers force them to use it. 'Supplier 2' doesn't have a say in costs. Some trusts negotiate third party carriers who say they only use that carrier, so suppliers have to use them. This model is largely customer led. – if there is an on-cost the cost goes onto the product and then on to them.

Would delivery charges still be used? For £150 would charge be used? – If NHS feel they are paying for the carriage to the hospital, the supplier may struggle to charge for carriage as the hospital are making the final mile delivery.
Q. *Are there any internal policies within the hospital and wider healthcare legislation which may make the pursuit of this concept viable? i.e. hospital operations procedures? Future reception and handling of items? Fiscal drivers such as procurement?*
No Comment
Q. *Would you foresee any ownership issues for the concept? i.e. maintenance, operational ownership, liability ownership issues?*
Legislation on environmental freight would be up to the third party carrier.
LOOKING FORWARD
Q. *How might care in the community impact on this model?*
No Comment
EXTERNAL
Q. *Sustainable logistics policies: White Paper policies - Essentially CO_2 free city logistics by 2030? How might this change hospital supply?*
No Comment
Q. *How do the LEZ and Congestion Charge affect the cost of deliveries to your hospital?*
No Comment
Additional Data
Q. *Stock and non-stock procurement proportions?*
No Comment
Q. *Any existing consolidation / sustainable logistics?*
No Comment
Q. *Emissions targets for the hospital?*
No Comment

MISC
No Comment

Appendix E Economic Impact Assessment for the Proposed Mobile Consolidation Centre

WEEKLY OPERATING METRICS			
GOSH Only	Distance (Miles)	Number of Units	Total Hours (Rounded up)
1 site	22.45	1	1.00
2 sites	37.21	1	2.00
3 sites	45.32	1	2.00
4 sites	61.37	1	3.00
London-wide			
4 sites per hospital	1083.05	36	1.00
4 sites per supplier group	25.33	36	17.00
WEEKLY COSTS (£)			
Vehicle Operating Costs (pence per mile)	139.18[a]		
Hospital Parking Space (£)	20		
x 33[b]	660		
Day Driver Wages (£ / hour)	11.85[c]		
Warehousing Staff (£ / hour)	9.42[d]		
60 hour week	565.2		
Vehicle Operating Costs (£)			
GOSH Only			
1 site	31.24		
2 sites	51.78		
3 sites	63.07		
4 sites	85.41		
London-wide			
4 sites per hospital	1,507.39		
4 sites per supplier group	1,269.10		

Staff Wages (£)		
	Day Driver	Warehouse Staff (x2)
GOSH Only		
1 site	11.85	1,130.40
2 sites	23.7	1,130.40
3 sites	23.7	1,130.40
4 sites	35.55	1,130.40
London-wide		
4 sites per hospital	11.85	1,130.40
4 sites per supplier group	201.45	1,130.40
Rental of Space (£)		
GOSH Only	660	
London-wide	(x 9) 5,940 [e]	
TOTAL ANNUALISED COSTS (£)		
GOSH Only		
1 site	**95,341.51**	
2 sites	**97,026.02**	
3 sites	**97,613.04**	
4 sites	**99,390.70**	
London-wide		
4 sites per hospital	**446,661.23**	
4 sites per supplier group	**444,129.37**	

[a.] Vehicle operating costs are based on figures given for a 16 to 18 tonnes GVW – box or curtain-sided HGV, accruing an average mileage of 60,000 per annum [(FTA Cost Information Service 2014a), pp 16].

[b.] 33 parking spaces are required to accommodate the space requirements of the proposed unit (Section 5.2.1), which were rounded up to a site 50 x 60 metres. A single parking space was assumed to measure 4.8m length by 2.5m width [source: (Department of the Environment)calculations to determine this requirement were as follows: 50 / 2.5 + 60 / 4.8 = 33.

[c.] Day driver wages were based on the average gross per hour worked for Heavy Rigid Vehicles from the FTA Cost Information service [(FTA Cost Information Service 2014b), pp.4].

[d.] Warehousing staff wages were based on the average gross per hour worked from the FTA Cost Information service [(FTA Cost Information Service 2014b), pp.13].

[e.] Space requirement for London-wide scenario using 36 units will average 9 units per site, thereby multiplying the space requirements of a single units operations by 9.

Appendix F List of Urgent Items Received by GOSH

Product Description	Quantity	Order Quantity
(NUMED) SIZING BALLOON CATHETER	3	3
16MM SEPTAL OCCLUDER REF:9-ASD-016	7	7
60CM, 6FR, 45' AMPLATZER TORQVUE DELIVERY	3	2
60CM, ASD/MUSC VSD REF:9-ITV06F45/60	9	6
Aortic Hemo+ Master Series 17mm	2	2
BOM-CI24RE(CA) unilateral freedom co/implant	38	33
Flextome peripheral cutting balloon	4	2
GELWEAVE VALSALVA GRAFTS 26MM	4	4
GRAFT VASCULAR GORETEX STRETCH STANDARD WALL	7	2
NEONATAL HAEMODIALYSIS LINES VENOUS	82	33
NUMED BIB DILATATION CATHETER	49	48
NUMED CP COVERED STENT 0.013' X 3.4CM	4	4
NUMED MULLINS DILATIONCATHETER	8	8
NUMED MULTI-TRACK CATHETER 6F INTRODUCER 4F	13	10
NUMED PTS SIZING BALLOON CATHETER	1	1
NUMED TYSHAK II BALLOON CATHETER	47	47
Numed Z-MED Balloon Catheter 16mmx 2.0 cm	2	2
NUMED Z-MED II VALVULOPLASTY CATHETER	12	12
Peripheral cutting Balloon	10	4
PERIPHERAL CUTTING BALLOON FLEXTOME MONORAIL	8	3
REPLOGLE SUCTION CATHETER 10F 4.7CM, 3.3MM	12	6
SPINAL PACK - CUSTOMIZED PROCEDURE PACK	44	19
SUPLENA	19	13
SYRINGE 150ML FASTURN PROD CODE 01775436	5	3
TUBING PACK 1-2 X 3-8	504	59
ULTRASOUND COVERS	18	15
V18 CONTROL WIRE	13	9
vascular graft 100 x 40cm	12	8
VASCULAR GRAFT 3 X 15MM	3	2
vascular graft 3.5 mm	3	2
VASCULAR GRAFT 5.0MM L40CM	1	1
vascular graft 5mm	1	1
VASCULAR GRAFT REGULAR 14MM LENGTH 40CM	6	5
VASCULAR GRAFT THIN WALL 3.5MM X 10CM	52	18
VASCULAR GRAFTS STRETCH 10MM X 40CM	3	3
XXL BALLOON 14MM 60MM 5.8FR 75CM	34	19
XXL BALLOON CATHETER	19	9
Z-MED II DILATION CATHETER 12MM X 3CM	3	1
Total	**1065**	**426**

Appendix G Locker Bank Questions and Responses

Questions

A clinician places an order on the hospital procurement system, specifying it as urgent.

Upon verification of the order with the supplier, the supplier is issued with special instructions to deliver the urgent item to a warehouse location for the unattended locker bank operator, same-day / overnight delivery.

Once the item arrives at the operator's warehouse, it is labelled with RFID tags for tracking and to enable secure use of the unattended electronic locker bank. The item is couriered to the locker bank during night-time hours the following night.

When the item arrives at the locker bank, it is scanned. A secure locker partition opens and the item is deposited inside. Upon closing of the partition door, the items delivery is confirmed and an electronic receipt is sent to the email / mobile phone belonging to the clinician who placed the order. The receipt message contains a unique code to be entered into the locker bank to enable access of the item that has been delivered.

Once delivered, the clinician has until the end of the working day to personally collect the item. If the item is not collected before 17:00, after it was delivered, the code for the item is forwarded to the materials management team to enable a member of the materials management team to collect all the items held within the locker bank and deliver them to the ward in the traditional system of delivery rounds.

