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Drone deliveries of medical goods in urban healthcare

Patient safety improvements enabled by a drone-based logistics system

Master's Thesis in the Master's Program Management and Economics of Innovation

SOFIA MAGNUSSON
PAULINE PETTERSSON HAGERFORS

Department of Technology Management and Economics
Division of Service Management and Logistics
CHALMERS UNIVERSITY OF TECHNOLOGY
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SOFIA MAGNUSSON
PAULINE PETTERSSON HAGERFORS

Tutor, Chalmers: Iván Sánchez-Diaz
Tutor, Innovation Platform VGR: Magnus Kristiansson
Tutor, Chalmers Centre for Healthcare Improvement: Patrik Alexandersson

Department of Technology Management and Economics
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Department of Technology Management and Economics
Division of Service Management and Logistics
Chalmers University of Technology
SE-412 96 Gothenburg Sweden
Telephone + 46 (0)31-772 1000

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SOFIA MAGNUSSON
PAULINE PETTERSSON HAGERFORS
Department of Technology Management and Economics
Chalmers University of Technology

Abstract

There is an ongoing trend of centralization and specialization in the healthcare sector that entails requirements for fast, flexible and reliable deliveries of medical goods between healthcare facilities. Logistics systems in healthcare are additionally highly impacted by the importance of high patient safety. Due to the potential time savings compared to road-based transports in urban areas, unmanned aerial vehicles (UAVs), more commonly known as drones, are emerging as a mode of transport. This qualitative single case study intends to combine findings in healthcare and logistics, and from a patient safety perspective assess the potential benefits of a drone-based delivery system of medical goods. The study combines literature on patient safety, centralization and the state of the art of drones, together with a comprehensive current state analysis of the urban delivery system of medical goods in Gothenburg, Sweden. The analysis is based on a total of 17 interviews, six observations and historical data on delivery statistics.

The study shows that the delivery system of medical goods in Gothenburg is extensive and complex, partly due to centralization and scattered facilities, and includes both regular and on-demand deliveries chosen based on required delivery lead time. It is also shown that transports are impacted by an unpredictable traffic environment today, resulting in long and unreliable delivery lead times. Thus, there are benefits, primarily related to the possibility to reduce delivery lead time, which can be enabled by a drone-based delivery system. Additional benefits are increased flexibility and reliability of deliveries, reduced risk of errors and potential for security improvements. Through the translation of patient safety aims into logistics performance indicators, we further show that these benefits could improve patient safety in a healthcare organization.

Furthermore, characteristics of medical goods are mapped in order to investigate the compatibility and suitability with drone deliveries. We conclude that urgently needed replaceable medical goods with low economic value and low risk of theft, which are lightweight and frequently delivered on-demand in low volumes between facilities, are suitable for drone deliveries. This study mainly focuses on urban drone deliveries of medical goods from a strategic point of view, hence, it is of great importance to explore operational and design aspects of drone delivery systems in future research. The findings from this study can be used as guidance for healthcare organizations' strategic decisions upon the use of drones as a mode of transport for medical goods.

Keywords: drones, UAVs, patient safety, healthcare, medical goods, urban logistics, centralization

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1. Introduction

In this introductory chapter, the research and project background is firstly presented in order to address the relevance of the study's purpose. The research background aims to justify the need for this research, whereas the project background is exclusively related to the case study. The two background sections are followed by a section with the research contribution, where the purpose and related research questions are presented. Lastly, the delimitations of the study are presented.

1.1 Background

Urban areas, or cities with high population density, have evolved due to the benefits arising from the increased number of contacts available for both citizens and decision-makers. However, urbanization results in several major challenges such as those related to environmental impact, logistics and transport related issues (Antrop, 2004). The number of transports to, from and within cities is increasing for each year, resulting in problems such as traffic congestions, noise and pollution. Additionally, urbanization puts high pressure on the healthcare sector with requirements to meet the needs of a large number of citizens, and organize the services accordingly (Prewitt, 1997).

The specific characteristics of healthcare organizations result in complex supply chains of support and delivery services, where the requirements for speed, availability and security are of high importance (Vincent, 2010). A way of organizing in order to handle these challenges is to centralize activities, services and inventory (Abrahamsson, 1999), which is an ongoing trend in the healthcare sector. Centralization entails requirements for fast, flexible and reliable transports that are able to meet the demands in the healthcare sector where time often is of high importance (Abrahamsson, 1999; Vincent, 2010). According to patient safety principles, all activities in a healthcare system should also be designed in a safe, effective, patient-centered, timely, efficient and equitable way (Vincent, 2010), which further puts pressure on transports in the healthcare sector.

As a response to the increasing volumes of transported goods in urban areas, the use of drones as a mode of commercial transport has developed rapidly lately. One of the main benefits of using drone deliveries are the time saving potential compared to road-based transports (Stolaroff, Samaras, O'Neill, Lubers, Mitchell & Ceperley, 2018). As a consequence of the maturity of the drone technology and potential time savings that can be reached through drone deliveries, several healthcare organizations and related transport partners have started to explore the use of drone deliveries of medical goods between healthcare facilities. The use of autonomous drones, or unmanned aerial vehicles (UAVs), results in increased reliability of transports (Wertheimer, 2018), less environmental impact compared to road transports (Stolaroff et al., 2018; Fosse, 2018; Wertheimer, 2018), less traffic on the roads (NESTA, 2019b), faster test results to patients (Fosse, 2018; Sundhedsdroner, 2019; NESTA, 2019b), improved patients logistics by predictable time from sampling to analysis and allowance for centralization (Fosse, 2018). Although the ongoing healthcare projects for drone deliveries in urban areas reveal some of the benefits associated with drone deliveries, the existing literature on the topic is currently limited.

Based on the potential time saving that drones offer, and limited existing literature on the use of drones within urban healthcare, this thesis aims to investigate the needs and potential benefits of drones as a mode of transport of medical goods. Although the time saving potential is already known, there is a need to investigate a current healthcare delivery system of medical goods in order to find the greatest need for faster and more flexible deliveries, and how drone deliveries can enable for improvements of patient safety. Furthermore, there is no existing literature on what types of medical goods that are most suitable for drone-transports, why this thesis aims to contribute by mapping characteristics of goods that have most potential to be delivered by drones from a patient safety perspective.

1.2 Project background

Gothenburg is Sweden's second largest city with 1.03 million inhabitants in the region, where 570 000 live in urban areas (Statistiska centralbyrån, 2018). As the city is growing both geographically and in the number of citizens (Stadsutveckling Göteborg, 2019), so does the demand for a well-functioning infrastructure. Medical goods are often time sensitive and are in Gothenburg delivered with road-based transports today, which are affected by traffic congestions and geographical hinders that results in unpredictable and unreliable delivery lead times. In order to explore the potential benefits of drone deliveries of medical goods within the Gothenburg region, the two regional departments the Innovation platform VGR and Regionservice were assigned to investigate the potential application areas between the three main hospitals in the city. Thus, a pre-study was performed with a limitation to the transportation of blood and laboratory samples between the three hospitals Mölndals Sjukhus (MS), Sahlgrenska Sjukhuset (SS) and Östra Sjukhuset (ÖS) in central Gothenburg with focus on the time saving potential of using drones. Based on calculations from the Gothenburg based drone company Everdrone, presented in Damgaard's (2019) pre-study, the table below shows the time difference between road-based and drone-based transports between SS-MS and SS-ÖS.

Table 1. Time savings from drone-based deliveries compared to road-based deliveries (Damgaard, 2019). Adapted by authors.

Route	**Blood car**	**Drone**	**Time saving**
SS-MS	10 min 3 s	4 min 33 s	5 min 30 s
SS-ÖS	21 min 36 s	6 min 53 s	14 min 43 s

The calculation is based on a speed of 70 km/h, height of 60 meters and a six-axis drone (Damgaard, 2019) whereas it is possible to fly even faster with other types of drones (Sällström, March 13, 2019). The flight route between SS and MS is 4,46 km and between SS and ÖS 7,16 km. In both cases, the flight routes have been laid to minimize flight over populated areas. The time saving of using drones was estimated to be between 50-70 % compared to road transport. The calculations reflect the actual transport time, whereas handling time before pick up and drop off are excluded. According to Mion (2018), there is a major time saving potential from the use of drones also in terms of handling the goods in connection to the transports.

1.3 Research contribution

The aim of this master thesis is to investigate the potential benefits that can be enabled by drone deliveries of medical goods in the urban healthcare sector. Thus, there is a need to map a current delivery system of medical goods between healthcare facilities in an urban setting in order to investigate whether there is a need for improvements that are enabled by drone deliveries, as well as to map the characteristics of the medical goods in order to find the most suitable goods for drone deliveries from a patient safety perspective. Therefore, this master thesis aims to answer the following research questions:

RQ1: *How can patient safety be supported by a drone-based delivery system of medical goods within an urban healthcare organization?*

RQ2: *Which types of medical goods are initially most beneficial to be delivered by drones from a patient safety perspective?*

By answering these research questions, strategic suggestions for the use of drones as a mode of transport for medical goods in an urban healthcare organization are presented.

1.4 Delimitations

The study is delimited to the urban transportation system of medical goods between the three hospitals SS, MS and ÖS in Gothenburg, Sweden. The transport of medical goods to, from and internally within the hospitals is only briefly considered. Transplantation logistics are excluded from the medical goods investigated. Operational and regulatory aspects of the use of drones are not elaborated on. The study focuses on the current transportation system during the spring of 2019, whereas collected data span from 2011 to the beginning of 2019. Technical specifications of drones are only briefly considered.

2. Theoretical framework

The first part of this chapter aims to describe theories about patient safety, which is an overall goal in the healthcare sector. Patient safety can for instance be ensured through improved logistics, where centralization and time-based distribution are two concepts presented in the framework that can support a patient safe logistics system. However, centralization and time-based distribution require fast and reliable transport modes. Drone deliveries are both fast and reliable compared to road-based deliveries, hence, the final part of this chapter presents the state of the art of drones, application areas within healthcare and drone deliveries of medical goods in urban healthcare.

2.1 Patient safety

Patient safety is defined as "*The avoidance, prevention and amelioration of adverse outcomes or injuries stemming from the process of healthcare.*" (Vincent, 2006), and is of the utmost importance when working in and with healthcare. A patient safety focus addresses health damage events such as errors, deviations and accidents (Vincent, 2010), where health damage refers to either suffering, bodily or mental injury, illness or even death of a patient that could have been avoided if adequate measures have been taken in the patient's contact with the healthcare system (Socialstyrelsen, 2019). The Swedish patient safety act Patientsäkerhetslagen (2010:659) is a law with the aim to promote a high level of patient safety within both healthcare and dental care in Sweden (Riksdagen, 2019). The law includes, among other things, regulations for caregivers and healthcare staff who are obliged to plan, manage and control the operations in a systematic way so that the requirement for safe healthcare is fulfilled. Risks should be eliminated if possible, or kept under control (Socialstyrelsen, 2019).

Security is an important part of patient safety. Security refers to procedures and measures used to prevent data and health records from being exposed to unauthorized access, modification or use (Turn and Ware, 1976; Nass, Levit & Gostin, 2009). Any transfer of patients, physical goods or information increases the vulnerability in a system, where each transfer represents a higher risk of errors, deviations or accidents (Vincent, 2010). Human errors also represent a considerable risk in a system, where some but not all can be avoided through standardization and technology. For instance, there are technologies directly targeted at the reduction of error and the improvement of safety. Thus, some technologies do directly reduce the variability that humans provide in a system.

When improvements projects are made within the healthcare sector, patient safety should always be one of the top priority factors. Improvement work for increased quality of care should according to Vincent (2010, pp. 38-39) have the six following specific aims:

Table 2. Specific aims for improvement in terms of patient safety (Vincent, 2010, pp. 38-39)

Aim for improvement	Explanation
Safe	Avoiding injuries to patients.
Effective	Avoiding underuse and overuse of services to patients based on scientific knowledge.
Patient-centered	Providing respectful care based on patient values based on individual preferences, needs and values.
Timely	Reducing wait and harmful delays for both patients and healthcare professionals.
Efficient	Avoiding waste of resources, ideas and energy.
Equitable	Providing equal care that does not vary in quality because of personal characteristics or geographic location.

Although some improvement work might have considerable effects on factors such as cost or satisfaction of healthcare personnel, the patient safety factor should always be prioritized before other factors in case the aims collide (Vincent, 2010).

2.1.1 Patient safety in medical goods logistics

The specific aims for improvement in terms of patient safety (Vincent, 2010), can be translated into the logistic performance indicators (table 3). Each logistics performance indicator is further explained below the table.

Table 3. Patient safety aims translated into logistics performance indicators (Vincent, 2010). Adapted by the authors and a healthcare logistics expert.

Patient safety aims	Logistics performance indicators
Safe	Percentage of deliveries conducted without deviations such as destroyed or lost goods, or dissemination of personal information.
Effective	Transport system is sufficient to meet the demand for deliveries of the customer.
Patient-centered	Flow efficiency. Value-adding activities in relation to the throughput time.
Timely	Percentage of goods delivered on time. Can be put in relation to dependability, where the sequence of activities is of high importance.
Efficient	Utilization rate of resources, such as modes of transport, or percentage of time healthcare professionals spends on non-patient related activities such as administrative tasks or goods handling.
Equitable	Availability of deliveries independent of location, day of the week or time of the day.

Deviations such as destroyed or lost goods or dissemination of personal information, can have major negative consequences for patients in terms of default or reduced quality of care. Therefore, safety can be measured by the percentage of deliveries conducted without deviations. For an organization to be effective from a patient safety perspective, it is important to match the capacity with the demand (Jacobsson, April 25, 2019). From a logistics point of view, it means to match the capacity of the transport resources with the demand for deliveries. Overcapacity indicates an ineffective system with waste of resources whereas undercapacity can result in negative consequences from a patient safety perspective.

Patient-centered healthcare can be measured through flow efficiency, where the performance is measured by the value-adding activities in relation to the throughput time (Jacobsson, April 25, 2019; Modig & Ahlström, 2012). The patient is regarded as a customer in the healthcare system and the assumption is that customer satisfaction is increased if the throughput time through the healthcare system, before and after the value adding activities, is as short as possible. Thus, the value adding activities, such as when the patient receives care from or meets the caregivers, should not be shortened. Delays of deliveries are associated with wait for patients or healthcare professionals, which reduces the quality of care and sometimes result in harmful consequences impacting the patient's health. Therefore, the patient safety aim "timely" should be measured by the percentage of goods delivered on time (Jacobsson, April 25, 2019). Furthermore, the term dependability is important to have in mind since some activities must be performed in certain sequences, where goods cannot be delivered either too early or too late in relation to other activities in a particular sequence.

The efficiency of medical goods logistics can be measured by the utilization rate of transport resources, or by the percentage of time healthcare professionals spend on non-patient related activities such as administrative tasks or goods handling, where first should be as high as possible whereas the latter should be as low as possible (Jacobsson, April 25, 2019). The utilization rate is a measurement of how much a resource is utilized in relation to a specific time period (Modig & Ahlström, 2012). The equitability of medical goods logistics can be measured by the availability of deliveries independent of location, day of the week or time of the day since these factors should not affect the quality of care.

Furthermore, the two aims of effectiveness and efficiency can be matched. When a healthcare unit has control over variations that can be controlled, there is a basis for creating an effective patient flow without major variations (Jacobsson, April 25, 2019; Schmenner & Swink, 1998). However, some variations that cannot be controlled due to the nature of healthcare. It is therefore crucial to reduce unwanted variations, such as variations in lead time, in order to create efficient processes. Additionally, the more even and fast a process flow is the higher the productivity in the system.