Appendix G

LOCKER BANK INTERVIEW RESPONSES
Head Nurse, Head of Corporate Facilities, Head of Supply Chain (GOSH), Head of Supply Chain (UHS)
Intelligent storage receipting is being done twice, downstairs and at the cabinet. – therefore there is an issue of delay at receipts. Phones are not issued at GOSH therefore notification of an items arrival would have to be made through the hospital help desk (a telephone switchboard which feeds notifications and phone calls to staff via the bleeper system or office landline connections). Laboratories, theatres, pharmacy and interventional radiology typically make more regular non-stock urgent orders (items required within 24 – 48 hours from the time of ordering). This can include guide wires and stents for which only standard ranges are kept. Therefore requiring special orders for unusual cases. Locker bank system is less useful for inter-departmental transfers since person-to-person transfers are quicker. The system may be useful for deliveries and returns and shortfalls in orders. It may be of use for special deliveries for particular cases for a given date. This system could also provide better track and trace of items. With regards to the pick-up process, it is likely that anyone to hand e.g. ward sister to porters would collect the item given its urgency. Urgent items are typically defined as anything required in less than 2-3 days, i.e. typically overnight parcels. However, the hospital would not like to encourage staff to get into the habit of leaving product orders until the last minute, so its use would be regulated to strict one-offs. The hospital tries to maintain a 48 hour lead time for all product orders as a means to prevent staff cutting it fine. The proposed system may provide some use for the completion of faulty batches of equipment / items.

The box would be good for couriers to deposit items when goods are being sourced from numerous hospitals during emergency situations. Referential integrity – if a product not on the system is ordered an automatic query is raised and an assessment is initiated. Box banks should be located depending on who the main users would be – departments / wards. It also needs to be situated in a public area of the hospital, and internal to clinical areas to prevent de-sterilisation of staff. There may be an issue with personal deliveries being made to the box utilising the useable space available for urgent items. However, they may be good for clinically relevant deliveries of text books and toys, but with over 2,000 staff this could lead to over-use. But its use for non-clinical deliveries could be good for the reduction of work for porters. The boxes would be good to separate and prioritise clinical / surgical items.
Clinical Procurement Lead for Theatres – VCB Reception, Portering and Task Management Manager (Stores department)
Team leaders place orders and are the only ones who have bleepers therefore notification would be issued to them. Issue of urgent items left in stores – clinical staff have to chase up stores. Items are delivered to stores and lost or misplaced and staff have to find them. Courier dishonesty – collection process has to be scanned out – expensive items. Could the system operate on a same day basis too? Accountability is a big benefit from the system making people take responsibility. Implants are meant to have a 2-week notice period from surgeons, but this is not always the case. Procurement systems don't recognise back order / low stock orders resulting in next day delivery requirements. The system may be useful for such situations. Otherwise the system

may be useful for emergency cases whereby items have to be sourced from local surrounding Trusts.

There would be some concerns regarding the condition of items delivered via an automated system.

The proposed system would be useful for overnight stocking.

With regards to collection of urgent items from the locker bank would likely be done by porters, health care assistants and nursing staff.

Controlled drugs should be counter-signed and are in GOSH theatres.

Is there any evidence of errors from ByBox?

Staff in theatres spending time to find urgent items isn't a daily occurrence but it does happen.

Lab samples are taken directly to labs. Occasionally these samples go missing or are left resulting in an infection and / or biohazard risk.

Traceability is a good benefit the system can provide.

We would perceive use for small boxes to be more likely.

Porters clearing the locker bank daily would be vital for its success.

Clinicians aren't able to make product orders because they don't hold budgets. However, occasionally orders can be made by materials management staff. Therefore designation of urgent orders would fall down to team leaders / designated senior staff members responsible for budgets and orders.

Wards shouldn't need urgent items therefore it would expected that theatres would be the main users of the system.

Placement of the system in the hospital reception may be considered prime.

If there were potential for refrigeration of samples / transplants the system may be used for the delivery of transplants which occasionally arrive over the weekend and require signing i.e. Cornea (things with extended lifespans).

Lead Nurse & Advanced Nurse Practitioner, Surgery, Sky Ward
Porter collection – individual portering job Choice to log for portering Maybe not a case for urgent items on wards. How would the system prevent those ordering items from ticking everything as urgent? – Additional costs incurred for the use of the system may reduce abuse of the system. Porters could be logged to collect items rather than clinicians having to collect the packages personally. The proposed system would be beneficial for delivery of small, high value items. ICT ‘stuff’ is the biggest problem – delivering to the ward rather than a central store would prevent loss of items. Items such as CDs with CT scans etc. do occasionally get lost. The proposed system may be beneficial for such items. Person-to-person transfers are better than the locker bank due to speed of transactions. However, intelligent storage for access from all wards with auto charging to the department taking the transfer would be particularly beneficial. Theatres would be the biggest user of equipment transfers as they are the common customers of such transactions. External / patient referrals data would be good to go through the proposed system. The location of the locker bank will affect its use, i.e. basement locations would mean its use by porters; a central location would be good for clinical staff. However, many clinical areas are no longer open for public access. How would the system overcome the problem of items being intentionally marked as urgent by practitioners in an attempt to expedite their delivery, even when they aren’t urgent. The proposed system would be useful for personal staff deliveries.

Who would maintain the system?

Appendix H User Analysis for Locker Bank

			Week															
	Av order size	Av Weekly Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
XMR LEVEL 1 VCB	2	3	5	6	1	3	1	1	4	1	5	2	2	3	0	0	0	0
PERFUSIONIST THEATRE LVL3 CW	9	2	0	2	0	3	1	3	0	0	4	3	0	0	3	0	2	0
INTERVENTION RADIOLOGY	2	1	2	2	0	1	0	0	0	1	2	2	0	0	3	0	1	1
CARDIAC THEATRES CW RM RK3045/29	3	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	3	0
COCHLEAR IMPLANT LVL1 FRONTAGE BUILDING	2	1	0	0	1	0	11	0	0	1	0	8	0	0	0	0	0	0
HAEMODIALYSIS WARD S7C (HIPPO) (MMS)	4	1	1	0	0	0	2	1	0	2	1	1	1	0	0	0	0	0
OCEAN THEATRES L1 OBW (SPINAL)	3	1	1	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0
MILK ROOM	2	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
ANGIO RECEPTION LVL1 CW	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
HAEMODIALYSIS WARD S7C	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
CARDIAC THEATRES MSCB L3	2	1	1	0	0	1	0	2	0	0	1	0	1	0	1	0	0	0
VCB THEATRES L3 RM B3083 (SHARED)	2	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
DOLPHIN WARD NICU LVL4 VCB	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
CARDIAC THEATRES CW RM 1022	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQUIRREL WARD L5 VCB	3	1	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0
AUDIOLOGY DEPARTMENT	1	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
VCB THEATRES L3 RM 3083/34 (UROLOGY)	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CATS RETRIEVAL	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MOBILE UNIT (INTELLIGENT STORAGE)	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
MSCB THEATRES L3 (NEURO)	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQUIRREL WARD LVL5 VCB	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

	Week																		
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
XMR LEVEL 1 VCB	0	0	0	5	2	0	1	1	1	1	1	6	2	3	2	5	3	5	3
PERFUSIONIST THEATRE LVL3 CW	3	0	0	0	2	0	0	3	0	3	0	0	2	0	4	0	0	3	0
INTERVENTION RADIOLOGY	1	0	2	1	0	2	0	3	3	0	1	1	0	0	3	0	0	0	0
CARDIAC THEATRES CW RM RK3045/29	2	0	4	0	0	2	2	0	2	0	1	0	4	1	0	1	2	0	1
COCHLEAR IMPLANT LVL1 FRONTAGE BUILDING	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HAEMODIALYSIS WARD S7C (HIPPO) (MMS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OCEAN THEATRES L1 OBW (SPINAL)	0	0	1	0	0	1	0	0	0	0	1	1	0	1	1	1	1	0	0
MILK ROOM	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0
ANGIO RECEPTION LVL1 CW	0	0	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HAEMODIALYSIS WARD S7C	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	2	0	1	2
CARDIAC THEATRES MSCB L3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VCB THEATRES L3 RM B3083 (SHARED)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
DOLPHIN WARD NICU LVL4 VCB	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
CARDIAC THEATRES CW RM 1022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQUIRREL WARD L5 VCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AUDIOLOGY DEPARTMENT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VCB THEATRES L3 RM 3083/34 (UROLOGY)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
CATS RETRIEVAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MOBILE UNIT (INTELLIGENT STORAGE)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MSCB THEATRES L3 (NEURO)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQUIRREL WARD LVL5 VCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix H

	Week																		
	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	
XMR LEVEL 1 VCB	3	2	12	2	6	2	1	6	4	3	1	11	2	0	3	2	5	3	143
PERFUSIONIST THEATRE LVL3 CW	0	2	1	0	3	0	0	3	0	2	0	0	3	1	0	2	1	0	59
INTERVENTION RADIOLOGY	1	0	0	1	0	0	0	1	0	0	1	1	3	1	1	0	1	0	43
CARDIAC THEATRES CW RM RK3045/29	0	1	0	0	1	0	1	0	3	0	0	0	5	0	0	0	0	0	38
COCHLEAR IMPLANT LVL1 FRONTAGE BUILDING	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	3	0	0	31
HAEMODIALYSIS WARD S7C (HIPPO) (MMS)	0	0	0	1	2	2	1	1	0	0	2	1	2	0	1	1	0	0	23
OCEAN THEATRES L1 OBW (SPINAL)	0	0	2	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	19
MILK ROOM	0	0	1	0	1	0	0	0	1	1	0	0	1	1	0	1	0	0	13
ANGIO RECEPTION LVL1 CW	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	12
HAEMODIALYSIS WARD S7C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
CARDIAC THEATRES MSCB L3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	8
VCB THEATRES L3 RM B3083 (SHARED)	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	7
DOLPHIN WARD NICU LVL4 VCB	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	6
CARDIAC THEATRES CW RM 1022	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3
SQUIRREL WARD L5 VCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
AUDIOLOGY DEPARTMENT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
VCB THEATRES L3 RM 3083/34 (UROLOGY)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
CATS RETRIEVAL	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
MOBILE UNIT (INTELLIGENT STORAGE)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
MSCB THEATRES L3 (NEURO)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
SQUIRREL WARD LVL5 VCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Glossary

Throughout this thesis there are a number of terms used, defined in the Table below. An extensive list of definitions, used in this study, is contained in the Glossary at the end of this thesis.

Table of Main Terms and their definitions

Term	**Definition**	**Source**
NHS Supply Chain	A dedicated consolidation service operated by DHL, established in 2006	(NHS Supply Chain 2014)
Supply Chain	A set of connected nodes (organisations, people, activities, information and resources) through which a product moves from a raw material state to a useable commodity at the end of the chain where it is consumed.	(Christopher 2011)

Bibliography

A2B (2015). "Roll Cages." Retrieved 21/01/15, from http://www.a2boffice.co.uk/roll-cages-c-75_290.html.

Al-Azzawi, M. and I. Mathie (2011). Integrating A Consolidation Centre Within A Dryport for Improved Freight Distribution. European Transport Conference 2011: 18.

Alien (2008). White Paper: Pharmaceutical Shifts Towards UHF RFID for Savings. California, Alien Technology Corporation and RFID Switchboard: 14.

Allen, B. A., E. Wade and H. Dickinson (2009). "Bridging the Divide - Commercial Procurement and Supply Chain Management: Are There Lessons For Health Care Commissioning In England?" Journal of Public Procurement **9**(1): 505 - 534.

Allen, J. and M. Browne (2010). Considering the Relationship Between Freight Transport and Urban Form. Green Logistics Project: Work Module 9 (Urban Freight Transport), University of Westminster: 1 – 74.

Allen, J., M. Browne, A. Woodburn and J. Leonardi (2012). "The Role of Urban Consolidation Centres in Sustainable Freight Transport." Transport Reviews: A Transnational Transdisciplinary Journal **32**(4): 473-490.

Álvarez, E. and A. de la Calle (2011). "Sustainable Practices in Urban Freight Distribution in Bilbao." Journal of Industrial Engineering and Management **4**(3): 538 – 554.

Amazon (2012). "Amazon Locker Delivery." Retrieved 29th October 2012, from http://www.amazon.co.uk/gp/help/customer/display.html?nodeId=200742950.

Anand, A. and S. F. Wamba (2013). "Business Value of RFID-Enabled Helathcare Transformation Projects." Business Process Management Journal **19**(1): 111-145.

Angulo, A., H. Nachtmann and M. A. Waller (2004). "Supply Chain Information Sharing in a Vendor Managed Inventory Partnership." Journal of Business Logistics **25**(1): 101 - 120.

Aptel, O. and H. Pourjalali (2001). "Improving Activities and Decreasing Costs of Logistics in Hospitals: A Comparison of U.S. and French Hospitals." The International Journal of Accounting **36**(1): 65 - 91.

Aronsson, H., M. Abrahamsson and K. Spens (2011). "Developing lean and agile health care supply chains." Supply Chain Management: An International Journal **16**(3): 176-183.

Bibliography

Azzi, A., A. Persona, F. Sgarbossa and M. Bonin (2013). "Drug Inventory management and Distribution: Outsourcing Logistics to Third-Paty Providers." Strategic Outsourcing: An International Journal **6**(1): 48 - 64.

BAA-PLC (2002). Good Practice Case Study 402: Heathrow Airport Retail Consolidation Centre. Retrieved 25/09/12, from http://www.dft.gov.uk/rmd/project.asp?intProjectID=10239.

Badea, A., G. Prostean, G. Goncalves and H. Allaoui (2014). "Assessing Risk Factors in Collaborative Supply Chain with Analytic Hierarcy Process (AHP)." Procedia - Social and Behavioural Sciences **124**: 114 - 123.

Bailey, G. (2014). Unattended Electronic Locker Bank. U. E. L. B. P. S. Forecourt.jpg.

Bailey, G., T. Cherrett, B. Waterson, L. Breen and R. Long (2015). "Boxed Up and Locked Up, Safe and Tight! Making the Case for Unattended Electronic Locker Bank Logistics for an Innovative Logistics Solution for NHS Hospital Supplies (UK)." International Journal for Procurement Management **8**(1-2): 104 – 125.

Bailey, G., T. Cherrett, B. Waterson and R. Long (2013). "Can Locker Box Logistics Enable more Human-centric medical supply chains?" International Journal of Logistics: Research and Applicaitons **16**(6): 447-460.

Basterfield, S. (2012). "Yellow Jersey Delivery - An Innovative, Emission-Free, Bicycle-based, Postal Delivery Service in Coventry (UK)." Retrieved 25/09/14, from http://eltis.org/index.php?id=13&lang1=en&study_id=3501.

Bhakoo, V., P. Singh, A. Sohal (2012). "Collaborative Management of Inventory in Australian Hospital Supply Chains: Practices and Issues." Supply Chain Management: An International Journal **17**(2): 217 - 230.

BikeHub (2014). "Office Depot Introducted Cargo Bikes in London." Retrieved 20/06/14, from http://www.bikehub.co.uk/news/office-depot-introduces-cargo-bikes-in-london/.

Björklund, M. and S. Gustafsson (2012). The Role of Swedish Municipalities in the Establishment of Urban Consolidation Centres. The 18th Greening of Industry Network Conference, 22-24 October. Linköping Congress Centre, Sweden: 19.

Black, D. and A. Zimmerman (2012). “Mercy ROi-BD Case Study: Perfect Order and Beyond, Mercy ROi-BD.” Retrieved 27/05/15, from http://www.roiscs.com/node/103.

Boerkamps, J. and A. Binsbergen (1999). GoodTrip - A New Approach for Modelling and Evaluation of Urban Goods Distribution. 1st International Conference on City Logistics, Cairns, Australia: 175 – 186.

Bosona, T. (2013). Integration of Logistics Network in Local Food Supply Chains. Faculty of Natural Resources and Agricultural Sciences, Department of Energy and Technology. Uppsala, Swedish University of Agricultural Sciences, Uppsala: 83.

Bowersox, D. J., D. J. Closs and T. P. Stank (2000). "Ten Mega-Trends That Will Revolutionize Supply Chain Logistics." Journal of Business Logistics **21**(2): 15.

Breen, L. (2004). "Is there a place for Third Party Logistics providers in the NHS Pharmaceutical Supply Chain in Hospital Pharmacy? - the case of Central Manchester and Manchester Children's University Hospitals NHS Trust (CMMC)." Hospital Pharmacist **11**(3): 33.

Brom, M., J. Holguín-Veras and S. Hodge (2011). "Off-Hour Deliveries in Manhattan, New York City: Experiences of Pilot Test Participants." Transportation Research Record: Journal of the Transportation Research Board(2238): 77 - 85.

Browne, M., J. Allen, T. Nemoto, D. Patier and J. Visser (2012). "c." Procedia - Social and Behavioural Sciences: Seventh International Conferenec on City Logistics **39**: 19 -33.

Browne, M., J. Allen, A. Woodburn and M. Piotrowska (2007). Literature Review WM9: Part I - Urban Freight Transport. Transport Studies Group, University of Westminster: 49

Browne, M., M. Sweet, A. Woodburn and J. Allen (2005). Urban Freight Consolidation Centres. London, Transport Studies Group, University of Westminster and Department for Transport: 185.