2.2 Centralization

This section aims to describe centralization as a way of organizing goods and services, and the related benefits and challenges for an organization. Benefits associated with centralization are cost reductions, better utilization of resources and improved service levels by decreased uncertainty and variations. Challenges are related to the geographical distance between units that centralization results in. Lead times are of high importance in the healthcare sector since short lead times can reduce wait and harmful delays for both patients and healthcare professionals, hence, fast and reliable transports are crucial when healthcare services and goods are centralized. A way of organizing inventories according to demanded lead time, while at the same time making use of the benefits associated with centralization, is time-based distribution that is a theory further explained in 2.2.1. Theories on time-based distribution are followed by examples of centralization initiatives in the healthcare sector. These findings are important in order to understand how services and goods are or should be organized, and how the centralization affects the requirements of transport modes in healthcare.

2.2.1 Time-based distribution

In contrast to traditional logistics and marketing models, where the distribution structure is a function of several variables, lead time is the only variable to consider when deciding upon the number of warehouses in a system (Abrahamsson, 1999). There are two important tools to use when setting up a time-based distribution system, where the lead time determines the distribution structure and information systems are used to decrease the lead time (Abrahamsson, 1999). Lead time can be divided into administrative lead time and physical lead time, where modern information systems enable the administrative lead time to be almost negligible.

The number of warehouses in a traditional logistics system is usually a result of three factors (Abrahamsson, 1999). First, if the demand for short lead times from order to delivery is high and the customer demand is hard to predict, the number of warehouses usually increases, and warehouses are placed near the customers. Second, if the consequences and costs related to default deliveries are considerable, the number of warehouses usually increases. Third, the number of warehouses is affected by the results of a total cost analysis, where coordinating functions are of high importance and are used in order to reduce the total distribution costs. The total distribution costs in a system includes inventory cost, transportation cost and costs associated with default deliveries (Abrahamsson, 1999). The primary cost implications related to centralization or concentration of warehouses is less tied up capital, decreased costs of operating warehouses and administration of the physical distribution.

The time focus in a time-based distribution system implies that the gap between warehouses and customers is measured in terms of minutes or hours, instead of distance (Abrahamsson, 1999). Simplified, the design of a time-based distribution system starts with the identification of lead times demanded by customers; if one warehouse is enough in order to reach the customer with the chosen transport mode within the requested lead time, then no additional warehouses needs to be added to the system. Otherwise, another warehouse must be added, or faster transports must be used. In the planning and design phase of a time-based distribution system, it is important to have a so called "helicopter-view" on the organization and activities connected to logistics in order to see potential benefits instead of getting stuck in problems on the unit or department level (Abrahamsson, 1999). Furthermore, it is of the utmost importance to use fast transports to secure good customer service.

A major benefit associated with a time-based distribution system is more timely deliveries, which implies higher customer satisfaction and reduced costs of default deliveries (Abrahamsson, 1999), which in the healthcare sector can be translated to improved patient safety. It also enables for correct and fast information about deviations of the deliveries to the customers. Furthermore, from a total cost perspective, a time-based distribution system entails several of the benefits associated with centralized inventories.

2.2.2 Centralization in healthcare

During the past years, there has been a trend of centralization in the healthcare sector where both services, activities and inventories have been centralized. In Denmark in 2007, there was a large reorganization of healthcare sector services where the number of acute hospitals was significantly reduced from 40 to 21 (Christiansen & Vrangbæk, 2018). In addition, a few centralized "joint acute care facilities" with specialist doctors in the front line replaced the previous many scattered emergency care services. In order to achieve increased quality, medical specialties were centralized at fewer hospitals. The performance results ten years after the reorganization in Denmark were positive, both activity levels and overall productivity had increased meanwhile costs were stable, which indicates a successful reform. Additionally, centralization of specialized healthcare services has taken place in UK, where a new model of commissioning specialized services was launched in the recent years (Svederud, Virhage, Medin, Grundström, Friberg & Ramsberg, 2015). In the new system, the treatment of a range of rare medical conditions was centralized.

In addition to the benefits of centralizing activities and services, there are several positive aspects of centralizing inventories; costs are reduced, resources are better utilized, and service levels are improved by decreased uncertainty (Duan, Su, Zhu, & Lu, 2018). One example of a distribution system that benefits of centralized inventories is blood product supply. It is proven that the blood management could be improved by having a centralization strategy. Through centralization, hospital costs can be reduced, shortage and waste of blood supplies can be decreased, and the occupancy of resources can be reduced.

However, major issues can arise in a system if a centralized function does not work. In systems with decentralized functions, one function could cover for another when problems arise, but this is not an option in centralized systems (Gustafsson, 2019). This has for instance been shown at the newly built hospital Nya Karolinska Sjukhuset where a new centralized sterile center was built, replacing a number of sterile technique units. The aim with the centralized sterile center was to benefit of economies of scale and to streamline the production for sterile goods to be delivered "just-in-time". The implementation of the centralized sterile unit was unsuccessful, which led to several problems in the healthcare organization, such a shortage of sterile instrument, delayed surgeries and a decrease in the overall productivity and capacity. The problems worsened due to the fact that there were no storages of sterile goods in connection to the surgery rooms as a result of the centralization strategy.

2.3 Drones

The development of commercial uses of drones has been rapid the recent years, and drones are now considered as a fast and environmentally friendly alternative to road-based transports. The global drone industry is experiencing rapid growth, both in the military defense and civilian area, and the development of both software and hardware of drones is fast (Business Insider Intelligence, 2016). Drones offer a wide range of possible application areas due to its ease of use and technical capabilities. In this section, the state of the art of drones is briefly presented, followed by examples on application areas in the healthcare sector in general and within urban deliveries of medical goods specifically. Additionally, the benefits and challenges of drone-based deliveries are presented in this section.

2.3.1 Drone characteristics

Unmanned aerial vehicles (UAVs), more commonly known as drones, are aircraft without human pilots aboard. The definition of drones is wide and comprises a range of aircraft (Holcombe, 2018). There is a difference between remote-controlled and autonomous drones, where the former requires that a human operator steers the drone and where the latter is self-driven without direct human guidance (Coyne, 2018). Drones are usually designed for different missions, resulting in a lot of different shapes and attributes of the aircrafts. In a literature review on design challenges, applications and classifications of drones by Hassanalian and Abdelkefi (2017), more than 100 different types of drones are presented. Additionally, there are several types of navigation systems and software that can be used with different types of hardware. Thus, drones can vary widely in several aspects such as size, weight, flight range, material, flight control systems and equipment.

Drones were first used in military purposes, equipped with cameras and most commonly used for reconnaissance (Nationalencyklopedin, 2019). Today, it is not unusual to see hobbyist drones for civilian purpose. Commercial drones usually have small rotary wings and the training required for operation is minimal. The capacity of drones in terms of flight time and payload varies depending on the size of the drone. The typical payload a small commercial drone can carry is slightly above 2 kg during 30 to 60 minutes of flight time (Thiels, Aho, Zietlow & Jenkins, 2015). According to Otto, Agatz, Campbell, Golden and Pesch (2018), drones can usually only carry one package per sortie and a payload of maximum 3 kg. The capacity of the drones' energy storage unit is closely related to the limitations the payload along with size, configuration and usually even the cost of the drone. Based on the limited capabilities and environmental impact from drone deliveries compared to road-based transports, it has been found that most environmental benefits of using drones are achieved for light packages whereas heavier packages are left for ground vehicles (Stolaroff et al., 2018).

A limiting factor for the utility of smaller drones is weather conditions, such as wind, rain or snow that could affect the operations and make the flight times uncertain (Otto et al. 2018). In addition, humidity and coldness results in risk of frost formations on the wings of the drones (Johannesson, April 5, 2019; Sällström, March 13, 2019). However, larger drones are not significantly affected by weather and have similar limitations to conventional aircraft (Thiels et al., 2015). The flight speed of a military drone with fixed wings can be over 160 km/h, whereas commercial drones usually have smaller rotary wings and are typically limited to about 65-95 km/h. Depending on fuel source and payload, military drones have a flight distance range up to 1600 km, whereas smaller commercial drones are limited to 30 up to 100 km.

Most drones carry an energy unit of limited capacity, such as a battery, with the exception for tethered drones that receives energy via a power cord (Otto et al., 2018). A multitude of factors affects a drone's energy consumption, such as what type of drone it is (fixed wing or rotorcraft), weather conditions, payload, speed, flight conditions (e.g. forward flight or hovering) and flying altitude. The limited capacity of the energy unit is often referred to and modelled as the maximal flying distance, operation time or a limited number of stops during flight. The assistance of a human operator is usually required for battery swaps or refueling but fully automated platforms exist.

Drones receive instructions and transfer collected data through communication links with ground control stations (Otto et al., 2018). The most common communication tool used is line-of-sight, which could be problematic in urban areas or indoors, where the signal gets weaker in the shadow of buildings. Other sources of disturbance that may cause signal interference are transmission lines and telecommunication towers. Handling by a human operator might be required due to regulations in some countries. Human operators are also sometimes required to the setup operations before a drone takes off or after its landing. With the use of drone autopilots, it is possible to hold a required altitude, maintain flight stability, and autonomously land and take off. Depending on the type and size of the drone, a specific size of the landing area is required. With some types of drones, it is possible to land at spots with little to no specialized facilities and require very little space to land (Thiels et al., 2015).

2.3.2 Drone deliveries of medical goods

In a literature review about the surgical and medical applications of drones by Rosser, Vignesh, Terwilliger and Parker (2018), it is shown that there has been an accelerating maturation of application of drone technology in several areas. Despite this, the development within the area of medical applications has been slower than in other areas, such as surveillance of military purposes. Rosser et al. (2018) explain this by stating that medical applications are more challenging due to the urgency of clinical situations, where date, time and location are factors that do not allow for control. Regulations and laws also heavily restrict the healthcare sector. Depending on how the drone is designed and what features it is equipped with, areas of use in healthcare could be search and rescue missions, to assess patients in disasters, to film accidents or medical services, where drones can enable for patient care at home and remote telemedicine.

One application area of drones in the healthcare sector is delivery of medical goods. In order to provide an overview of objects in a hospital, Kriegel has (2009) divided each type of item according to different criteria and logistics fields, where medical goods is a hospital logistics criterion with five subgroups. The characteristics of objects in hospitals are presented in figure 1 below.

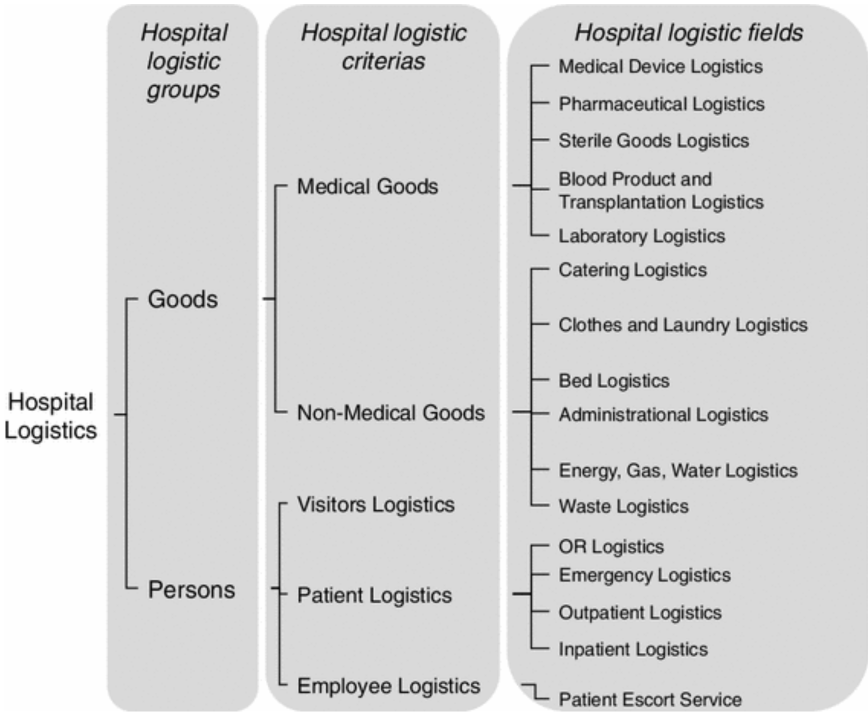

Figure 1. Characteristics of hospital logistics (Kriegel, 2009)

Medical goods include both biological and non-biological material and constitutes of medical devices, pharmaceuticals, sterile goods, blood and transplantation products, and laboratory samples. An example of medical goods deliveries with drones is the supply of blood products to remote villages. In Rwanda, the company Zipline has been working with the government and delivered blood supplies on-demand to 21 regional hospitals since 2011 (Glauser, 2018). More than 50 drones take off every day and the next step is to start delivering vaccines and medicines to hundreds of clinics, both in Rwanda and Tanzania.

The use of drones for medical goods has mainly been focused on rural areas in developing countries but several projects within urban areas have recently emerged. In Delft, the Netherlands, a not yet commercialized ambulance drone has been developed with a heart defibrillator and a smaller toolbox containing essential supplies for life support (Delft University of Technology, 2019). The whole drone is designed as a medical device, equipped with a video supported channel that enables a two-way communication through which an emergency operator gives personalized instructions to the first responder. One of the main purposes with this drone is that people suffering from cardiac arrest or other medical critical states should receive help faster compared to current solutions, where faster emergency care could increase the survival rates.

There are several ongoing projects related to drone deliveries of medical goods in urban areas; in Switzerland, the United Kingdom, Norway and Denmark, just to present some examples. Drones are used as a mode of transport in Switzerland today, whereas the other countries' projects are at a research state. Since the first Swiss drone delivery took place in October 2017, more than 3000 flights of laboratory samples have successfully been completed between clinics in Lugano and Zurich (Furer, 2019). In Denmark, a project called Sundhedsdroner started in 2019, with the aim to deliver patient samples, medicine and medical equipment between hospital units, medical practitioners and home-visiting nurses. According to Sundhedsdroner's official website (2019), a future goal is to transport persons in urgent situations, such as highly specialized doctors needed for surgeries. In London, the movements of pathology samples for post-kidney transplants between Guy's and St Thomas' hospitals are currently investigated in order to understand the feasibility of drone deliveries. Lastly, in Oslo, the medical goods that initially are planned to be transported between the hospitals are blood samples, blood banking products, tissue samples and biopsies (Fosse, 2018). In a future state, the goal is to transport both light and heavyweight medical goods with several different types of drones where small drones could be used short distances and the goods could be consolidated and delivered long distances with larger drones (Johannesson, April 5, 2019).

Laboratory samples are the most common medical goods that are, or are planned to be, delivered by drones in the ongoing projects. One of the arguments for drone deliveries of laboratory samples in Switzerland is that deliveries of laboratory samples often are of a time-sensitive matter and could be of the uttermost importance for physicians and patients (Mion, 2018). Additionally, drones can easily carry blood vials and pathology samples due to their lightweight nature. According to Mion (2018), the products are furthermore not unique products and have a little intrinsic value per se, why the risk of theft and consequently monetary loss is low. Moreover, in case of theft or an accident, it is argued that sampling could be repeated. Therefore, the benefits of delivering laboratory samples with drones are considered to overweight the risks.

The choice of drone deliveries of samples for post-kidney transplant monitoring in London was based on that the analysis results of these samples are used to control the dose of drugs applied, and the timeframe from when the sample is taken until the results are analyzed is critical (NESTA, 2019a). The locations were chosen based on the proximity to each other, the high frequency and volume of daily traffic between the locations, and the institutional links between the hospitals. The deliveries are today restricted to weekdays when existing logistic solutions are running, whereas drones could enable deliveries even on weekends. The future state delivery network in London, including drones, could enable for urgent medical products, such as blood products, pathology samples and equipment, to routinely be carried between the hospital facilities.

2.3.2.1 Benefits of drone deliveries

The projects in Switzerland, the United Kingdom, Denmark and Norway are all partly based on the time saving potential that drones offer compared to road-based transportation. The incentive for operating drones at the hospitals in Switzerland is the time saving potential from switching from delivery by taxi (Furer, 2019). There are three flight routes that are between 2 to 5,8 km long, and one of the routes crosses the Zurich lake basin. From the Swiss project at the multisite hospital Ente Ospedaliero

Cantonale (EOC), it has been found that the use of drones results in overall time saving of 4.5-39.5 minutes compared to conventional road transport (Mion, 2018). At the route across the Zurich lake basin, the transport time is reduced by up to 80 % when drones are used (Swiss Post, 2019). Between the hospitals RHL-C and RHL-I, the delivery time by the most common mode of transport was earlier up to 30 or even 50 minutes at one of the routes during the worst-case scenarios, such as traffic congestions, compared to 2.47 minutes with drones (Mion, 2018).