Buck Consultants International and G. Coffeng (2009). Effectstudie milieuzones vrachtverkeer, stand van zaken 2009. Nijmegen. Retrieved 27/05/15, from http://www.milieuzones.nl/effecten.

Burns, L. (2002). The Healthcare Value Chain: Producers, Purchasers, and Providers, Jossey-Bass: 1 – 216.

ByBox (2012). "ByBox." Retrieved 20/07/12, from http://www.bybox.com/.

Campbell, J., L. MacPhail and G. Cornelis (2010). SEStran (South East Scotland Transport Partnership): Freight Consolidation Centre Study. P. b. S. Wilson: 75.

Bibliography

Cardinal Health (2012). The Business of Healthcare: Optimising your supply chain. Retrived 27/05/15, from http://cardinal.com/mps/wcm/connect/fe0b43004d4b6f8b96509e14bdb5f78d/Essential+Insights_Optimizing+Your+Supply+Chain_FINAL.pdf?MOD=AJPERES&lmod=-1122125011&CACHEID=fe0b43004d4b6f8b96509e14bdb5f78d&lmod=-1122125011&CACHEID=fe0b43004d4b6f8b96509e14bdb5f78d: 16.

Chapman, T. L., A. Gupta and P. D. Mango (1998). "Group Purchasing is not a panacea for US hospitals." Retrieved 05/10/12, from http://www.mckinseyquarterly.com/Group_purchasing_is_not_a_panacea_for_US_hospitals_267.

Cherrett, T., J. Allen, F. Mcleod, S. Maynard, A. Hickford and M. Browne (2012). "Understanding Urban Freight Activity - Key Issues for Freight Planning." Journal of Transport Geography **24**: 22 – 32.

Christopher, M. (2011). Logistics and Supply Chain Management. Harlow, Pearson Educational Limited: 1 – 56, 83 – 120 & 241 – 256.

Chui, M., M. Löflet and R. Roberts (2010). "The Internet of Things." McKinsey Quarterly(2): 112.

Chung, J. W. and D. O. Meltzer (2009). "Estimate of the Carbon Footprint of the US Health Care Sector." Journal of the American Medical Association **302**(18): 1967 – 1972.

Collect+ (2011). "Collect+ Parcels made easy." Retrieved 09/10/13, from http://www.collectplus.co.uk/.

Compsee (2014). "Radio Frequency ID Systems." Retrieved 05/08/14, from http://compsee.com/products/hardware-and-supplies/rfid-systems.

Cordeau, J.F., G. Laporte, M. W. P. Savelsbergh and D. Vigo (2007) Chapter 6. Vehicle Routing. In: Barnhart, C and G. Laporte (Eds), *Handbook in OR & MS, Vol. 14.* Elsevier B. V: 367 – 428.

Costantino, N., M. Dotoli, M. Falagario, M. P. Fanti, A. M. Mangini, F. Sciancalepore and W. Ukovich (2010). A Model for the Optimisation Design of the Hospital Drug Distribution Chain. Health Care Management (WHCM), 2010 IEEE Workshop on, IEEE: 6.

Coulson-Thomas, C. J. (1997). "Process Management in a Hospital and Healthcare Context: Evidence of the HOCAPRIT Project." Business Process Management Journal **3**(2): 118-142.

Crainic, T. G., N. Ricciardi and G. Storchi (2009). "Models for Evaluating and Planning City Logistics Systems." Transportation Science **43**(4): 432 – 454.

DAF (2015a). Enquiry into turning circle requirements for DAF LF 220 (Wheelbase 6.25m). G. Bailey.

DAF (2015b). LF 220 FA 4x2 rigid, 19t Chassis / Body Specification Sheet. Retrieved 27/05/15, from https://www.daf.com/SpecsheetsMedia//TSIEEN018F5603AAAA201513.PDF.

Danese, P. (2004). "Beyond Vendor Managed Inventory: the Glaxosmithkline Case." Supply Chain Forum: An International Journal **5**(2): 32-40.

Danielis, R., E. Maggi, L. Rotaris and E. Valeri (2012). Urban Supply Chains and Transportation Policies. **1207**: 19.

de Vries, G., J. W. M. Betrand and J. M. H. Vissers (1999). "Designing requirement for health care production control systems." Production Planning & Control **19**(6): 559 – 569.

de Vries, J. and R. Huijsman (2012). "Supply Chain Management in Health Services: An Overview." Supply Chain Management: An International Journal **16**(3): 159 – 165.

DECC (2008). "Climate Change Act 2008." Retrieved 11/09/12, from http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx

DECC (2014). 2012 UK Greenhouse Gas Emissions, Final Figures: Statistical Release, Department of Energy and Climate Change; and, Office for National Statistics. **4th February**. Retrieved 28/05/15, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/295968/20140327_2013_UK_Greenhouse_Gas_Emissions_Provisional_Figures.pdf

DEFRA (2009). Guidance on how to measure and report your greenhouse gas emissions. Defra and DECC. London. Retrieved 27/05/15, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69282/pb13309-ghg-guidance-0909011.pdf.

DEFRA, DECC and Ricardo-AEA (2013a). 2013 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors. London, DECC. Retrieved 27/05/15, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224437/pb13988-emission-factor-methodology-130719.pdf.

DEFRA, DECC and Ricardo-AEA (2013b). UK Government Conversion Factors for Company Reporting. Retrieved 28/05/15, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224437/pb13988-emission-factor-methodology-130719.pdf.

Dembiríska-Cyran, I. (2005). "Internal and External Supply Chain of Hospital." LogForum **1**(1): 7.

Department of the Environment (2014) Parking Design Standards. Retrieved 25/09/14, from http://www.pkc.gov.uk/CHttpHandler.ashx?id=10565&p=0.

D'Este, G., (2000) Chapter 33. Urban Freight Movement Modelling. In: Hensher, D. A. and K. J. Button (Eds), *Handbook of Transport Modelling*. Elsevier Sceince Ltd: 541 – 552.

DfT (2010). DfT Annual Road Traffic Census Counts - Sites 37773, 37827, 57690, 17688, 8381, 37825 and 7671. Annual Average Daily Traffic Flows Estimates by year, site and vehicle type. DfT, TfL.

DHL (2012). "DHL Packstation." Retrieved 20/07/12, from http://www.dhl.de/en/paket/privatkunden/packstation.html.

DHL Excel Supply Chain (2012). "Hospital Logistics Solutions." Retrieved 18/12/12, from http://www.dhl-healthcare.com/about-dhl-healthcare/healthcare-downloads/category/6-hospital-logistics.html

DX-Business-Direct (2012). "DX: ParcelXchange." Retrieved 20/07/12, from http://www.dxbd.co.uk/.

Easton, M. (2009). "Promotion of Cycling and the Development of and NHS Cycling Strategy - Proposed Immediate Action and Medium Long Term Opportunities for NHS London.": 5.

EC (2011). "White Paper 2011: Roadmap to a Single European Transport Area - Towards a Competitive and resource efficient transport system." Retrieved 27/05/15, from ec.europa.eu/transport/strategies/2011_white_paper_en.htm

ECF (2011). Cycle More Often 2 Cool Down the Planet! Quantifying CO_2 Savings of Cycling, European Cyclists' Federation, Brussels, 2011. Retrieved 27/05/15, from http://www.ecf.com/wp-content/uploads/ECF_CO2_WEB.pdf.

Edwards, J., A. McKinnon, T. Cherrett, F. Mcleod and L. Song (2009). The impact of failed home deliveries on carbon emissions: are collection / delivery points environmentally-friendly alternatives? Logistics Research Network Annual Conference. Cardiff, UK: 102 – 108.

Edwards, J., A. McKinnon, T. Cherrett, F. Mcleod and L. Song (2010). "Carbon Dioxide Benefits of Using Collection-Delivery Points for Failed Home Deliveries in the United Kingdom." Transportation Research Record: Journal of the Transportation Research Board(2191): 136 - 143.

European Centre for Environment & Human Health (2011). "New Research Could Help NHS Reach Carbon Targets." Retrieved 09/08/13, from http://www.ecehh.org/news/new-research-could-help-nhs-reach-carbon-targets.

Everard, L. J. (2001). Blueprint for an Efficient Healthcare Supply Chain. White Paper, Medical Distribution Solutions: 34.

Eye-for-Transport (2011). "FedEx launches enhanced resource for healthcare industry." Retrieved 27/05/11, from http://www.eyefortransport.com/content/fedex-launches-enhanced-resource-healthcare-industry.

Fakhimi, M. and J. Probert (2013). "Operations Research within UK Healthcare: A Review." Journal Enterprise Information Management **26**(1/2): 21-49.

Finesilver, J. (2002). Electronic Data Interface - EDI What's in it for pharmacy?**:** 2.

Fisher, M. L. (1997). "What is the Right Supply Chain for Your Product?" Harvard Business Review **Reprint 97205**(March - April): 106 - 116.

Floerkemeier, C. and M. Lampe (2004). "Issues with RFID Usage in Ubiquitous Computing Applications." Pervasive Computing: 188 – 193.

Foucras, C. (2013). "Campaign to Deliver Goods by Bike in Pamiers, France." Retrieved 25/09/14, from http://eltis.org/index.php?id=13&lang1=en&study_id=2886.

Franklin, B. D., G. McLeod, B. Miller, B. Langfield and A. Jacklin (2010). "Using Ward Based Automation to Manage Controlled Drugs." Pharmacy Management **26**(2): 9 – 14.

Freudenheim, M. (1991). All About/ Medical Supplies; Removing the Warehouse from Cost-Conscious Hospitals. The New York Times. **March 3rd 1991**. Retrieved 27/05/15, from http://www.nytimes.com/1991/03/03/business/all-about-medical-supplies-removing-the-warehouse-from-cost-conscious-hospitals.html.

Fry, J., P. Wollaston and D. Nash (2012). Interviews with Supply Chain Staff at Great Ormond Street Hospital. G. Bailey

FTA Cost Information Service (2014a). FTA Cost Information Service: Vehicle Operating Costs - October 2014 Update, FTA: 16.

FTA Cost Information Service (2014b). FTA Cost Information Service: Wage Trends - October 2014 Update, FTA: 3, 4 & 13.

Galli, G. (2012a). "Distropolis: A New City Logistics Solution in Paris, France." Retrieved 25/09/14, from http://eltis.org/index.php?id=13&study_id=3639.

Galli, G. (2012b). "Padova Cityporto: A Success Model of Urban Logistics (Italy)." Retrieved 25/09/14, from http://eltis.org/index.php?id=13&study_id=3550.

Gazzard, N. (2013). Phone interview with Nick Gazzard regarding current techniques for appraisal of consolidation centres. G. Bailey.

GHG-Protocol and LMI (2012). The Greenhouse Gas Protocol for the U.S. Public Sector: Interpreting the Corporate Standard for U.S. Public Sector Organisations, World Resources Institute; and, LMI. **2014**: 112.

Glickman, S. W., K. A. Baggett, C. C. Krubert, E. D. Peterson and K. A. Schulman (2007). "Promoting quality: the health-care organisation from a management perspective." International Journal for Quality in Health Care **19**(6): 341-348.

Gonzales-Feliu, J., J. M. S. Grau, J. Morana and E. Mitsakis (2012). "Urban Logistics Pooling Viability Analysis via a Multicriteria Multiactor Method." HAL: 867 – 882.

GOSH (2011). "Great Ormond Street Hospital Charity." Retrieved 04/04/12, from http://www.gosh.org/gen/.

GSTT (2014). Interview with David Lawson (Director of Procurement at Guy's and St Thomas' NHS Foundation Trust) and Alexandra Hammond (Sustainability Manager at Guy's and St Thomas' NHS Foundation Trust.

Guimarães, C. M., J. C. de Carvalho and A. Maia (2011). "Vendor Managed Inventory (VMI): Evidences from Lean Deployment in Healthcare." Strategic Outsourcing: An International Journal **6**(1): 8-32.

Gurobi Optimisation (2015). "MIP Basics: A Primer on the basics of mixed integer programming." Retrieved 27/05/15 , from http://www.gurobi.com/resources/getting-started/mip-basics.

Hammant, J. (1995). "Information technology trends in logistics." Logistics Information Management **8**(6): 32 – 37.

Healthcare Risk Management (2010). "Large pill theft shows challenge of securing hospital drugs." Healthcare Risk Management **32**(6): 61 – 63.

Hedditch, L. (2014). Phone Interview with Liz Hedditch, Accounts Manager at City Sprint. G. Bailey.

Holguín-Veras, J., K. Ozbay, A. Kornhauser, M. B. Brom, S. Lyer, W. F. Yushimito, S. Ukkusuri, B. Allen and M. A. Silas (2011). "Overall Impacts of Off-Hour Delivery Programs in New York City Metropolitan Area." <u>Transportation Research Record: Journal of the Transportation Research Board</u>(2238): 68 – 76.

Hopkins, C. (2010). "The (Near) Future of Medicine: Take Two Computers and IM Me in the Morning." Retrieved 31/05/11, from http://www.readwriteweb.com/archives/the_near_future_of_medicine_take_two_computers_and.php.

Hoyer, R. (2012). Distributing the Benefits of Urban Consolidation Centres: An Application on Westfield Shopping Centre, London. <u>School of Industrial Engineering</u>. Eindhoven, Eindhoven. **MSc in Operations Management and Logistics**: 88.

Huschebeck, M. (2007). "Night Delivery in Dublin (Ireland)." Retrieved 25/09/14, from http://eltis.org/index.php?id=13&lang1=en&study_id=1286.

Huschebeck, M. and J. Allen (2005). D1.1 BESTUFS Policy and Research Recommendations I: Urban Consolidation Centres, Last Mile Solutions**:** 22.

Häger, K. and C. Rosenkvist (2012). Freight Consolidation's Impact on CO2 Emissions and Costs: An Evaluation of DHL Global Forwarding's Control Towers' Work and of Factors Concerning Consolidation. <u>Department of Management and Engineering</u>, Linköping University Institute of Technology. **Masters**: 157.

IBM (2011). "A Smarter Planet." Retrieved 31/05/11, from http://www.ibm.com/smarterplanet/us/en/?ca=v_smarterplanet.

IGD (2009). "How Nestlé and United Biscuits are workign together to share resources." Retrieved 14/09/13, from http://www.igd.com/Nestle_and_United_Biscuits_collaboration.

IMRG (2014). "IMRG: Failed online deliveries will cost more than £¾BILLION this year." Retrieved 07/07/12, from http://www.imrg.org/ImrgWebsite/User/Pages/PressReleases.aspx?pageID=85&parentPageID=0&itemID=193&pageTemplate=7&isHomePage=false&isDetailData=true&specificPageType=5

Indu, P. and S. Govind (2008). "Supply Chain Practices of Three European Apparel Companies: Zara, H&M and Benetton." <u>ICMR Centre for management Research</u>: 608 – 620.

Intersurgical (2014). Interview with Sally Powell (Logistics Manager) and Mark Ellis (UK Sales and Marketing Manager) and Maxine Taylor (UK Customer Services Manager).

Jarret, P. G. (2006). "An analysis of International health care logistics." Leadership in Health Services **19**(1): 10.

Johnson, R. A. and G. K. Bhattacharyya (2001). Appendix A2: Rules for Counting. Statistics: Principles and Methods. Quebecor USA, John Wiley & Sons, Inc.**:** 660 - 662.

Kaszubowski, D. (2012). "Evaluation of Urban Freight Transport Management Measures." Scientific Journal of Logistics **8**(3): 217 - 229.

Kizilateş, G. and F. Nuriyeva (2013). "On the Nearest Neighbour Algorithms for the Travelling Salesman Problem." Advances in Intelligent Systems and Comuting **225**: 111 - 118.

Klaus, P. (2005). A Future Role for Urban Consolidation Centres? German Experiences and Prospects, Boston University: for BESTUFS: 22

Kok, M. (2015). Private Communciation regarding the construction and implementation of the proposed MCC unit. G. Bailey.

KonSULT (2014). "KonSULT: Knowledgebase on Sustainable Urban Land use and Transport - Policy Guidebook." Retrieved 26/05/2015, from http://www.konsult.leeds.ac.uk/pg/.

Kowalski, J. C. (1991). "Inventory to Go: Can Stockless Delivery Efficiency?" Hospital Materials Management **45**(11): 21-2.

Kulis, B. (2012). Lecture in Monte Carlo Sampling Methods. Retrieved 27/05/15, from http://web.cse.ohio-state.edu/~kulis/teaching/788_sp12/scribe_notes/lecture7.pdf.

Kumar, A., L. Ozdamar and C. N. Zhang (2008a). "Supply chain redesign in the healthcare industry of Singapore." Supply Chain Management: An International Journal **13**(2): 95-103.