In London, the goods transported between the hospitals are in many cases time sensitive. However, deliveries are restricted due to the varying road speed across the city, where the average traffic speed is about 30 km/h and in the central parts about 13 km/h, causing unreliable and unpredictable delivery lead times for medical deliveries (NESTA, 2019a). In order to achieve more reliable transport times, a future state goal is to create a drone delivery system for medical goods between 34 hospitals in London, which are located relatively close to each other and make use frequent deliveries between the hospital facilities. Similar to this is has been found from the Danish project that the route between Odense University hospital and Svendborg hospital are expected to take less than an hour with drones, compared to road transports in delivery routes that take up to 12 hours (Sundhedsdroner, 2019).

Earlier, every hospital in Oslo ran its own operations with laboratories at each hospital site but due to the centralization of healthcare services, transports between hospitals are needed to a larger extent today (Forskningsrådet, 2019). The current transportation system between hospitals is road-based and characterized by delays due to traffic congestions. The congestions in Oslo result in a slow delivery service with unpredictable transport time. The unpredictability, lack of control and status of the transports in the delivery process represents a risk to patient safety. Today, it takes about four hours from the point where the sample is taken until it is analyzed in Oslo (Erichsen, 2018). With drone transports, the time is reduced to one hour.

Value expected to be added by drone transports, other than faster transport time, are increased reliability of transports (Wertheimer, 2018), less environmental impact compared to road transports (Fosse, 2018; Wertheimer, 2018), less traffic on the roads (NESTA, 2019b), faster test results to patients (Fosse, 2018; Sundhedsdroner, 2019; NESTA, 2019b), reduced use of antibiotics (Autonomous Mobility, 2019), improved patients logistics due to that the time from sampling to analysis is predictable, and allowance for centralization (Fosse, 2018). There are also potential cost savings from using drones for medical deliveries, where €19 billion are estimated to be saved annually in the UK (Minion & Postelnicu, 2018) and €27 million to be saved annually in Denmark (Sundhedsdroner, 2019).

2.3.2.2 Challenges for drone deliveries

There are several challenges related to drone deliveries in the healthcare sector, both operational and organizational. A critical aspect of operation of drone-based deliveries today is that there currently are no fully autonomous solutions for takeoff or landing. In the Swiss project, the drone flight is autonomous whereas takeoff and landing currently are handled by operators (Mion, 2018). A future state scenario is to have autonomous take-off and landing operations, including an automated battery and package exchange, where additional time savings could be enabled.

In cities with dense population, high buildings and extensive air traffic there are specific challenges of using drones. For example, London has one of the busiest air spaces in the world (Telegraph, 2018), has about 9 million inhabitants (Statista, 2019) and a large number of skyscrapers, where the number is increasing for each year (Kollewe, 2019). This environment poses several challenges, for instance problems for drone navigation and flight planning. From the urban UK drone project, it was found that several key challenges must be identified and addressed related to technology, safety, laws, regulations, infrastructure and privacy (NESTA, 2019a).

One main organizational issue highlighted in the Norwegian project is the need for hospitals and laboratories to adapt their internal solutions and logistics in order to realize the full effect from drone transport (Forskningsrådet, 2019; Johannesson, April 5, 2019). In order to avoid human handling while loading and receiving small medical goods, pneumatic tubes have been suggested to be connected to the drone landing platform in a fully automated solution (Johannesson, April 5, 2019). Another challenge investigated in the Norwegian projects is that different samples should be transported in different temperatures that require extra cold or heating, a fact that complicates the use of drones. Therefore, an ongoing study in Oslo aims to investigate the possibilities of transporting several of these samples in 37ºC due to the fact that bodily fluids usually have this temperature prior extraction by sampling.

Furthermore, a study by Amukele, Sokoll, Pepper, Howard & Street (2015) was performed in order to investigate the effects from drone deliveries on biological samples, where 336 samples for chemistry, hematology and coagulation analysis from healthy volunteering individuals were tested. Half of the samples were held stationary and half were flown with drones for a range of time, from 6 to 38 minutes. The 33 most common tests within chemistry, hematology and coagulation were performed after the flights. The routine chemistry, hematology and coagulation tests results from selfsame samples showed that the accuracy of was not affected for the laboratory specimens that were transported by drones. However, the precision was slightly poorer for some analytes. Johannesson (April 5, 2019) adds to these findings by stating that the same accuracy and precision might not be reached when testing on ill patients with deviating sample results.

The challenges of weather conditions in relation to drone operations are very much dependable on the climate in which the drones are operated. An issue highlighted in the Norwegian drone project is the Scandinavian climate where weather conditions can be both windy and cold, which pose challenges for drone operations (Forskningsrådet, 2019).

2.3.2.3 Risks and safety systems

In a study by Ekström and Johnsson (2019) about autonomous drone deliveries of laboratory samples, some major risks of drone operations were identified. The identified risks during flight were engine breakdown, collision, navigation and/or localization system failure, shooting by object, and flight during unauthorized weather conditions. The risk analysis was based on the assumption that three safety systems are used; (1) a parachute is installed on the drone that slows down the speed in case of accident during flight, (2) the flight control station is informed in case of accident and (3) the autonomous flight is taken over by a human operator. The consequences if any of the risks incidents occur depend on whether the safety systems are functioning or not, where harm to people on the ground or damage on the drones or carried items are not likely if all three security systems are functioning. On the other hand, if none of the safety systems are in place, critical consequences might occur such as harm to people or objects on the ground, damage on the drone and destroyed goods. If the parachute unfolds but the other two safety system fail, the drone might not be located, and the goods are lost. If the parachute unfolds, the flight control station is informed but there is a failure in taking over the operations by a human operator, there is a risk of damage on the drone and the goods, but the items can be located and there is a chance that the carried goods are salvaged.

An example of a drone operation safety system is the one that is used in Switzerland, where the safety system triggers the drone rotors to switch off and a parachute to unfold if the drone registers an unsolvable problem or deviates from its defined route (Furer, 2019). In addition, the drone starts to beep and flash while it descends to the ground. The safety systems were triggered during a flight over Lake Zurich at January 25th, 2019, where the Swiss Post lost contact with one of their drones of the type Matternet M2 V9. The cause of the accident is at this date unknown, but the crashed drone was located in the search area and recovered by divers from the water police. The drones operated by University hospital of Zurich and Lugano hospital will remain on the ground until the cause of the crash has been examined.

3. Methodology

This chapter describes how the study was conducted and why certain methods were considered suitable for the research purpose. The research design and approach, the literature review, data collection and analysis are described in detail in this chapter.

3.1 Research design and approach

The qualitative research design chosen for the study was a single case study. Since this study investigated the potential benefits of using drones as a mode of transport of medical goods from a patient safety perspective, the case context of the hospitals and professionals involved in the transport system were of high relevance. According to Baxter and Jack (2008), a case study approach is suitable when the aim of the study is to answer “how” and “why” questions and when contextual conditions are relevant to take into consideration. The benefit of using a case study design is that it allows for using a variety of data sources, which ensures that the phenomenon investigated is explored from several different viewpoints. One of the drawbacks of a single case study is that the results reflect one single organization at a given time, and that the results from studying another healthcare organization or at another time could be different from our findings. There is also a risk that the findings must be adjusted within a relatively short time frame due to the rapid technical development of drones. Due to the nature of the research questions that aim to contribute to generalizable findings, the relatively large number of interviewed professions, and the theoretical findings of state of the art of drones, the result from this study should be applicable to other healthcare organizations as well.

Case studies are based on the underlying philosophical paradigm of constructivism, which claims that truth is relative and dependent on each person’s perspective (Baxter & Jack, 2008). By using a case study approach, the researcher collaborates with the participants who are able to describe their view of reality. Furthermore, the case study design allows combining the qualitative findings from the participants of the study with quantitative data. Quantitative data, such as time and frequency of transports, are relevant for this study as well as qualitative data from professionals with insight in patient safety and from those involved in the current transport system in the region Västra Götaland (VGR) that Gothenburg's main hospitals are a part of. A benefit of combining different types of data is that a greater understanding of the case is promoted (Baxter & Jack, 2008). The case study is of an exploratory character due to the fact that the outcomes of the study neither was clear, nor predictable from the beginning and that several potential outcomes were possible.

3.2 Literature review

The literature review process was based on the steps presented by Easterby-Smith, Thorpe and Jackson (2015). The first step according to Easterby-Smith et al. (2015) is to set the topic including scope and aim. Literature about healthcare, centralization, patient safety and drones were in this case chosen to constitute the basis for the topic (figure 2).

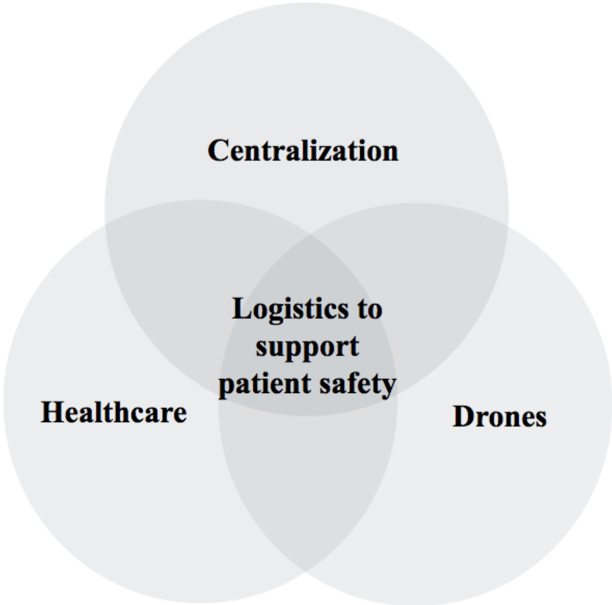

Figure 2. The research topic of the study. Authors' own copyright.

The second step in the process is to search for relevant literature (Easterby-Smith et al., 2015). Keywords such as "drones" and "healthcare" were thus combined and used as search phrases in library databases such as Chalmers University Library database and Google Scholar. Articles that were considered to be the relevant for the chosen topic were used in the study and articles were left out if considered to not be relevant. Other selection priorities were that the articles should preferably be peer-reviewed, have a large number of citations and be up to date. A literature search was also done through screening published literature reviews on the chosen topics, and through looking into the reference list of articles that were considered to be relevant.

The third step of the process was to organize the selected articles based on theme and content and to later read and evaluate them. The final step of the process is according to Easterby-Smith et al. (2015) to write the actual literature review, which in this case was done during several different stages of the study. When details in the scope of the study or the nature of the research question were changed, the literature review process was repeated with new keywords and, hence, new occasions of writing.

3.3 Primary data

Primary data were collected through interviews, observations and small talks. Details about the sampling and collection are further described in the following sections.

3.3.1 Interviews

The main goal with the interviews conducted in this case study was to gain knowledge about the organization that was not possible to get through a literature review or through secondary data. In order to get an understanding of the current situation of the transportation system between the three hospitals, interviews were held with professionals within VGR. Based on Kriegel's (2009) characteristics of hospital logistics, interviews were held in order to gain knowledge about transportation of medical goods within the hospital logistic fields; medical device logistics, pharmaceutical logistics, sterile goods logistics, laboratory logistics and blood product logistics. All respondents chosen worked at a unit or department connected to activities handling these kinds of medical goods within the region.

Since the study was conducted within the healthcare sector, which has a complex organizational structure and is a difficult setting, snowball sampling was chosen as sampling method. Snowball sampling is recommended when studies are performed in settings where it is difficult to access relevant data (Easterby-Smith et al., 2015, pp.138). The method suggests that sampling should be based on previous respondents' recommendations. Therefore, the sampling took off by interviewing the author of the pre-study, who recommended other participants relevant to the study, who in turn referred to others with knowledge of transportation of medical goods.

All interviews conducted during the study are presented in table 4**.** The chosen respondents have insight into deliveries of medical goods within their area of expertise and were, therefore, relevant to interview in this study. However, not all recommended professionals were interviewed since not all of them worked within a relevant field of this study. Examples of suggested interviewees that were excluded are unit managers at healthcare centers with extended opening hours outside SU.

Table 4. List of interviews conducted during the study

Role of the respondent	Department/ organization	Interview focus	Length of interview	Location	Date
Project Coordinator	Innovation platform, VGR	Pre-study	120 min	Innovation platform office	2019-02-05
Service Manager	Regionservice, VGR	The transportation system of medical goods	120 min	Janitorial office	2019-02-21
Department Manager	Regiontransport, VGR	The transportation of primarily laboratory and blood samples	120 min	Sisjön Depot	2019-02-27
Transport Coordinator	Sisjön Depot, VGR	The transportation of medical goods from the depot	45 min	Sisjön Depot	2019-03-07
Unit manager	Clinical chemistry MS, VGR	Deliveries of blood bags, laboratory and blood samples	60 min	Clinical chemistry MS	2019-03-08
Operations Developer	Orthopedics and sterile techniques, VGR	Deliveries of sterile goods	30 min	Orthopedics and sterile techniques SU	2019-03-12
CEO	Everdrone	Drones and logistics system including drones	60 min	Everdrone office and test site	2019-03-13
Unit Manager	Clinical chemistry ÖS, VGR	Deliveries of blood supplies, laboratory and blood samples	45 min	Clinical chemistry ÖS	2019-03-14
Project Leader in Infrastructure and Development	Biobank Väst, VGR	Deliveries of blood bags, laboratory and blood samples	90 min	Biobank Väst office	2019-03-15
Quality responsible pharmacist	Hospital pharmacy, Management Healthcare, VGR	The transport of pharmaceutical goods	40 min	Skype	2019-03-18
Project Manager	Högsbo Specialist Hospital, VGR	Drones and logistics system	30 min	Regionens hus (Region's building)	2019-03-19

Unit Manager	Surgery 1 MS, VGR	Blood product and lead time requirements	30 min	Surgery 1 MS	2019-03-27
Unit Manager	Clinical immunology and transfusion medicine, VGR	Blood product distribution and transport	30 min	Blood center SS	2019-03-28
Department Manager	Clinical genetics, VGR	The transport of samples	25 min	Telephone	2019-04-03
Researcher and Project Manager of Drone Transportation in Healthcare	Intervention Center, Oslo University Hospital	Oslo drone project	50 min	Skype	2019-04-05
Expert in Healthcare Logistics and Organization	Chalmers Centre for Healthcare Improvement	Patient safety	20 min	Telephone and e-mail	2019-04-24
Quality Coordinator	Bacteriological laboratory, VGR	The transport of samples		E-mail	2019-04-26

The interviews were semi-structured. Prior to the interviews, lists of semi-structured interview questions were prepared in order to keep the conversation around particular topics. The choice of semi-structured interviews enabled the respondents to talk freely and allowed for flexibility to explore the topics further. Swedish was chosen as interview language since it was the mother tongue of both the interviewers and respondents, hence enabling the participants to express themselves easily. Complementary emails were also sent to some respondents in order to clarify certain details. The decision to hold one of the interviews through email correspondence was based on the limited number of questions to and accessibility of the respondent. The interviews held orally were recorded, transcribed and most of the interviews were coded by a method inspired by Burnard (1991). Coding and analysis are further explained in section 3.5.

3.3.2 Observations

In order to get insight into how the transport system of blood products works between the three hospitals MS, SS and ÖS, observer-as-participant was chosen as data collection method. Since the transport system, and not the driver's behavior per se, was in focus during the observation, observer-as-participant was chosen as the most suitable research method. The observer-as-participant research method means that researcher engages relatively passively in the field of study by asking questions, but at the same time tries to avoid influencing the field of study (Easterby-Smith et al., 2015, pp.162). This method enables researchers to not only observe activities but also to explore why certain activities are conducted as they are pursued. When using the observer-as-participant method, the persons observed are aware of the researcher's status as a researcher (Bryman, 2011). The advantage of using observations compared to qualitative interviews is that it enables the researchers to in person see how something works, instead of having a topic retold and described. Through observations, information that is less likely to surface in an interview, due to the fact that a respondent might take it for granted, could be obtained (Bryman & Bell, 2011, pp. 495).