Kumar, S., R. A. DeGroot and D. Choe (2008b). "Rx for Smart Hospital Purchasing Decisions: The Impact of Package Design within US Hospital Supply Chain." International Journal of Physical Distribution and Logistics Management **38**(8): 601-615.

Kumar, S., E. Dieveney and A. Dieveney (2009). "Reverse logistic process control measures for the pharmaceutical industry supply chain." International Journal of Productivity and Performance Management **58**(2): 188-204.

Lamb, J. (2012). "How Collaboration Trimmed Truck Travel by 204m Miles." Retrieved 14/08/2014, from http://www.supplychainstandard.com/liChannelID/3/Articles/4018/How+collaboration+trimmed+truck+travel+by+204m+miles.html.

Land, A. H. and A. G. Doig (1960). "An automated method of solving discrete programming problems." Econometrica **28**(3): 497 - 520.

Langabeer, J. R. (2008). Health Care Operations Management: A Quantitative Approach to Business and Logistics, Jones and Bartlett Publishers Inc: 209 – 240.

Lapierre, S. D. and A. B. Ruiz (2005). "Scheduling Logistics Activities to Improve Hospital Supply Systems." Computers and Operations Research **34**: 624 – 241.

Lee, Sang M., DonHee Lee, and Marc J. Schniederjans. "Supply chain innovation and organizational performance in the healthcare industry."International Journal of Operations & Production Management 31.11 (2011): 1193-1214.

Lega, F., M. Marsilio and S. Villa (2012). "An evaluation framework for measuring supply chain performance in the public healthcare sector: evidence from the Italian NHS." Production Planning & Control: 1-17.

Lewis, A., M. Fell and D. Palmer (2010). Freight Consolidation Centre Study, Department for Transport. Retrieved27/05/15, from http://www.ttr-ltd.com/downloads/pdf/DfTFreightConsolidationCentreStudy-04112010.pdf.

Li, S., J. K. Visich, B. M. Khumawala and C. Zhang (2006). "Radio frequency identification technology: applications, technical challenges and strategies." Sensor Review **26**(3): 193-202.

Liang, H., Y. Xue, T. A. Byrd and K. R. Rainer Jr (2004). "Electronic Data Interchange Usage in China's Healthcare Organisations: The Case of Beijing's Hospitals." International Journal of Information Management **24**(6): 507 - 522.

Lin, C., Choy, K. L., Lam, H. Y., & Wong, D. W. (2012, July). A web-based intelligent collaborative logistics management decision support system for enhancing the cost effectiveness of door-to-door delivery. In Technology Management for Emerging Technologies (PICMET), 2012 Proceedings of PICMET'12: 744-753. IEEE.

Lin, Y. C., Lin, C. C., & Lin, C. C. (2011, July). Determining the governance controllability of organizations in supply chain management using fuzzy expert system. In Proceedings of the 15th WSEAS international conference on Computers. World Scientific and Engineering Academy and Society (WSEAS): 393-398.

Lindsey, K. A. (2012). Improving Freight Consolidation Networks Using IP-Based Local Search. H.Milton Stewart School of Industrial and Systems Engineering, Georgia Institute of Technology. **Doctor of Philosophy**: 108.

Lodi, A., S. Martello and M. Monaci (2002). "Two-dimensional packing problems: A survey." European Journal of Operational Research **141**(2): 241-253.

LPP (2013). "London Procurement Partnership: Commercial Advantage for the NHS by the NHS." Retrieved 11/10/13, from http://www.lpp.nhs.uk/.

MacManus, R. (2009, 4th December 2009). "FedEx Joins the Internet of Things With SenseAware." Retrieved 11/04/11, from http://www.readwriteweb.com/archives/fedex_joins_the_internet_of_things_with_senseaware.php.

MacManus, R. (2010a, 3rd March 2010). "McKinsey: Get Ready For Sensor-Driven Business Models." Retrieved 11/04/11, from http://www.readwriteweb.com/archives/mckinsey_internet_of_things.php.

MacManus, R. (2010b, 15th December 2010). "Top 10 Internet of Things Developments of 2010." Retrieved 11/04/11, from http://www.readwriteweb.com/archives/top_10_internet_of_things_developments_of_2010.php.

Malhene, N., A. Trentini, G. Marques and P. Burlat (2012). Freight Consolidation Centres For Urban Logistics Solutions: The Key Role of Interoperability. 2012 6th IEEE International Conference on Digital Ecosystems Technologies (DEST), Campione, Italy: 6.

Mallampati, D. R., P. P. Mutalik and R. L. Wainwright (1991). A Parallel Mutli-Phase Implementation of Simulated Annealing for the Travelling Salesman Problem. Distributed Memory Computing Conference, Portland, Oregon: 488 – 491.

Mans, R. S., W. M. P. Van der Aalst, R. J. B. Vanwersch and A. J. Moleman (2013). "Process Mining in heatlhcare: Data Challenges When Answering Frequently Posed Questions. Process Support and Knowledge Representation in Health Care, Lecture Notes." Computer Science **7738**: 140-153.

Marcucci, E. and R. Danielis (2008). "The Potential Demand For A Urban Freight Consolidation Centre." Transportation **35**: 269 – 284.

Marinov, M., T. Zunder and D. Islam (2010). "Urban Freight Consolidation Concepts: Is There Something Missing." Transport Problems **5**(2): 5 - 12.

McKinnon, A. C. and D. Tallam (2003). "Unattended Delivery to the Home: An Assessment of the Security Implications." International Journal of Retail and Distribution management **31**(1): 30-41.

McKone-Sweet, K., P. Hamilton and S. B. Willis (2005). "The Ailing Healthcare Supply Chain: A Prescription for Change." The Journal of Supply Chain Management **41**: 4-17.

Mcleod, F. and T. Cherrett (2011). "Loading Bay Booking and Control for Urban Freight." International Journal of Logistics: Research and Applications **14**(6): 385 - 397.

McLeod, S. (2011). "Internet of Things: Prescription Medicine." Retrieved 31/05/11, from http://www.minddump.org/internet-of-things-prescription-medicine.

MDS Transmodal Ltd and CTL (2012). DG Move European Commission: Study on Urban Freight Transport, MDS Transmodal Ltd: 154.

Medeiros, C. R., C. C. Serra, C. A. Fernandes and J. R. Costa (2011). UHF RFID Cabinet. IEEE International Symposium on Antennas and Propagations (APSURSI): 1429 – 1432.

Menge, J. and P. Hebes (2011). Optimisation of Urban Deliveries: Evaluating A Courier, Express and Parcel Services Pilot Project in Berlin. City Distribution and Urban Freight Transport. C. Macharis and S. Melo. Cheltenham, UK, Edward Elgar Publishing Limited: 201 – 216.

Michael, K., G. Roussos, G. Q. Huang, A. Chattopadhayay, R. Gadh, B. S. Prabhu and P. Chu (2010). "Planetary-Scale RFID Services in an Age of Uberveillance." Proceedings of the IEEE **98**(9): 1663 – 1671.

Moore, M. (2014). Interview with Mark Moore, Global Transport Manager at Bunzl Healthcare.

Mun, I. K., A. B. Kantrowitz, P. W. Carmel, K. P. Mason and D. W. Engels (2007). Active RFID System Augmented With 2D Barcode for Asset Management in a Hospital Setting. IEEE. Texas, USA: 205 – 211.

Mustaffa, N. H. and A. Potter (2009). "Healthcare Supply Chain Management in Malaysia: A Case Study." Supply Chain Forum: An International Journal **14**(3): 234-242.

Nagy, P., I. George, W. Bernstein, J. Caban, R. Klein, R. Mezrich and A. Park (2006). "Radio Frequency Identification Systems Technology in the Surgical Setting." Surgical Innovation **13**(1): 61-67.

Nemoto, T. (1997). "Area-wide inter-carrier consolidation of freight in urban areas." Transport Logistics **1**(2): 87-101.

Nguyen, C., A. Toriello, M. Dessouky and J. Moore II (2013). "Evaluation of Transportation Practices in The California Cut Flower Industry." Interfaces **43**(2): 182 – 193.

NHS (2012). "NHS Supply Chain." Retrieved 09/10/12, from http://www.supplychain.nhs.uk/.

NHS SDU (2012). NHS England Carbon Footprint, NHS Sustainable Development Unit. Retrieved 27/05/15, from http://www.sduhealth.org.uk/policy-strategy/reporting/nhs-carbon-footprint.aspx.