The observation of the transportation system of blood supplies took place during half a day where the researchers followed the driver of the blood car a morning between 9.00-12.30. Questions were asked in order to understand why the driver took certain decisions. The focus area of the observation was to understand how the blood car transportation system works, to see the locations of the pick up and drop off points, to gain knowledge about the drivers' role in the transportation system and to see how goods are handled in connection to the transport. Notes were taken during the observation and later that day summarized and discussed by the researchers. The data was later used as a base for the description of blood supply logistics in the empirical findings.

In addition to the observation related to the blood car, limited observer-as-participant observations were held in connection to the interviews at the locations of clinical chemistry (which is a division that is responsible for conducting analyses on bodily fluids, further referred to as CC) at MS and ÖS, transfusion medicine, Everdrone and the Sisjö depot.

3.4 Secondary data

Secondary data about potential time savings though drone deliveries within VGR have been obtained from the pre-study by Damgaard (2019). In addition, interview material from the pre-study was used as a complement to the primary data collected in this report. Furthermore, statistics about the frequency of blood product deliveries between the three hospitals were provided by Regionservice VGR. The frequency data were compiled and analyzed in Excel and later visualized in tables in the empirical findings chapter.

3.5 Data analysis

The analysis process was based on an inductive approach since an inductive approach allows for generalization to be made based on data obtained during the study (Kvale & Brinkmann, 2014). Data analysis was performed concurrently with data collection, which according to Baxter and Jack (2008) is crucial in order to understand an overall case and not just various parts. When the recordings of interviews had been transcribed, the analysis method presented by Burnard (1991) was used. According to the method, each relevant transcribed quote is transformed into a phrased sentence that in turn results in a code of 2-3 words, which are sorted into a category. Codes from each category are then analyzed and translated into a paragraph in the empirical findings. When new questions arose during the analysis, the earlier interviewed participants or new participants were asked for explanation.

The KJ-Shiba method was used as the data analysis method of the literature review and empirical findings. The method was considered suitable due to a large amount of coded qualitative data. The KJ-Shiba method consists of four fundamental steps (1) label making, (2) label grouping, (3) chart-making and (4) written or verbal communication (Scupin, 1997). Label making was done jointly by the authors of both the empirical findings and the existing literature. About 100 labels were written on sticky notes and randomly placed on a wall. One of the authors grouped and moved the labels depending on the topic, and the grouping was afterwards adjusted by the other author. Adjustments of the grouping were done until the authors reached consensus about the groups of labels. Chart-making of problems, solutions and relationships between labels were done jointly and verbally communicated. The KJ-method was used to extract key takeaways from the collected data, and to find problems and connections that were relevant based on the purpose of the study.

4. Empirical findings

The following chapter presents the organizational context, including involved parties, modes of transport and ongoing projects, in order to give the reader an overview of the context of the study. Additionally, regular and on-demand deliveries of medical goods transported between SS, MS and ÖS are described, as well as characteristics of the medical goods transported. Lastly, the current logistics system's risk factors are addressed. All information in this chapter is retrieved from interviews and observations, unless otherwise stated.

4.1 Organizational context

VGR is responsible for healthcare, development and public transport within the region of Västra Götaland in Sweden. Healthcare is the most extensive function within VGR with its 48.000 employees (Västra Götalandsregionen, 2018), and consists of four units of hospitals, primary care and dental care. One of the units of hospitals is Sahlgrenska University Hospital (SU), which includes five hospital sites; SS, MS, ÖS, Högsbo Sjukhus (HS) and Queen Silvia's Hospital for Children and Young People, all located in the city of Gothenburg. In this section, the main actors and units related to deliveries are presented, as well as examples of projects affecting the future medical goods deliveries.

4.1.1 Regionservice

Regionservice is a supplier of materials, including food and equipment, and services such as transports and communication tools internally within VGR. The function is also responsible for personnel transports between the hospital locations. Regionservice's customers are hospitals, healthcare centers, public dental clinics and VGR's departments, privately owned companies and a few municipalities in other regions. The aim is to provide effective service functions in order to facilitate for healthcare departments to focus on their core activities.

There are several depots with medical goods within VGR. The Sisjö depot is a Regionservice depot that works as a central warehouse for consumables with about 16 000 articles from about 350 suppliers, to 4 000 customers in the region**.** the Sisjö depot is responsible for freight and price control, invoice handling, warehousing, customer packing and distribution to customers. The purpose of the Sisjö depot is to provide a comprehensive supply of consumables in customized quantities and to ensure that critical consumables are available within VGR. In addition to the Sisjö depot, there is one VGR depot handling medical goods such as ostomy bags, one VGR depot that handles helping aids and lastly a depot of pharmaceuticals, where external parties operate the latter.

4.1.2 Transport modes within VGR

The most common transport modes for deliveries of medical goods between the SU facilities are Regiontransport, the blood car and external carriers. These modes are described below.

Regiontransport
Regiontransport is in charge of most regular deliveries in the region and is VGR's haulage for transport of samples, pharmaceuticals, mail and small goods. Mail and goods are sent internally with Regiontransport within the region. Regiontransport delivers a variety of goods in the region and one important function is to deliver different kinds of blood and laboratory samples for analysis from healthcare facilities to CC units. In addition, Regiontransport is responsible for meeting the healthcare needs of empty boxes used for deliveries of medical goods.

Through a extensive network of transport loops, Regiontransport's drivers visit most of the region's administration and healthcare facilities daily. There are 41 cars connected to Regiontransport in the region, that handles 12 to 60 customers a day per car. 19 of these cars are located in central Gothenburg. The cars are operated daytime on weekdays, as long as the primary care is open, between hundreds of different units. Regiontransport's 19 cars in Gothenburg city deliver about 9000 samples to CC every weekday.

Blood car

Regionservice is a function with the primary mission to supply MS, which do not have a blood center, with blood from the main blood center at SS. This so-called blood car is manned 24 hours a day, each day of the year. In order to make use of its excess capacity, the blood car is also used for some regular and on-demand deliveries of laboratory samples. The blood car is driven by fossil fuel, runs about 200-250 km a day and costs approximately €100.000 per year to operate. The number of deliveries per year and month completed by the blood car is relatively evenly distributed. In average, the blood car performs about 4000 deliveries per year (Regionservice VGR, 2018a), where less than 2 % of the deliveries were acute and driven with emergency lights in 2017 (Regionservice VGR, 2018b). The most common delivery hauls are presented in table 5 below.

Table 5. Most common hauls October 2017-September 2018, on-demand deliveries conducted by the blood car (Regionservice VGR, 2018a). Adapted with permission

Pick up unit	**Drop off unit**	**Most common good transported**	**Average frequency/ month**	**Frequency min/max**
CC MS	Blood center SS	Samples for BAS-test	127	103/147
CC MS	CC SS	Laboratory samples	109	83/129
Blood center SS	CC MS	Blood products	44	27/55
Memory unit	Neuro chem. Unit 7	Laboratory samples	14	5/26
CC MS	CC ÖS	Laboratory samples	11	4/15

The distance between the units, CC MS and the blood center, which is the main mission for the blood car to serve, is 4,7 km one way and constitutes of approximately 53 % of the total number of deliveries performed by the blood car per year. Since the blood car is stationed at MS, all deliveries to and from SS entails that the distance must be driven twice each time; a total 9,4 km. In addition to the hauls presented in the table, there were within one year 98 other delivery distances with less than five deliveries per month performed in order to use the excess capacity of the blood car. These more uncommon deliveries are otherwise performed by external carriers. The drivers of the blood car prioritize to be available for deliveries of BAS-test samples and blood products between the blood center at SS and MS, hence deliveries to and from ÖS are avoided during rush hours. The deliveries of blood products and laboratory samples are further described in 4.2.

External carriers

External pre-procured carriers are used to a wide extent. For regular deliveries of goods from the Sisjö depot, an external haulage firm is used and when deliveries are required outside the regular transport system, an external carrier is usually used. The external carriers are mainly used during evenings and weekends, and for on-demand deliveries of different types of goods, foremost helping aids but also medical goods such as blood bags and laboratory samples. All external carriers and haulages are procured through the principle of public procurement and the vehicles are neither equipped with or have permission to drive with emergency lights. VGR pays approximately €50 for each on-demand delivery within the city of Gothenburg, independent of the size, weight or volume of the delivered good.

4.1.3 Ongoing hospital projects in VGR

There are several ongoing projects in the region. Two main projects that will influence the transportation system of medical goods investigated in the near future are the building of Högsbo specialist hospital and new laboratory buildings at ÖS and SS.

Högsbo specialist hospital
The building of a new specialist hospital, Högsbo specialist hospital (HSS), should be completed in 2023. The plan is to replace HS as well as another specialist hospital that will be closed down in order to improve the overall healthcare capacity in the region. The day surgery operations and related patient reception will be moved from SS to HSS in order to relieve the emergency care at SS and enable for a larger part of non-acute care to be performed outside SS. SS is an acute care hospital occasionally exposed to low availability and long waiting times.

HSS will be built without any storage for pharmaceuticals, blood products, sterile instruments or other medical goods, based on the logistics principle "just-in-time". There will for instance not be a sterile technique unit, CC unit or blood center at Högsbo. Since most of the surgeries and activities at HSS will be planned in a so-called planned production, there is no instant need of having medical goods stored or all medical functions available at the hospital location. Instead, a new supply solution with a hub in the center of the region is under construction, where the hub will constitute a unit that produces and delivers medical goods to several hospitals. From the hub, medical goods will be delivered directly to HSS. In order to enable sequencing and ensuring that the right material comes to the right place and at the right time, different types of medical goods will be consolidated. Initially, HSS will receive most of the supplies from MS. Healthcare laboratory samples will be transported to CC SS for analysis, except for the few most common analyses that not require advanced laboratory equipment.

The aim of HSS is to improve accessibility, increase productivity and to reduce costs for performing healthcare. However, the lack of storages will make HSS sensitive to interferences and it is therefore crucial to manage distribution of goods in a reliable way. Therefore, transport reliability and short lead times will be of high importance. Even if no acute care will be performed at HSS, there will still be a need for acute deliveries of medical goods due to deviations and unpredictable situations.

Laboratory facilities
The laboratory units at SS and ÖS are currently scattered at the hospital sites. There are ongoing projects at both locations, which should enable the laboratory operations to be more centralized in the future. At ÖS, a new modern facility of 9,900 square meters and additional 5,600 square meters of renovated and rebuilt facilities, are planned to be finished in 2023. The units for intensive care and clinical physiology will be located in the new facilities, as well as a new pressure chamber (Västfastigheter, 2019a). The new facilities will enable for coordinating personnel in a more efficient way and for a 24/7 reception of more types of samples than today.

The project at SS is called Sahlgrenska Life and aims to create an environment that enables collaboration between healthcare, academia and business. In this project, four new buildings of 115 000 square meters will be built (Västfastigheter, 2019b). The laboratory activities that today are spread at hospital site, will be centralized in the new buildings. The construction starts in 2019 and is planned to be finished in 2023.

4.2 Medical goods logistics

Based on Kriegel's (2009) characteristics of hospital logistics, medical goods within the hospital logistic fields are divided into medical device logistics, pharmaceutical logistics, sterile goods logistics, laboratory logistics and lastly blood product logistics. Blood products are further referred to as blood supplies, and laboratory samples are divided into healthcare laboratory samples and research laboratory samples. When requesting deliveries of medical goods between MS, SS and ÖS, there are several options regarding the mode of transport. The choice of transport depends on how acute the delivery is, which time of the day it is and which vehicles that are available. If the deliveries of medical goods are not acute, goods are usually delivered by vehicles in fixed routes, also referred to as regular deliveries. If the deliveries of medical goods are acute, there are several options depending on the time of the day, type of medical good, place of the ordering and receiving unit and availability of internal vehicles. This type of immediate transport that is used upon requests when a demand arises, compared to a scheduled delivery, is referred to as an on-demand delivery. In general, healthcare personnel within VGR use regular deliveries as far as possible before ordering on-demand deliveries. Otherwise, external carriers are usually used for on-demand deliveries.

4.2.1 Medical device logistics

Medical devices are, simply put, any device intended for medical purposes. The core medical equipment for each unit within a hospital is usually permanently placed at the unit. There are also medical device commodities, such as injection needles and consumable surgery equipment, which are distributed from external or internal depots, but these goods are seldom transported between hospitals.

Regular deliveries
Most deliveries of medical device commodities from the depots are planned in advance and made with regular transports provided by Regionservice in trucks to goods receptions at the hospitals (figure 2). The goods are then transported from the goods reception to each health care unit within the hospital.

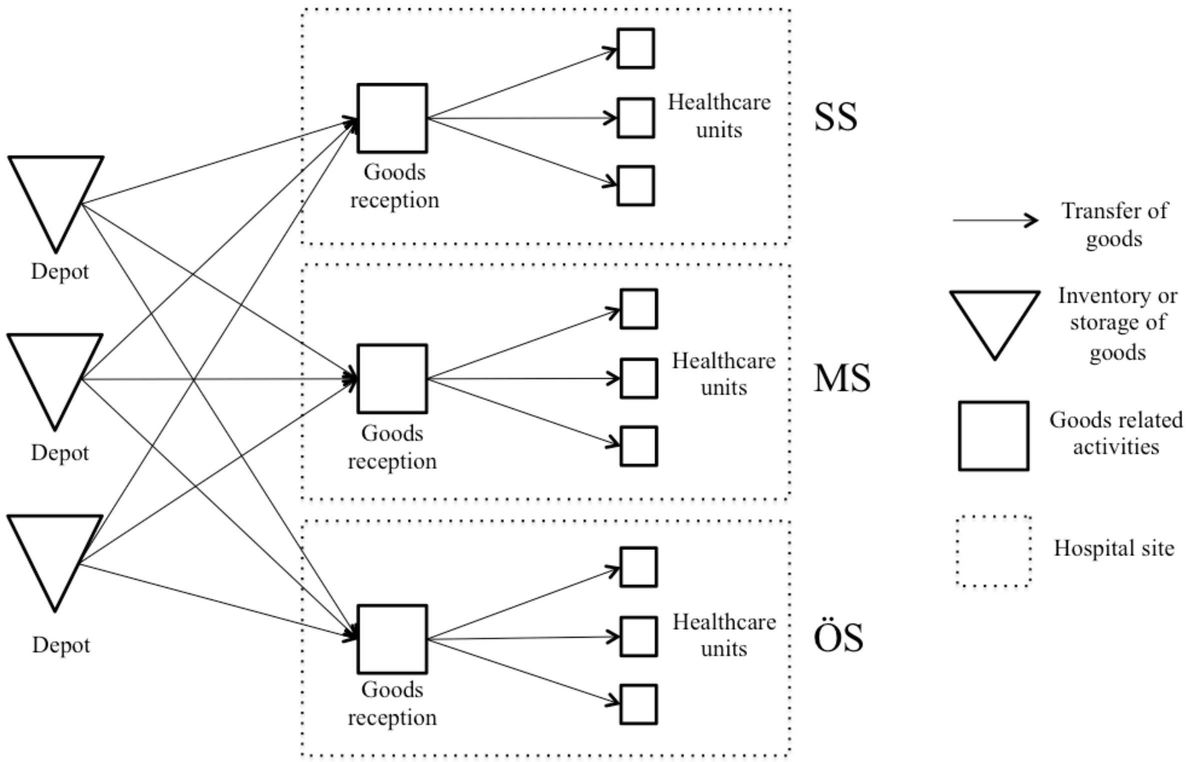

Figure 2. Regular deliveries of medical devices to the SU hospitals. Authors' own copyright.