NHS SDU and NHS SBS (2010). Goods and Services Carbon Hotspots: NHS England Breakdown of Goods and Services Carbon Footprint by Organisation Type, NHS Sustainable Development Unit (SDU); and, NHS Shared Business Services (NHS SBS): 40. Retrieved 27/05/15, from https://www.google.co.uk/search?q=Goods+and+Services+Carbon+Hotspots%3A+NHS+England+Breakdown+of+Goods+and+Services+Carbon+Footprint+by+Organisation+Type&oq=Goods+and+Services+Carbon+Hotspots%3A+NHS+England+Breakdown+of+Goods+and+Services+Carbon+Footprint+by+Organisation+Type&aqs=chrome..69i57.279j0j4&sourceid=chrome&es_sm=122&ie=UTF-8.

NHS Supply Chain (2014). "About NHS Supply Chain." Retrieved 24/03/14, from http://www.supplychain.nhs.uk/about-us/key-facts/.

Nicholson, L., A. J. Vaharia and S. S. Erenguc (2004). "Outsourcing inventory management decisions in healthcare: Models and applications." European Journal of Operational Research **154**(1): 271 – 290.

Nollet, J. and M. Beaulieu (2005). "Should an organisation join a purchasing group?" Supply Chain Management: An International Journal **10**(1): 11 – 17.

NorthShore LIJ (2013). "Healthier Operations: Setting the Standard for Sustainability in Healthcare." Retrieved 09/08/13, from http://www.northshorelij.com/hospitals/community/healthier-operations-reducing-carbon-footprint.

Novartis (2014). "Remote Monitoring." Retrieved 21/01/15, from http://www.novartis.com/innovation/focus-on-patient-outcomes/remote-monitoring.shtml.

Office-Depot (2010). "Launch of Cargo Cycles, Office Depot Briefing Document." Retrieved 09/10/12, from http://www.officedepot.co.uk/OD_content/data/documents/press-kit/Cargo%20Cycle%20%20briefing%20doc1.pdf.

OLEV (2013). Driving the Future Today, A Strategy for Ultra Low Emissions Vehicles in the UK. London, Office for Low Emission Vehicles: 104. Retrieved 27/05/15, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/239317/ultra-low-emission-vehicle-strategy.pdf

Olsson, J. and J. Woxenius (2012). "Location of Freight Consoldiation Centres Serving the City and its Surroundings." Procedia Social and Behavioural Sciences **39**(13): 293 - 306.

Omnicell (2011). "Omnicell: Integrated Automation Solutions." Retrieved 18/07/12, from http://www.omnicell.com/Success_Stories/Case_Studies.aspx.

Özkil, A. G., Z. Fan, S. Dawids, H. Aanaes, J. K. Kristensen and K. H. Christensen (2009). Service Robots for Hospitals: A Case Study of Transportation Tasks in a Hospital. Proceedings of the IEEE International Conference on Automation and Logistics. Shenyang, China**:** 289 – 294.

Pan, Z. X. and S. Pokharel (2007). "Logistics in hospitals: a case study of some Singapore hospitals." Leadership in Health Services **20**(3): 195-207.

Panero, M., H. Shin and D. Lopez (2011). Urban Distribution Centres A Means to Reducing Freight Vehicle Miles Travelled. NY, The NYU Rudin Centre for Transportation Policy and Management: 121.

Parnaby, J. and D. R. Towill (2008). "Seamless Healthcare Delivery Systems." International Journal of Healthcare Quality Assurance **21**(3): 249-273.

Parnaby, J. and D. R. Towill (2009). "Engineering Cellular Organisation and Operation for Effective Healthcare Delivery Supply Chains." The INternational Journal of Logistics Management **20**(1): 5-29.

Pharmaceutical Journal Online (2012a). "Pharmacy managers struck off for theft of medicines." Pharmaceutical Journal **288**: p.50

Pharmaceutical Journal Online (2012b). "Prescription drug abuse spreading through UK prisons." Pharmaceutical Journal **289**: 29th August: p.219.

Pipe-Wolferstan, K. (2013). Expert Review of NHS Supply Chain Operations at Bury St Edmunds with Keith Pipe-Wolferstan, Regional Business Manager (South-East England).

Pohl, E. A., M. D. MRossetti, H. L. Nachtmann and V. M. Varghese (2012). Healthcare vs Retail Gap Analysis: Measuring the Gap between Healthcare and Retail in Supply Chain Best Practices. Fayetteville: Centre for Innovation in Healthcare Logistics, University of Arkansas: 10.

Porter, M. E. (1998). Competitive Advantage: Creating and Sustaining Superior Performance. New York, The Free Press: 11 – 61.

Potdar, M., E. Chang and V. Potdar (2006). Applications of RFID in Pharmaceutical Industry. Industrial Technology, 2006. ICIT 2006. IEEE International Conference on, Mumbai, IEEE: 2860 – 2865.

Poulin, E. (2003). "Benchmarking the Hospital Logistics Process: A Potential Cure for the Ailing Health Care Sector." CMA Management **77**(1): 20 – 23.

Qiu, X. and G. Q. Huang (2013). "Supply Hub in Industrial Park (SHIP): The Value of Freight Consolidation." Computers and Industrial Engineering **65**: 16 – 27.

Quak, H. (2008). Sustainability of Urban Freight Transport Retail Distribution and Local Regulations in Cities. Erasmus Research Institute of Management (ERIM). Netherlands, Erasmus University Rotterdam. **Doctorate:** 262.

Ducret, R. and L. Delaïtre(2013). Parcel Delivery and Urban Logistics - Changes in Urban Courier, Express and Parcel Services: The French Case. 13th World Conference on Transport Research, Rio de Janeiro, Brazil: 20.

Rego, C., D. Gamboa, F. Glober and C. Osterman (2011). "Travelling salesman problem heuristics: Leading methods, implementations and latest advances." European Journal of Operational Research **211**(3): 427 - 441.

Regué, R. and A. L. Bristow (2013). "Appraising Freight Tram Scemes: A Case Study of Barcelona." European Journal of Transport and Infrastructure Research **13**(1): 56 – 78.

Revere, L. (2004). "Re-engineering proves effective for reducing courier costs." Business Process Management Journal **10**(4): 400-414.

Revere, L. and R. Roberts (2004). "Improving Resource Efficiency Through Management Science." Journal of Healthcare Management **49**(5): 323-333.

Ritchie, L., B. Burnes, P. Whittle and R. Hey (2000). "The Benefits of Reverse Logistics: The Case of The Manchester Royal Infirmary Pharmacy." Supply Chain Management: An International Journal **5**(5): 226-233.

Rivard-Royer, H., S. Landry and M. Beaulieu (2002). "Hybrid Stockless: A Case Study. Lessons for Health-care Supply Chain Integration." International Journal of Operations and Production Management **22**(4): 412 – 424.

Roeller (2012). "Urban Hub "BentoBox" Fosters More Sustainable Urban Freight Delivery in Berlin (Germany)." Retrieved 25/09/14, from http://eltis.org/index.php?id=13&lang1=en&study_id=3520.

Rojas, R. (1996). Neural Networks: A Systematic Introduction: Chapter 17, Genetic Algorithms. Berlin, Springer-Verlag: 427 – 448.

Roussos, G. (2009). Sensor and Actuator Networks and the Internet of Things.

Rowlands, P. (2007). "Smart Delivery - More than just the sum of the parts?". Retrieved 20/07/12, from http://www.elogmag.com/magazine/42/smart-delivery.shtml.

Russell, S. and P. Norvig (2010). Artificial Intelligence: A modern approach. New Jersey, Prentice Hall: 53 – 121.

Schoemaker, J., J. Allen, M. Huschebeck and J. Monigl (2006). BESTUFS II: Quantification of Urban freight Transport Effects I, BESTUFS.NET: 72.

Schulz, M. (2014). Private Communication with Danny Luu (TfL) and Martin Schulz (TNT). G. Bailey.

Screeton, J. (2013). "Integrating Passenger Trains into Sustainable Supply Chains in the UK." Retrieved 25/09/14, from http://eltis.org/index.php?id=13&lang1=en&study_id=3886.

Shapiro, R. and J. Byrnes (1992). "Intercompany Operating Ties: Unlocking the Value in Channel Restructuring." Harvard Business School Working Paper **92**(058): 27.

Shieh, S. C. (2008). Using RFID technology on clinic's pharmacy operations management and development of intelligeent medicine dispensing cabinet. IEEE International Conference on Industrial Engineering and Engineering Management: 2006 – 2009.

SmartPlanet (2009). "Fedex Launches Senseaware: Collaboration Meets GPS Meets Sensory Data." Retrieved 21/01/15, from http://www.smartplanet.com/blog/smart-takes/fedex-launches-senseaware-collaboration-meets-gps-meets-sensory-data/.

Song, J., C. T. Haas and C. H. Caldas (2007). "A proximity-based method for locating RFID tagged objects." Advanced Engineering Informatics **21**(4): 367-376.

Song, L., T. Cherrett, F. Mcleod and W. Guan (2009). "Addressing the Last Mile Problem: Transport Impacts of Collection and Delivery Points." Transportation Research Record: Journal of the Transportation Research Board(2097): 9 – 18.

Stadtschreiber, E. (2011). "Emission - Free Delivery Service with Cargo Bikes in Central Cambridge, UK." Retrieved 25/09/15, from http://eltis.org/index.php?id=13&lang1=en&study_id=3015.

Stanger, S. H. W., R. Wilding, N. Yates and S. Cotton (2012). "What Drives Perishable Inventory Management Performance? Lessons Learnt From The UK Blood Supply Chain." Supply Chain Management: An International Journal **17**(2): 107 – 123.

Steps and Stillages (2015). "Lorry Access Mobile Platform." Retrieved 27/01/15, from https://www.stepsandstillages.co.uk/products/mobile-steps/product/890-lorry-access-mobile-platform.

Stiehler, A. (2005). Workshop at DIW Industrial Conference: RFID / Auto-ID Approaches in the Pharmaceutical Industry. DIW Industrial Conference, 11 May 2005.; 10. Retieved 27/05/15, from http://ec.europa.eu/enterprise/archives/e-business-watch/events/documents/Stiehler.PDF

Straightsol (2012a). "Demonstration B: TNT in Brussels - City Logistics Mobile Depot." Retrieved 30/08/12, from http://www.straightsol.eu/demonstration_B.htm.

Straightsol (2012b). "Demonstration F: TNT In Night in Utrecht." Retrieved 31/08/12, from http://www.straightsol.eu/demonstration_F.htm.

STRAIGHTSOL (2014a). "Project Demonstrations, Demonstration F: Colruyt and Delhaize in Brussels - Night-time deliveries." Retrieved 10/07/14, from http://www.straightsol.eu/demonstration_F.htm.

STRAIGHTSOL (2014b). STRAIGHTSOL - Strategies and Measures for Smarter Urban Freight Solutions: Project Results. Retrieved 28/05/15, from https://drive.google.com/file/d/0ByCtQR4yIfYDUFU1X2d5dkdReEk/view?pli=1.

Taniguchi, E. (2012). Concept and Best Practices of City Logistics. International Transport Forum, Leipzig. Retrieved 27/05/15, from http://2012.internationaltransportforum.org/sites/itforum2012/files/documents/en/WCTR_Side_Event_UrbanFreight_Taniguchi_20120502.pdf.

TfL (2007). London Freight Plan, Sustainable Freight Distribution: A Plan for London. T. f. London. London, Transport for London. Retrieved 27/05/15, from https://www.tfl.gov.uk/info-for/freight/planning/london-freight-plan.

TfL (2009). TfL Northern Screenline Counts: 2007 and 2009 - Site 7 (530600, 181800); Site 8 (530476, 181985); Site 9 (530250, 182068); Site 10 (530251, 182159). TfL, TfL.

TfL (2011). Incoming Courier Survey, Palestra 6th - 10th December 2010,. London, Transport for London: 7.

TfL (2012a). Delivery and Servicing Plans. London, Transport for London. Retrieved 27/05/15, from https://www.tfl.gov.uk/info-for/freight/planning/delivery-and-servicing-plans.

TfL (2012b). Road Task Force - Technical Note 5, What are the main trends and developments affecting van traffic in London?, TfL. Retrieved 27/05/15, from https://www.tfl.gov.uk/cdn/static/cms/documents/technical-note-05-what-are-the-main-trends-and-developments-affecting-van-traffic.pdf.

Thompson, C. (2004). "Everything is alive." Internet Computing, IEEE **8**(1): 83-86.

Thompson, C. W. and F. Hagstrom (2008). "Modelling Healthcare Logistics in a Virtual World." IEEE Internet Computing: 100 – 104.

Toronto Atomospheric Fund, MetroLinx and Ministry of Transportation of Ontario (2013). Freight Consolidation for Toronto's Healthcare Sector, University of Toronto: 48. Retrieved 28/05/15, from http://www.civil.engineering.utoronto.ca/Assets/Civil+Engineering+Digital+Assets/research/transportation/Session+2.1+Fangzhou+Su+-+Toronto+Atmospheric+Fund.pdf.pdf

Towill, D. R. (2009). "Enabling effective change in helathcare delivery systems: Did Gerry Robinson teach us anything new?" Leadership in Health Services **22**(2): 176 – 188.

Towill, D. R. and M. Christopher (2005). "An Evolutionary Approach To The Architecture of Effective Healthcare Delivery Systems." Journal of Health Organisation and Management **19**(2): 130-147.

Turner, D. (2011). Interview regarding the operation of ByBox operations.

UNPFA (2012). State of World Population 2012, UNPFA**:** 140. Retrieved 27/05/15, from http://www.unfpa.org/publications/state-world-population-2012.

UPS (2013). "The UPS Store." Retrieved 09/10/13, from http://www.ups.com/content/us/en/locations/store/.

Varghese, V., M. Rossetti, E. Pohl, S. Apras and D. Marek (2012). "Applying Actual Usage Inventory Management Best Practice in a Health Care Supply Chain." International Journal of Supply Chain Management **1**(2): 10.

Verdonck, L., A. Caris, K. Ramaekers and G. K. Jansses (2012). Modeling Freight Consolidation From the Perspective of Transportation Carriers. 26th Annual Conference of the Belgian Operations Research Society (2-3 February). Brussels, Belgium.

Verlinde, S., C. Macharis, L. Milan and B. Kin (2014). "Does a mobile depot make urban deliveries faster, more sustainable and more economically viable: results of a pilot test in Brussels." Transportation Research Procedia **TUM 2014, Sustainable Mobility in Metropolitan Regions**(May 19-20): 361 – 373.

Waitrose (2014). "Waitrose Click and Collect Lockers." Retrieved 21/01/2015, from http://www.waitrose.com/content/waitrose/en/home/groceries/click-collect-lockerscomingsoon.html?wtrint=1-Content-_-2-Homepage-_-3-home-_-4--_-5--_-6-lockers.

WEDI (1993). Workgroup for Electronic Data Interchange 1993 WEDI Report and Recommendations. Retrieved 28/05/15, from http://www.wedi.org/docs/public-policy/1993-wedi-report.pdf?sfvrsn=4.

WEDI (2013). 2013 WEDI Report: The Right Information, To The Right Place, At The Right Time, Wedi Foundation: 97. Retrieved 27/05/15, from https://www.wedi.org/topics/2013-wedi-report.

Weiser, M. (1991). "The Computer for the 21st Century." Mobile Computing and Communciations Review **3**(3): 94 – 104.

Weisstein, E. W. (2015). "NP-Hard Problem." Retrieved 27/05/15, 2015, from http://mathworld.wolfram.com/NP-HardProblem.html.

Werner, C. (2005). "Heathcare Purchasing News: Thoughtful Supply Chain Management Plans Can Make A Big Difference." Retrieved 03/10/12, 2012, from http://www.hpnonline.com/inside/2002-04/0402supply.html.

Woodburn, A. (2005). Overview of Consolidation Centres for Urban and Specialist Use, University of Westminster: for BESTUFS II - First Workshop 13-14th January: 18. Retrieved 27/05/15, from http://www.bestufs.net/download/Workshops/BESTUFS_II/London_Jan05/BESTUFS_London_Jan05_Woodburn_UoW.pdf.

Woodside, J. M. (2007). "EDI and ERP: A Real-Time Framework for Healthcare Data Exchange." Journal of Medical Systems **31**: 178 - 184.

Xie, Y. and L. Breen (2012). "Greening community pharmaceutical supply chain in UK: a cross boundary approach." Supply Chain Management: An International Journal **17**(1): 40-53.

Yan, S., J. Lin and C. Lai (2013). "The Planning and Real-Time Adjustment of Courier Routing and Scheduling under Stochastic Travel Times and Demands." Transportation Research: Part E **53**: 34-48.