The frequency of the regular deliveries varies depending on the size and needs of the healthcare facilities in the region. MS, SS and ÖS receive delivers several times a day, whereas small healthcare centers can receive deliveries once a week or less often. The volume, size and weight of the deliveries are often large, and trucks are used as a mode of transport.

On-demand deliveries

Medical device commodities are stored in inventories within the hospitals and ordered regularly from the depots by personnel when a stock reaches a low level, hence, deliveries of these goods seldom are acute. However, in case of a shortage of medical device commodities, there can be a need for urgent deliveries from a depot to a healthcare facility and in these cases, external carriers are used. These on-demand deliveries are made directly to the ordering unit without passing the goods reception.

Goods characteristics

Medical devices vary in both size and weight. Since it simply put could be any device intended for medical purposes, the goods could range from a small tweezer to a large X-ray device or a wheelchair. The most common medical devices are usually durable, however larger electrical medical devices could be very susceptible to shocks.

4.2.2 Pharmaceutical logistics

A hospital pharmacy is defined as all the activities that are required in order to ensure that there are pharmaceuticals available for a healthcare organization. Within VGR, a regional hospital pharmacy function is in charge of the supply of pharmaceuticals and local units are responsible for performing the activities required for delivering pharmaceuticals to the healthcare units' inventories. There are two types of pharmaceutical supply chains; pharmaceuticals from a standardized assortment and extempore pharmaceuticals that are custom-made for an individual patient or patient group. Standard pharmaceuticals are distributed from a regional warehouse, also called RGL, which is managed by two privately owned companies. There are two extempore pharmacies within SU, one at SS and one at ÖS.

Regular deliveries

Each unit at the hospital is responsible for ordering pharmaceuticals from RGL or from the extempore pharmacies. The pharmaceuticals are delivered during the night by RGL to goods units located at the hospital sites in connection to the goods reception. Regionservice is responsible for delivering the pharmaceuticals from the goods units to the healthcare units at the hospitals in fixed routes. The distribution system is presented in figure 3 below.

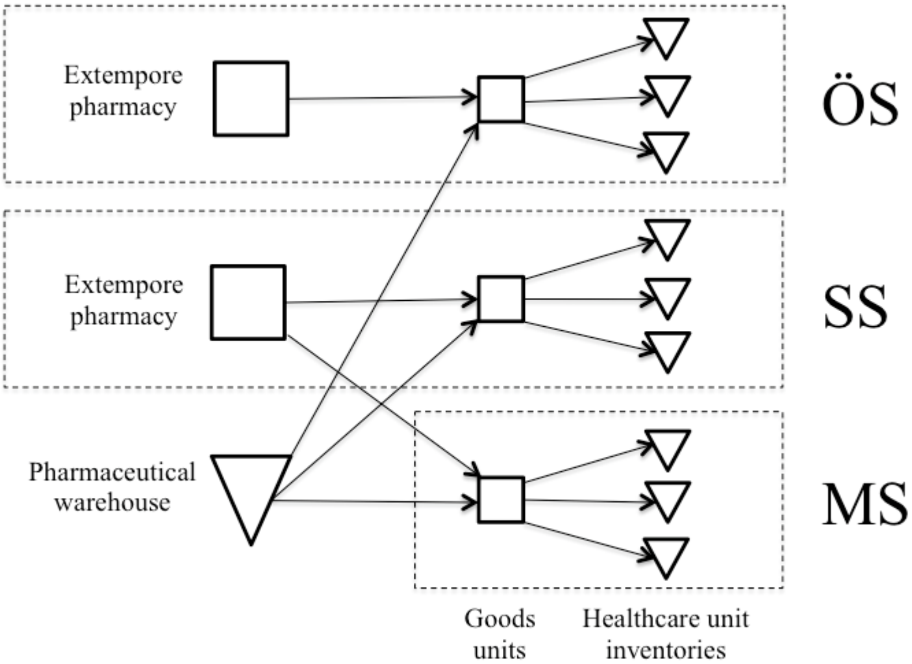

Figure 3. Regular deliveries of pharmaceuticals to the SU hospitals. Authors' own copyright.

The figure visually presents the regular distribution system of pharmaceutical goods to the SU hospitals, where one single pharmaceutical warehouse is responsible for the supply of standard pharmaceutical goods and two units are responsible for the supply of extempore pharmaceuticals.

On-demand deliveries

When pharmaceuticals are needed urgently, due to shortage in the inventories or in case a patient needs a type of pharmaceutical that is not available in stock, and on-demand deliveries can be performed any time of the day. In these cases, the ordering unit registers an order in an IT system and calls RGL in order to inform the RGL pharmacist about how acute the delivery is. The ordered pharmaceutical good should be prepared and ready for delivery within two hours from when the order has been placed and the transport must take less than three hours, a maximal lead time of five hours from order to delivery. The acute deliveries are made directly from the RGL warehouse to the ordering unit with an external carrier, without passing the goods unit. When the acute delivery reaches the ordering unit, the order must be receipted by a healthcare professional. In rare cases, pharmaceuticals can also be delivered between units at the hospitals and when deliveries are needed between the hospitals, external carriers are used.

Goods characteristics

The pharmaceutical goods transported within VGR range from small and lightweight to large and heavyweight goods. Some goods are transported in glass ampoules and are, therefore, fragile and must be handled carefully. Fluid pharmaceutical goods are sometimes delivered in very large and heavy packages, where a trolley is needed in order to move them. There is a constitution by the Swedish Medical Products Agency with requirements on how the distribution of pharmaceutical goods should be arranged, with certain requirements that need to be met during transport. The healthcare providers are obliged to ensure that the requirements are met, such as that pharmaceuticals are kept inaccessible to unauthorized persons and that the quality of pharmaceuticals does not deteriorate during transport. Pharmaceutical goods must not be exposed for dirt, contamination risks, incorrect temperatures or humidity. Photosensitive pharmaceutical goods should be protected from light and some pharmaceutical goods must be delivered in an unbroken cold chain. In addition, some pharmaceutical goods are classed as narcotics and are thus theft-attractive. The temperature is traced during transport for the pharmaceutical goods that require special temperature conditions and the boxes in which the pharmaceuticals are delivered are sealed with cable ties that must be cut in order to access the goods.

4.2.3 Sterile goods logistics

Sterile goods are both reusable and consumable medical instruments and material. The sterile technique units are functions responsible for ensuring that medical instruments are sterilized and to a certain extent stored. Each of the three hospitals SS, MS and ÖS has their own sterile technique unit at the hospital sites but all three units are organized in one common business area. The sterile technique units are located in the basements of each hospital where sterile goods are sterilized and stored between usage.

From the Sisjö depot, sterile consumable goods are delivered to the sterile technique units where the goods are re-packed together with reusable sterile goods (figure 4). Sterile goods are distributed from sterile technique units at the hospital sites, mainly to units performing surgeries. The ordering units usually have some sterile commodities stored and these are refilled when needed, whereas reusable sterile goods are ordered directly from the sterile technique unit before surgery.

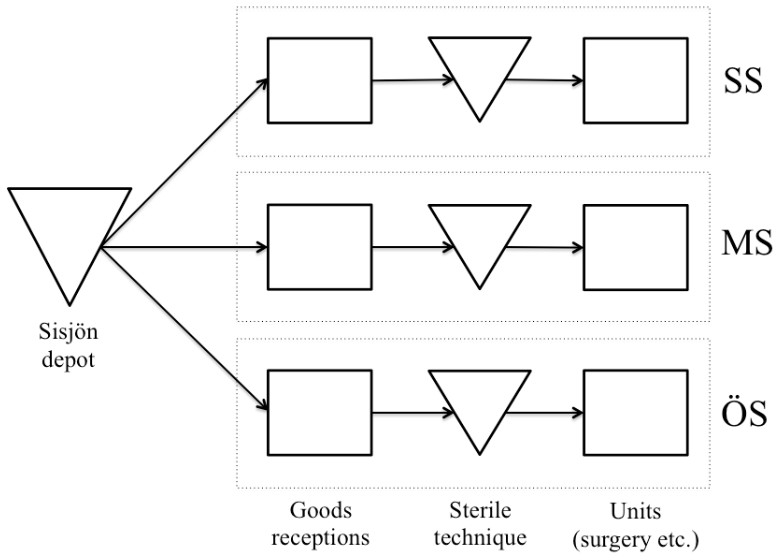

Figure 4. Supply chain of sterile goods within SU. Authors' own copyright.

At MS, most of the internal deliveries from sterile technique are regular, compared to SS where most of the deliveries of sterile goods are on-demand. A reason for this is that more acute surgeries are performed at SS compared to MS, where the surgeries usually are planned at least 24 hours in advance. The internal deliveries of sterile goods at each hospital are handled by Regionservice.

Regular deliveries
Orders are placed from the surgery units in a surgery planning system and the personnel at sterile technique pick the orders. When an order is ready, Regionservice delivers it from the sterile technique unit to the ordering unit. When a reusable medical instrument has been used during surgery, it is transported back to the sterile technique unit where it is sterilized, packed, controlled and stored until it is used again. Since the sterile technique units are located at each hospital location, each sterile technique supplies the hospital it is located at, which results in that regular deliveries of sterile goods are not needed between MS, SS and ÖS. The regular deliveries of consumable sterile goods from the Sisjö depot are consolidated with other goods from the depot and transported with external carriers.

On-demand deliveries
The occasions for when on-demand deliveries of sterile goods are needed between hospitals are limited. Acute deliveries from the sterile technique units to surgery units are made within 15 minutes if the ordered good is available. If there is a lack of a sterile reusable medical instrument, it is not always possible to wait for the sterile technique unit to sterilize it since the process takes several hours, why instruments are sometimes borrowed between the units. For this purpose, instruments are sometimes transported between the hospitals and external carriers are used. However, this is extremely uncommon. When there is a lack of a consumable sterile good, an external carrier delivers it from the Sisjö depot directly to the ordering unit.

Goods characteristics
Sterile goods vary in both weight and volume. For instance, the prefabricated sterile goods packages required during an eye surgery are often very small in size, about 15x15 cm, while orthopedic surgeries could require saws or drilling machines which are bulky and heavy. Surgery packages can easily weigh more than 20 kg in total. Most sterile goods must be transported in three-layers packages, where the last layer often constitutes of a delivery box. In addition to the prefabricated packages of sterile goods, sterile technique is responsible for preparing customer specific kits that are delivered on-demand to ordering units.

4.2.4 Blood supply logistics

Blood supplies refer to whole blood, thrombocytes and plasma. Clinical Immunology and Transfusion Medicine is a department at SU, with one unit at SS and one unit at ÖS, which is responsible for the diagnosis of disease states that affect the body's immune system. The unit is responsible for the blood supply and for medical care with blood components, as well as examinations and advice prior to blood transfusions. The units also handle the blood centers within SU. Blood bags from blood donation locations in Gothenburg are collected and transported to the main blood center located at SS (figure 5). The blood center at SS works as a centralized warehouse of blood supplies and is responsible for distributing blood supplies to the other blood center, which is located at ÖS, as well as to other units within Gothenburg. MS has no blood center, hence, blood supplies are ordered on-demand from SS to MS. The most common volume transported from SS to MS is one to six blood bags.

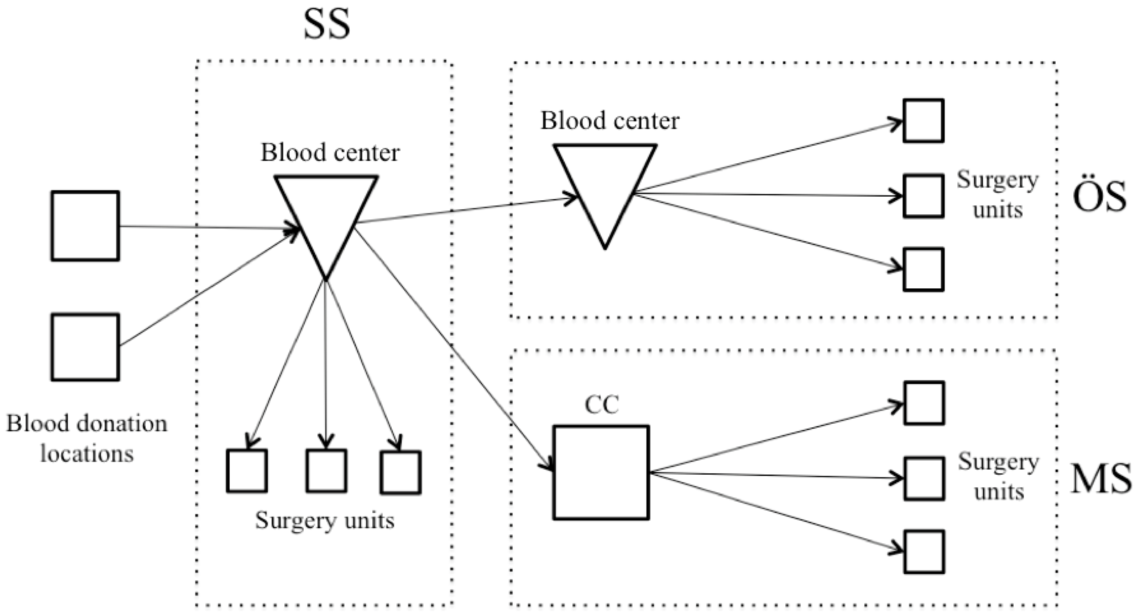

Figure 5. Deliveries of blood supplies within SU. Author's own copyright.

The reason why MS does not have a blood center is that MS is a relatively small hospital located near SS that has the main regional blood center and centralization makes it easier to keep track of stock levels and reduces costs. Surgeries at MS are usually planned, which enables for the ordering of blood supplies in advance prior to each surgery. In addition, most surgeries performed at MS are of a standardized character and do not require large volumes of blood supplies. When the maternity ward was moved from MS to ÖS in 2017, the need for acute deliveries of blood decreased drastically but there is still a need for acute deliveries of blood between SS and MS. CC MS works as an intermediary responsible for ordering transport of blood supplies from the blood center at SS to the ordering units at MS, as well as to store the blood supplies until they are picked up by someone from the ordering unit.

Prior to each blood transfusion, two analyzes are required. Firstly, a sample is used for blood grouping analysis. This sample can be at taken any time at all hospitals within SU, and the results of the analysis are stored in a database. Secondly, a sample is used for a so-called BAS-test, which is a compatibility analysis that is required to be taken in connection to the actual transfusion. The BAS-test takes approximately one hour and if a patient is in an acute need of a blood transfusion, universal blood is transfused until the result of BAS-test is ready. BAS-tests are conducted both at the blood center at SS and the blood center at ÖS, but not at MS.

Regular deliveries

There are regular deliveries both from the blood donation locations to the main blood center at SS, and from the main blood center at SS to both the blood center at ÖS and CC MS. An external carrier is used for deliveries between blood donation locations to the blood center at SS, as well as the routes between the blood center at SS to the blood center at ÖS. Both Regiontransport and the blood car are responsible for the routine deliveries between the blood center at SS to CC MS. Unused or excess blood supplies at MS and ÖS are returned with the regular deliveries to the blood center at SS.

On-demand deliveries
Although ÖS has a blood center, acute deliveries on-demand for blood supplies are sometimes needed from the blood center at SS. In these situations, an external carrier is used. However, due to the lack of a blood center at MS, most on-demand deliveries of blood supplies are between the blood center at SS to MS. In order to handle the supply of blood to MS, the blood car is used. This blood car and its drivers are stationed at MS where they await calls from hospital units in need of deliveries. The driver receives information about the pick up and delivery units, and how acute the delivery is through a phone call from either CC MS or other ordering units. If the driver receives several orders within a short time span, it is up to the driver to decide where to go first, depending on how acute the deliveries are. However, it is up to the ordering person to let the driver know if it is an emergency light transport. The driver is responsible for picking up, transporting and delivering goods directly from the sending to the receiving units. The pick up and drop off points can be located at different distances from where the blood car is parked. Sometimes it is a stair or two, other times the driver have to walk a longer distance.

CC MS is responsible for coordinating the need for blood supplies at MS and works as an intermediary to facilitate the hospital's units with blood supplies. If the need for blood supplies at MS is acute, the blood car delivers the blood from SS to MS within 30 minutes if the results from the blood grouping and the BAS-test are ready. Otherwise, a sample must be sent to the blood center at SS in order to conduct a BAS-test before the blood supplies are sent from SS to MS. The process, when BAS-test has not been done in advance, is visualized in figure 6 below.

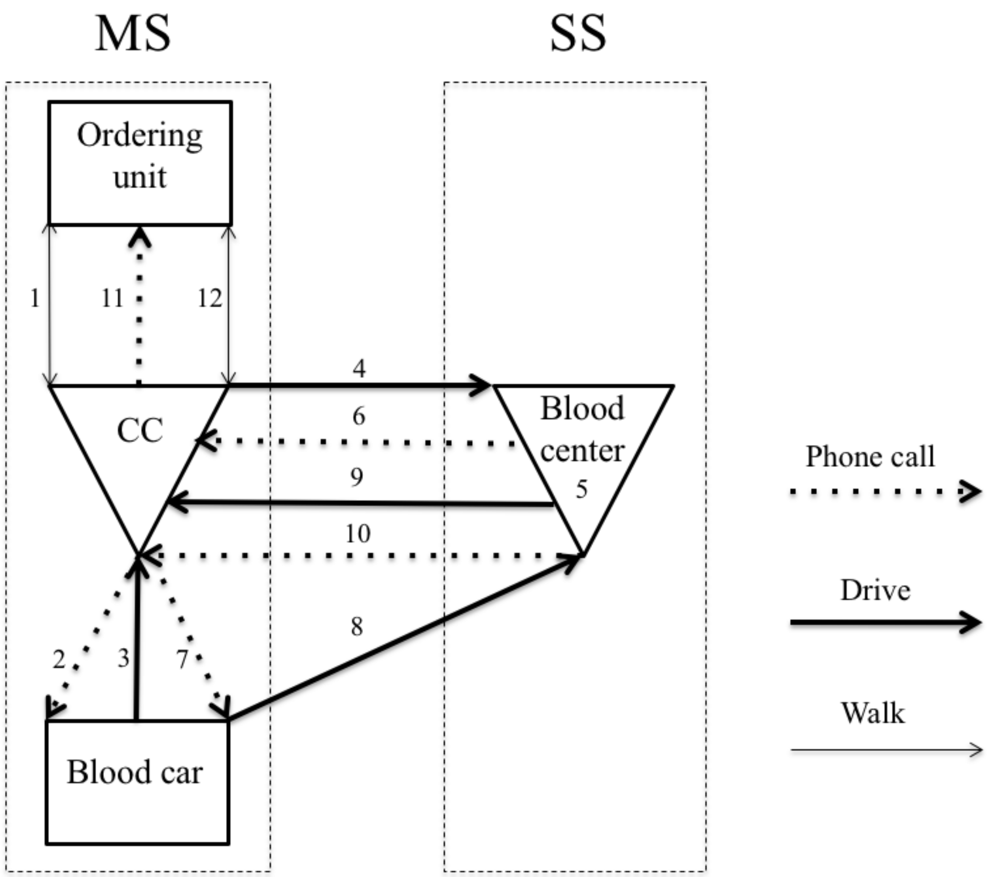

Figure 6. The process of ordering and delivering blood supplies from SS to MS, when a BAS-test has not been conducted in advance. Authors' own copyright.

1. Someone at the ordering unit at MS walks to CC MS with a BAS-test sample
2. CC MS calls the blood car to come and pick up the BAS-test sample
3. The blood car drives to CC MS and picks up the BAS-test sample
4. The blood car delivers the BAS-test sample from CC MS to the blood center at SS
5. A BAS-test is conducted at the blood center at SS
6. The blood center calls CC MS when the analysis of the BAS-test is ready and blood supplies are available
7. CC MS calls the blood car and ask for pick up of blood supplies at the blood center
8. The blood car drives to the blood center
9. The blood car delivers the blood supplies to CC MS
10. The blood center calls CC MS to notice them that the blood supplies have been sent
11. CC MS calls the ordering unit to notice them that the blood supplies have arrived and are ready for pick up
12. Someone at the ordering unit walks to CC MS and collects the blood supplies

Out of these 12 process steps, all except for the BAS-test (5) are points of transfers. Although it happens that a BAS-test is required urgently, it is more usual that it has been done in advance. The process of ordering blood supplies, when BAS-test has been done in advance, is less complex and is visualized in figure 7 below.

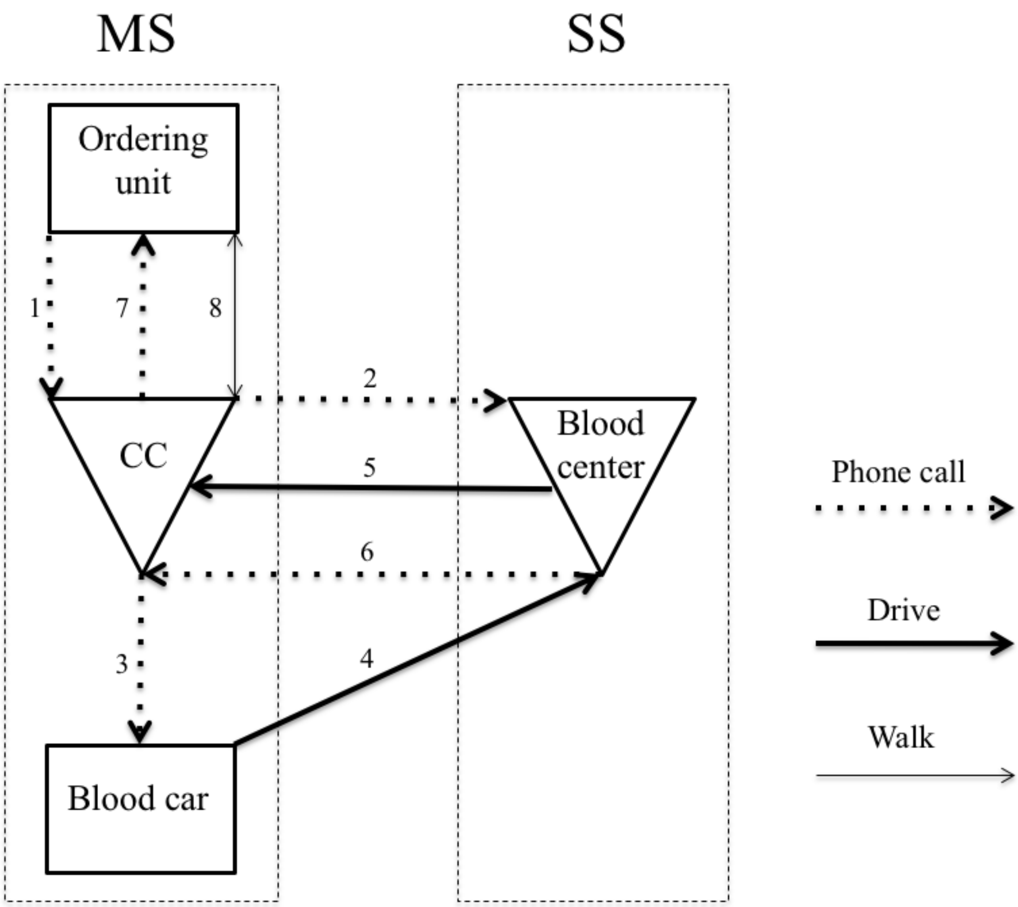

Figure 7. The process of ordering and delivering blood supplies from SS to MS, when BAS-test has been conducted in advance. Authors' own copyright.

1. Ordering unit calls to CC MS and orders blood supplies
2. CC MS calls the blood center and orders blood supplies
3. CC MS calls the blood car and asks for pick up of blood supplies at the blood center
4. The blood car drives to the blood center
5. The blood car delivers blood supplies from the blood center to CC MS
6. The blood center calls CC MS to notice them that the blood supplies have been sent
7. CC MS calls the ordering unit to notice them that the blood supplies have arrived and are ready for pick up

All these seven process steps are points of transfer. The process of ordering and delivering blood supplies from SS to MS, when BAS-test has been conducted in advance, is less complex and require fewer transfers of both goods and information compared to when a BAS-test has not been done in advance.

Goods characteristics

Blood, thrombocytes and plasma are stored in 250-300 ml bags. Blood bags transported from the blood donation locations to the blood center are slightly larger, 450 ml. The blood supplies have different requirements during transport. Blood bags need to be kept under cooling, in a temperature between 2°C to 6°C, at all times, and stable during transport since shaking could destroy the red blood cells in the blood. Thrombocytes are transported in temperature between 20°C and 24°C, and should be kept in rocking motion. Plasma is stored and kept frozen, between -18°C and -25°C, at the blood center and some bags of plasma are thawed. During transport, the bags of plasma are frozen when the intention is to store the products, and in thawed condition when the intention is to use the products immediately. Cooling or styrofoam boxes, with predetermined places to put ice packs, are used in order to keep the goods in the right temperature. The BAS-test samples and blood grouping samples are transported in test tubes and are durable and the temperature during transport is not strictly regulated. However, thrombocytes are not transported with extra heating even if it is cold outside.

4.2.5 Laboratory logistics

The medical goods within the field of laboratory logistics can be divided into two separate logistic systems, healthcare laboratory logistics and research laboratory logistics.

4.2.5.1 Healthcare laboratory logistics

CC is a division with several subunits at SS, ÖS and MS that is responsible for conducting analyses on bodily fluids. The fluids analyzed are collected within the hospitals and from a large variety of healthcare centers and units in the region. There is a 24/7 unit within CC at each hospital site that has almost the same range of analyses available. The analyses performed at the 24/7 CC units are usually of common types. Additionally, there are several special labs at SS and ÖS that perform analyses of more uncommon types, for instance the department Clinical Pathology and Genetics. The delivery system of laboratory samples within SU is visualized in figure 8 below.

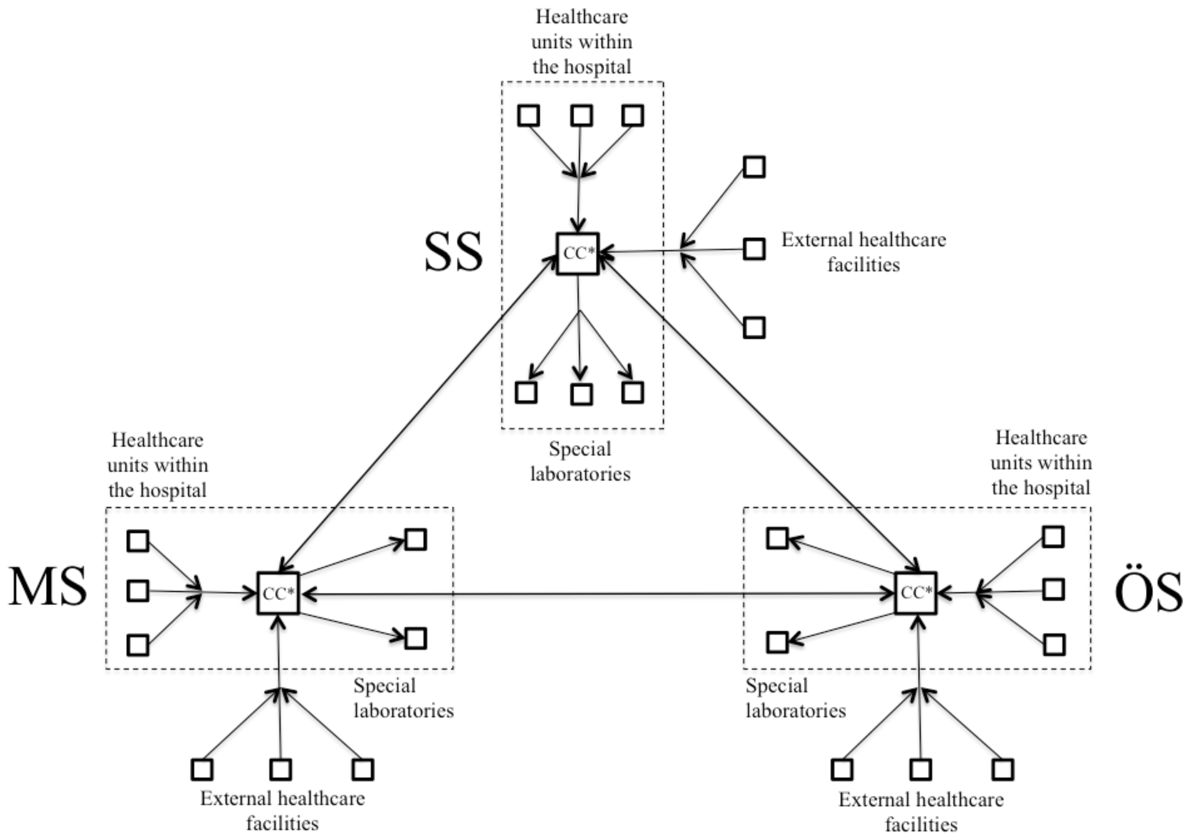

Figure 8. Deliveries of healthcare laboratory samples within SU. Authors' own copyright.

CC works as an intermediary for samples, where the units either analyze the received samples or sends the samples forward to special laboratories, either within SU or to other laboratories in Sweden or even Europe.

Regular deliveries

The regular deliveries from different healthcare facilities to the 24/7 CC units and from the 24/7 CC units to other SU-laboratories are performed both by Regiontransport and the blood car. Regiontransport handles the majority of the transports, whereas the blood car has been assigned one single route in order to make use of its excess capacity. If the blood car driver receives an order for an acute on-demand delivery, the route is interrupted in favor to the acute delivery and is hence delayed. Depending on the size and need of each healthcare unit, the deliveries takes place at different frequencies. The laboratory samples are always picked up and delivered directly to and from the laboratories. The predetermined deliveries allow healthcare facilities to plan the sampling based on the time for deliveries when the samples are time sensitive.

On-demand deliveries

The need for on-demand deliveries of laboratory samples is relatively low since the frequency of regular deliveries is planned based on each unit's needs. Pre-procured carriers are for instance used in acute situations or when samples have been delivered to the wrong unit. When acute deliveries are needed, pre-procured carriers should be used but on-demand deliveries are sometimes performed by the blood car due to its excess capacity. However, since it is not clear that all these deliveries are of an acute character, there is a possibility that several of these samples could have been transported with Regiontransport's regular deliveries or with an external carrier.

A special type of on-demand delivery of laboratory samples is a delivery called "Red situation delivery". The Red situation deliveries are extremely critical and take place during surgeries of young children at ÖS, where a sample needs to be analyzed acutely at SS when the child is kept anesthetized. This service is performed by an external carrier that stand-by awaits the sample outside the hospital building. The Red situation deliveries are sometimes escorted by the police due to its importance.

Goods characteristics

Healthcare laboratory goods are mainly human fluid samples in test tubes or human tissues in glass or plastic jars. Some fluid samples require stability and a certain temperature during transport, whereas other should be kept under movement. The healthcare laboratory goods are often of small size and low weight. If a certain sample requires to be kept at a low temperature or has to be frozen during transport, it is packed with dry ice that weighs a few kilos. Deliveries of laboratory samples can be acute in two ways; either when a patient's condition is critical and the results of the sample analysis are important, or when the quality of the sample deteriorates with time. The samples are transported in boxes sometimes equipped with freezer packs to keep the samples in required temperature. The boxes used in central Gothenburg are usually made of paper that are lightweight. Deliveries for analysis of Myoglobin, PCT, Alcohol intoxication, and MYO heart markers are some of the most deliveries of healthcare laboratory samples.

4.2.5.1 Research laboratory logistics

Biobank Väst is a cooperation between VGR and Sahlgrenska Academy at the University of Gothenburg. A biobank consists of one or more sample collections where the sample collections can be either research sample collections or sample collections for care, diagnostics and treatment. Within Biobank Väst, all stored sample collections are for research purposes. There are special laboratories within CC that handle liquid-based samples such as urine or blood, whereas Biobank's laboratory personnel handle special research samples such as tissues. Biobank Väst so-called freezer hotel, where the samples are stored, is located near the SS hospital site and is the only biobank in the region. There are two laboratories receiving and handling research laboratory samples, one located at SS and one at ÖS. In August an additional one is opening in connection to Biobank Väst's office, near the hospital site at SS.

Regular deliveries

When researchers set up studies where samples are needed, samples are collected at different healthcare facilities and usually delivered in predetermined routes by Regiontransport to CC MS, distributed to the laboratories at SS and ÖS before the final storage at Biobank's freezers. The deliveries take place weekdays during office hours.

On-demand deliveries

If on-demand deliveries are needed in a research study, researchers must arrange the deliveries of laboratory samples themselves with an external party and use the research budget to finance it. Due to the high expenses associated with on-demand deliveries, this is therefore unusual. Researchers that do not have room for these expenses in their budget must, hence, adapt their sampling to the regular deliveries. Researchers in the region demands more flexible deliveries that allow for sampling 24/7, but in order to enable this, the opening hours of special laboratories handling these kinds of samples must also be extended.

Goods characteristics
Research laboratory samples are usually liquid-based samples such as urine or blood or human tissues, and the characteristics are very similar to healthcare laboratory samples. Some research laboratory samples need to be kept frozen and are therefore transported together with dry ice. A regular sample is about 10 ml and weighs about 40-60 g, whereas the package of research laboratory samples usually weighs between 1-5 kg during transport, depending on the number of samples and dry ice needed. The most common transport box used for research laboratory samples weighs 4-5 kg, including eight frozen microtube plates and dry ice.

4.2.6 Overview of characteristics of medical goods logistics

Medical goods have characteristics that varies widely, hence, the table below aims to present a comprehensive overview. The table is followed by explanations of the content.

Table 6. Characteristics of medical goods logistics

Medical goods	**Sub-categories**	**Size**	**Weight**	**On-demand deliveries**	**Transport requirements**	**Personal info**	**Economic value**	**Replace-ability**
Medical devices		Small to large	Low to high	Rarely		No	Low to high	Yes
Pharma-ceuticals	Standard pharma-ceuticals	Small to large	Low to high	Some-times	Traceability Temperature Humidity Stability* Security (risk of theft)*	Some-times	Low to high	Yes
	Extempore pharma-ceuticals	Small to medium	Low to medium	Rarely	Traceability Temperature Humidity Stability* Security (risk of theft)*	Some-times	Low to high	Yes
Sterile goods	Reusable sterile goods	Small to large	Low to high	Rarely	Three-layers package	No	Low to high	Yes
	Consumable sterile goods	Small to medium	Low to medium	Rarely	Three-layers package	No	Low to medium	Yes
Laboratory samples	Healthcare laboratory samples	Small	Low to medium (with ice)	Daily	Traceability Temperature Stability*	Yes	Low	No*
	Research laboratory samples	Small	Low to medium (with ice)	Depends on each research project	Traceability Temperature Stability*	Yes, until aliquoted. Later coded.	Low	No*
Blood supplies	Blood	Small	Low	Daily	Traceability Temperature (2-6 ‘C) Stability	Yes	Medium (ca €100)	Yes
	Plasma	Small	Low	Some-times	Traceability Temperature (2-6’C)	Yes	Medium (ca €50)	Yes
	Thrombo-cytos	Small	Low	Some-times	Traceability Temperature (20-24’C) Movement	Yes	Medium (ca €200-400)	Yes

**Not applicable for all goods within the medical goods field*

Size

Medical goods vary widely in size and have been roughly estimated and divided into the three categories; small, medium and large. Medium refers to goods that fit in the boxes commonly used within VGR today, which is about the size of a shoebox. Small refers to goods that fit into half a shoebox and large are goods larger than a shoebox.

Weight

In the overview of characteristics of medical goods, three categories of weight are used. Low refers to goods up to 0,5 kg, medium refers to goods that weigh from 0,5 kg to 5 kg, and high refers to goods that weigh more than 5 kg.

On-demand deliveries

Laboratory samples and blood are examples of medical goods delivered on-demand between the three SU hospitals on a daily basis. Goods that sometimes are delivered on-demand between the hospitals refers to goods that are delivered on-demand but not commonly, and these are standardized pharmaceuticals, plasma and thrombocytes. Sterile goods and medical devices are rarely transported on-demand between healthcare facilities. The length of the time frame within which the on-demand deliveries of medical goods are required depends on the type of good. Acute deliveries of blood supplies should not take more than 30 minutes, whereas acute orders of pharmaceuticals should be delivered within five hours.

Transport requirements

Transport condition requirements refer to the environment required, during transport, for medical goods. Some goods are durable or in need of stability during transport and can be destroyed if they are exposed to vibrations or shaking. Temperature requirements refer to whether a medical good must be transported at a certain temperature or not, although the required temperature within each medical goods field can vary. Other requirements are special packaging, traceability, humidity or security due to a risk of theft. In the current transportation system, there is a lack of traceability of both the current location during transport and of the environment medical goods are transported in, except for transport of pharmaceutical goods where the temperature is traceable.

Personal information

Personal information refers to information on the goods that can be traced to a patient or individual, for instance, personal ID number or name. Most medical goods have no personal information attached, except for laboratory samples and blood supplies where items usually have both name and personal ID numbers visible. When it comes to research laboratory samples, the personal information on each sample is transferred into QR codes when the samples have been aliquoted before storage in Biobank's freezers.

Economic value

The economic value of medical goods refers to the value of the actual good and is divided into three different categories; low, medium and high. Low refers to an economic value under €50, medium refers to €50-1000, and high economic value is over €1000. Laboratory healthcare samples delivered for analysis do not have any economic value per se but are valuable from a patient perspective. Blood supplies, on the other hand, have a higher economic value due to the fact that they can be traded. Regarding pharmaceutical goods, the economic value could vary widely, and the goods of a higher economic value are often narcotic classed pharmaceuticals. The economic value of medical devices and sterile goods varies from low to high. The table does not consider the economic aspects connected to the activities in relation to goods handling, such as labor costs.

Replaceability

Most medical goods are available in stocks within VGR, resulting in that goods that are destroyed or lost can be replaced. This is, for instance, the case for pharmaceutical products, medical devices and blood supplies. Laboratory samples are the only goods identified that cannot be replaced. Although it sometimes is possible to retake a sample, this is avoided to a large extent due to patient safety. Some samples are not possible to retake due to the following reasons;

- Some samples are taken in order to analyze a patient's medical state at a given time
- It is difficult and sometimes impossible to retake samples from young children
- Seriously ill patients result in critical time frames

In addition, some types of sample analysis are uncommon and only performed once a month or every other month. Thus, if a sample is delayed, destroyed or lost, it could lead to delays of the results up to 1-2 months before it is possible to analyze a certain type of sample again. Some types of sampling are also extremely painful for the patients, why lost or destroyed samples could have critical consequences. Furthermore, it is inconvenient for patients to return to the hospital sites in order to retake a sample. Samples for BAS-tests and blood grouping can usually be retaken.

4.3 Logistics system risk factors

Although deviations are rare within VGR's delivery system of medical goods, deviations such as delays, faulty deliveries, forgotten and destroyed medical goods have been reported. The deviations have occurred during transport performed by the blood car, Regiontransport and external carriers. Deviations have occurred partly due to human errors and insufficient traceability systems of medical goods, where goods have been lost somewhere along the way, either during transport between or within the hospital sites. The current transportation system is based on a trust system, with no requirements to show identification when picking up medical goods at the hospitals. Neither are the boxes in which the goods are transported lockable. However, in the hospital personnel's knowledge, there have not been any deviations as a consequence of pick ups by unauthorized persons. If goods are lost, there is a risk that personal information about patients becomes available for unauthorized persons.

Another issue related to deliveries of medical goods within VGR is the traffic congestions, which often occur during rush hours between ÖS and the other two hospitals. The traffic situation has gotten worse since the summer 2018 when several large infrastructure reconstruction projects started in central Gothenburg. Although the drivers can choose from several routes, they experience that even the uncommon routes are blocked during rush hours. These traffic congestions have resulted in delays of both regular and on-demand deliveries between the hospitals.

Medical devices

Deliveries of medical devices are rarely time sensitive, and in case of delay or loss there is usually time to correct the deviations by ordering new material from the depots or other healthcare units.

Pharmaceuticals

Deliveries of pharmaceuticals are rarely of a time sensitive character since most important and time sensitive pharmaceuticals are stored most healthcare units. Some deviations have occurred due to incorrect temperature conditions, but these deviations are uncommon since a temperature traceability system was implemented. Additionally, narcotic pharmaceuticals have been stolen due to their high economic value, although such deviations are rare.

Sterile goods
It is important to have the right sterile goods available at the right time at the hospitals. There are storages of consumable sterile goods supplying the hospital and there is rarely a shortage of consumables. Reusable sterile goods must be sterilized and re-packed at the sterile technique unit in time, and the most common deviation is due to human errors such as that the hospital personnel have forgotten to order or ordered material or have ordered the wrong material, or that the sterile technique department has forgotten to pack or has packed the wrong material or instrument. The long lead times for sterilization of goods might result in consequences for the patient, such as delayed or even cancelled surgery if sterile goods that are not stored are missing. Additionally, this is causing a disturbance in the healthcare system, where the queues for surgeries might increase.

Laboratory samples
Healthcare laboratory samples are often of a time sensitive character. Delays, destroyed or lost laboratory samples therefore affects patient safety. Some samples require certain conditions during transports, such as stability or a special temperature. If the transport conditions are not met, the sample could be destroyed. The special laboratories rarely get information in advance about what samples they are about to receive. Due to the lack of traceability in the system, it could therefore take up to weeks before someone notices that a laboratory sample has been lost during transport.

In general, the faster an analysis is done, the better the quality of the results and the less wait for patients. Deviations related to healthcare laboratory samples results in that samples must be retaken, and results in severe consequences when this is not possible. If a research laboratory sample is lost or destroyed, researchers might have to ask patients to retake a sample. However, this is voluntary from the patient's perspective and the results of the analysis only affect the research, not the patient's state or safety.

Blood supplies
Blood supplies are replaceable but nevertheless, delayed, destroyed or lost blood supplies could have negatively consequences for the patient. Since MS has no blood center, MS is more vulnerable for deviations related to blood supplies deliveries compared to SS and ÖS. There is a backup of six units of universal blood on MS that can be used when a delivery is late or if the lead time is too long due to that a BAS-test has not been conducted in advance. Due to the back-up bags of universal blood and the routine of taking and analyzing BAS-test sample in advance of surgeries, the consequences of delayed, destroyed or lost blood supplies are limited.

5. Discussion

Since an overall goal for healthcare organizations is to maintain high patient safety (Vincent, 2010), all efforts in planning for and organizing services and activities in a healthcare system should have this focus. We argue that one way of improving patient safety is through logistics, where drones can constitute a fast transport mode. The figure below expands on how the theoretical fields are connected, and the intersections are described in further detail in 5.1.

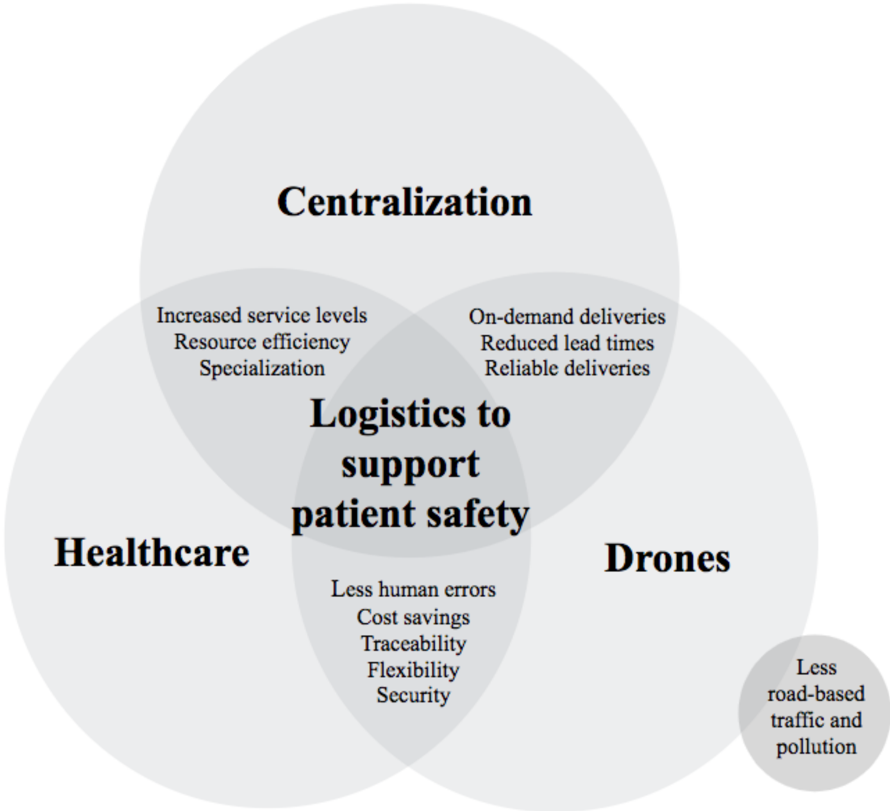

Figure 9. Logistics to support patient safety. Authors' own copyright.

This chapter aims to discuss in which ways drones can be used in a delivery system of medical goods and how patient safety can be improved by the potential benefits a drone-based delivery system implies. The potential benefits are discussed in 5.1. However, there are several risks associated with drone deliveries that impact the choice of whether or not to use drones, and which goods that are most suitable for drone deliveries. This discussion is presented in 5.2. Lastly, logistics design aspects for a future state drone-based delivery system are discussed in 5.3.

5.1 Potential benefits of drone deliveries of medical goods

The benefits directly related to patient safety aims are summarized in table 7 according to the logistics performance indicators presented in the theoretical framework, and the benefits are discussed in the following sections. The potential patient safety benefits that can be achieved through a drone-based delivery system of medical goods, compared to road-based deliveries, can be found by combining theories on patient safety and logistics according to section 2.1.1, and by applying the findings to drone deliveries. The potential benefits of a drone-based delivery system enable for logistics performance indicators to be improved, which in turn leads to improved patient safety. The table below summarizes the benefits and related logistics performance indicators. An improvement in a logistics performance indicator further results in improvements in the patient safety aims presented by Vincent (2010).

Table 7. Patient safety improved through a drone-based delivery system of medical goods

Patient safety aim	Logistics performance indicators	Enablers through autonomous drone delivery
Safe	Percentage of deliveries conducted without deviations.	Reduced risk of errors due to less human handling and reduced number of transfers of information and goods. Improved traceability and transparency in the delivery system with real-time updates about location. Improved security through authorization upon loading and reloading of drone deliveries.
Effective	Capacity of transport resources matched with demand for deliveries.	Enables for overcapacity to be reduced and for risks for undercapacity of on-demand deliveries to be eliminated.
Patient-centered	Flow efficiency. Value-adding activities in relation to the throughput time.	Shorter delivery lead time results in less waiting time for patients, which improves flow efficiency and patient centricity.
Timely	Percentage of goods delivered on time. Can be put in relation to dependability, where the sequence of activities is of high importance.	Increased reliability in delivery lead time compared to road-based transports, and enables for a reduction in the number of deviations.
Efficient	Utilization rate of resources, such as modes of transport, or percentage of time healthcare professionals spend on non-patient related activities.	Increased utilization rates of modes of transports, personnel and facility resources such as surgery rooms or medical equipment due to fewer delays and possibilities for further centralization.
Equitable	Availability of deliveries independent of location, day of the week or time of the day.	Improved flexibility of deliveries in terms of both location and time.

The enablers presented in the table above, will all be discussed in the following sections and it can from the table be found that drone-based deliveries of medical goods have potential to have a positive impact on patient safety aim compared to road-based deliveries. However, in order to realize the full potential of a drone-based delivery system, several challenges must be addressed. The design aspects are on a more operational level, whereas table 8 indicates the strategic value of a drone-based delivery system from a patient safety perspective.

5.1.1 Reduced delivery lead time

One of the major benefits with the use of drones in a distribution system is the potential reduction of lead time compared to a road-based delivery system. From the urban drone delivery projects in Switzerland, the United Kingdom, Norway and Denmark, it is shown that the time saving potential is one of the underlying factors for using drones (Mion, 2018; NESTA, 2019a; Erichsen, 2018; Sundhedsdroner, 2019), and in the pre-study by Damgaard (2019) it has been theoretically proven that drones could reduce transport lead times between SS, MS and ÖS compared to the current road-based delivery system. From this study, it is found that the current delivery system between SS, MS and ÖS is highly affected by the traffic situation in the city, where traffic congestions and infrastructure projects cause unpredictable delivery lead times for road-based deliveries. Drones are not affected by these hinders, hence delivery lead time can be reduced, and lead to several associated benefits.

Long and unpredictable lead times have a negative impact on patient safety since it is important to keep waiting time and harmful delays at a minimum, both for patients and healthcare professionals (Vincent, 2010). Vincent (2010) argues that wait for surgeries, the next step in the medical treatment or the decision upon medication could increase due to delays of deliveries. Furthermore, waiting is mentally and physically harmful for patients, and results in longer recovery time and unnecessary suffering. Thus, we argue that if delivery lead times are decreased through the use of drones, patients can receive better and faster medical care adapted to their medical status and suffering can be minimized. Faster test results can lead to more appropriate medication and in some cases reduced use of antibiotics, due to the possibility to adjust the frequency and dose of the medication (Autonomous Mobility, 2019; NESTA, 2019a). These benefits are in accordance with the aims of patient safety, where avoiding underuse and overuse of services to patients should be avoided (Vincent, 2010).

Similar to the centralization initiatives that have been seen in countries such as Denmark, Norway and the United Kingdom (Christiansen & Vrangbæk, 2018; Haugstad, 2018; Svederud et al., 2015), this study shows that VGR is making use of a centralized distribution strategy that results in requirements for fast deliveries. Most medical goods in the region are stored at centralized warehouses, and the goods are distributed according to the needs of the healthcare units both regularly and on-demand. However, it is shown in this study that most healthcare units that require access to medical goods urgently have some goods stored at the unit, which can be compared to a time-based distribution system where the distribution system and the number of warehouses is determined by the lead time demanded by customers (Abrahamsson, 1999). Although unit inventories exist, deliveries are still needed urgently between the hospitals and from the centralized warehouses due to the impossibility to predict or plan for acute healthcare. It is also found that most activities and services, such as CC, sterile technique and other specialized units, are centralized within SU. In the future, these units will provide HSS with services, which further centralizes the resources in the region and increases the need for deliveries. These findings are supported by Haugstad (2018), who argues that centralization puts additional pressure on a delivery system. This, in combination with that fact that centralized inventories and activities in a time-based distribution system require fast modes of transport (Abrahamsson, 1999), lead us to the conclusion that the use of drones for deliveries of medical goods improves both the current delivery system and enables for further centralization of healthcare systems, which results in increased utilization of resources and better control over stock levels.

5.1.2 Improved transport reliability

Each transfer of patients, physical goods and information increase the vulnerability in a system, where each transfer represents a higher risk of errors, deviations or accidents (Vincent, 2010). Deviations as a result of transfer errors negatively impact patient safety, where risk always should be eliminated or at least reduced. Although healthcare personnel are indispensable in order for the healthcare system to work and are invaluable in terms of the services they provide to patients, it is unfortunately inescapable that all human handling constitutes a risk for deviations in a delivery system. This study shows that human errors of drivers and healthcare personnel have occasionally resulted in lost and destroyed goods, delayed and faulty deliveries of goods within the medical goods delivery system in VGR. Therefore, we argue that the number of transfers and human errors can be minimized through an automated delivery process, including autonomous drones and associated IT ordering system. We argue that if orders are placed in an IT system, instead of through several phone calls, the number of transfers of information is reduced, and if road-based deliveries operated by human resources are replaced by a fully autonomous drone system, the risk for human errors can be avoided. These findings are in line with patient safety theories that state that deviations in a healthcare system can be avoided through standardization and implementation of new technologies, as well as the findings by Wertheimer (2018), who concludes that drones enable for increased reliability related to deliveries of medical goods.

Some medical goods deliveries within VGR are actually based on that orders are placed in an IT-based ordering system, but a concrete example from the case study where the number of transfers could be drastically reduced, is the ordering and delivery system of blood supplies between MS and SS, especially when a BAS-test has not been conducted in advance. By replacing phone calls with an IT ordering system, and using autonomous drones as a mode of transport, the number of transfers and associated risks can be reduced (figure 10).

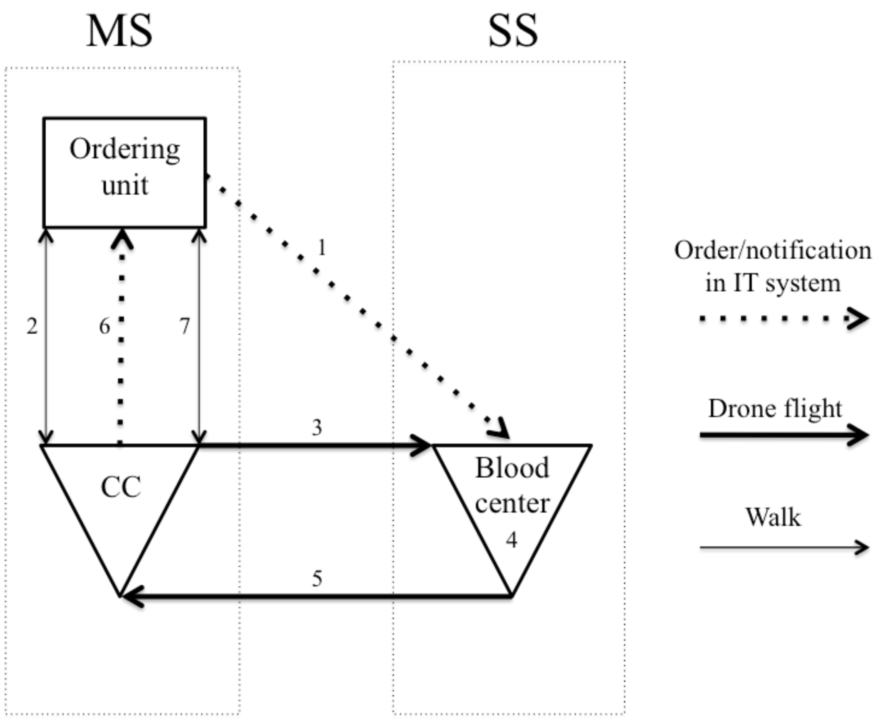

Figure 10. New ordering process of blood products when a blood test has not been conducted in advance. Authors' own copyright.

1. Order is placed in IT-system by the ordering unit at MS (available for blood center)
2. Someone at the ordering unit at MS walks to CC MS with a BAS-test sample
3. CC MS sends the BAS-test sample with a drone to the blood center
4. A BAS-test is conducted at the blood center at SS
5. Blood supplies are sent from the blood central at SS (according to the placed order in the IT system) with a drone to CC MS
6. CC MS receives the blood supplies and the ordering unit at MS is automatically notified through the IT system (with a signal or similar)
7. Someone at the ordering unit walks to CC MS and collects the blood supplies

Out of these seven process steps, all except for the BAS-test (4) are points of transfers and this is a reduction of five transfer points, corresponding to a reduction of approximately 40 %. Each removed information transfer constitutes an improvement in patient safety (Vincent, 2010).

The unpredictable transport times that the traffic situation in Gothenburg causes today, in combination with the lack of traceability of the goods' location, results in an unreliable system that makes it difficult for healthcare and laboratory personnel to plan their activities. The lack of traceability of the goods in the current VGR delivery system also results in that deviations sometimes are noticed long after they occur. Since autonomous drones are connected to control stations that enable for management and surveillance of the drone operations and locations (Otto et al., 2018), improved traceability of the goods is made possible through a drone delivery system with real-time updates about location. In addition, deviations are more likely to be noticed in connection to when they occur and consequences could, hence, be mitigated. If predetermined and reliable lead times are enabled, the chance for correct and fast information about deviations of the deliveries to customers increases (Abrahamsson, 1999).

There are improvements to be done in terms of security if a drone delivery system is designed so that unauthorized persons are not able to access the goods, which for instance can be done through fully autonomous drone take-off and landing including loading and reloading of goods that are presented in the future state scenario of the Swiss project (Mion, 2018). The solution presented in the Swiss project includes authorization in order to send and receive medical goods through drones. Identification checks are seldom required from drivers in the distribution system of medical goods within VGR today and the boxes in which most medical goods are transported are not locked or sealed in any way. Therefore, additional security in the delivery system could be enabled through drone deliveries. Even if the current security system, based on trust, is well functioning according to the respondents in this study, risk should always be eliminated or reduced in order to improve patient safety (Vincent, 2010), hence, drones can be used as a mean of improving security in a delivery system of medical goods.

5.1.3 Transport capacity matched with the need for on-demand deliveries

In order to achieve an effective delivery system, it is important that transport resources are matched with the demand for deliveries (Jacobsson, April 25, 2019). However, the demand for deliveries within the healthcare sector is hard to predict due to that urgent healthcare needs do not allow for control of date, time and location (Rosser et al. 2018). In addition, these needs occur at an unpredictable frequency. Undercapacity of resources is associated with high risks, and since patient safety always is prioritized, there is usually an overcapacity of resources in connection to delivery services. However, the overcapacity should be reduced if it does not compromise on patient safety.

There is an undercapacity of on-demand healthcare sample deliveries within VGR's delivery system today. This study shows that some healthcare units are restricted to plan their operations based on the regular delivery schedule due to this fact. For instance, if the transport pick up slot is scheduled early during the day, some sampling is restricted to mornings and if the time slot is missed, sampling is rescheduled until the next regular transport in order to avoid ordering an expensive on-demand delivery with an external carrier. The same goes for needs for deliveries that arise due to unpredictable healthcare situations. This indicates that there is a greater demand for on-demand deliveries than the current delivery system is able to meet. Deliveries with autonomous drones are not limited to human resources, hence, we argue that drones enable for increased flexibility of deliveries of medical goods in terms of both time and location, as well as for the possibility to be used on-demand. The undercapacity in the current system causes longer lead times and wait than necessary, which should be avoided to the greatest extent (Vincent, 2010), and implies that parts of the healthcare operations are based on the transport schedule for regular deliveries, whereas drones could enable for deliveries to be sent whenever needed. The upfront costs of a drone delivery system are high due to the purchase price of drones and the additional costs for setting up the system (Thiels et al., 2015), including both hardware and software. The operational costs are low compared to the current delivery system due to that fewer human resources are needed to handle the operations and that electrical drones are related to low costs of fuel. Hence, drones enable for on-demand deliveries without causing extra costs for each delivery. This is line with the findings by Minion & Postelnicu (2018) and Sundhedsdroner (2019), who states that less traffic on the roads and connected major cost savings could be enabled through the flexibility that drones offer.

Overcapacity of delivery resources has been identified for deliveries of blood supplies performed by the blood car. This study shows that the need for on-demand deliveries of medical goods is unpredictable and in order to handle the unpredictable demand for deliveries of blood supplies, the blood car is manned 24 hours a day all year with extensive excess capacity in terms of both labor and payload capacity (a full-size car exclusively delivering small and lightweight goods in low volumes). This indicates the importance of access to blood supplies deliveries but is also a very inefficient and costly delivery system. The on-demand deliveries that constitutes the main purpose of the blood car, representing 53 % of the total on-demand deliveries, could be substituted to drone deliveries and these are presented in table 8 below.

Table 8. Transport specifics for on-demand deliveries substitutable by drone deliveries.

Departure unit	**Arrival unit**	**Medical goods delivered**	**Volume**	**Weight**	**Total weight**
CC MS	Blood center SS	BAS-test samples	1-2 pcs	40-60 g	120 g (max)
Blood center SS	CC MS	Blood supplies	1-6 pcs	250-300 g	1 800 g (max)

As can be seen in table 8, the volumes and payloads for these deliveries are low and are, therefore, suitable for drones (Stolaroff et al., 2018). By replacing the blood car's deliveries between CC MS and the blood center at SS, savings in terms of time and fossil fuel road-based transports can be achieved according to table 9.

Table 9. Time savings and road-based transport savings enabled by drone deliveries.

Transport mode	Average frequency/ month *BAS-test samples*	Average frequency/ month *Blood supplies*	Distance two ways (km)	Total distance/ month (km)	Lead time two ways (min)	Total lead time/month (min)
Road-based	127	44	9,4	1607,4	10,05	1718,55
Drone-based	127	44	8,9	1521,9	4,55	254,80
				Total time savings/month (hours)		24,40

The data presented in table 8 and 9 above represent the sole purpose of the blood car and it can be concluded that less than six deliveries per day in average (maximum ten) is performed this distance, although deliveries performed due to the blood car's excess capacity have been excluded from the tables. This indicates that one single drone could handle these deliveries and by placing drone stations in connection to CC MS and the blood center at SS and using drone deliveries for blood supplies and samples for BAS-tests, average savings of 1607,4 km/month of fossil fuel driven road-based transports can be achieved. In addition, this would result in time savings corresponding to at least 24,4 hors per month, with potential additional time savings achieved by automatization in connection to handling. This would increase the overall capacity in terms of availability and at the same time increase the utilization rate of payload capacity compared to road-based deliveries, which indicates potential for improved efficiency where resources are better utilized (Modig & Ahlström, 2012). This would also reduce the risk of undercapacity of on-demand deliveries and, therefore, result in a more effective delivery system.

According to the interviews in this study, the majority of the remaining deliveries that today is delivered with the blood car due to its excess capacity, beside those presented in table 8, could be delivered within the extensive network of regular deliveries. Furthermore, the low number of urgent on-demand deliveries could be delivered with external carriers in an initial state, or in a future network of drones. We argue that this would result in that the operations of the blood car could be completely replaced, resulting in both environmental benefits, time savings, cost savings in terms of fuel, excess labor and better-matched payload capacity. A number of drones adapted to the need of the healthcare organization are more likely to match the need of low volume, small and lightweight goods that today either are restricted to regular deliveries or sent with on-demand deliveries in vehicles with overcapacity in terms of both payload and human resources. A future network of drones does also offer the possibility to handle the need for on-demand deliveries arising from a larger number of customers, a need that today is handled by expensive external carriers or the blood car that is more or less limited to the distance between SS and MS. Another benefit of the use of drones, compared to the blood car, is that drones are not limited by geographical hinders in the same way as road-based transport modes, which means that drones can cover a larger geographical area without reducing the accessibility, hence, reducing the risk of undercapacity.

5.2 Medical goods' suitability and compatibility with drone deliveries

The development of drone applications within healthcare has been slower than in other fields (Rosser et al., 2018), which partly can be explained by strict regulations in the healthcare sector. Patient safety principles result in that security and patient safety always is prioritized, sometimes to the disadvantage of new technology (Vincent, 2010). Compared to road-based deliveries, there are several patient safety benefits of a drone-based delivery system that we argue could weight up for the risks associated with drone deliveries. Worth considering is that the current delivery system entails several risks as well, where deviations have been reported for all transport modes within VGR. However, some medical goods result in more severe consequences than others if deliveries are unsuccessful, and this indicates that there is a need to weight the potential patient safety improvement from drone deliveries for each type of good against the consequences of unsuccessful deliveries of the same.

Due to the fast development of the technology and its capabilities, it is crucial not only to see to what drones can perform today but also to broaden the horizon and account for what drones potentially can be used for in the future. Today, most drones are limited to a payload of 2-3 kg (Thiels et al., 2015; Otto et al., 2018), hence, it is in an initial state reasonable to focus on low volume and lightweight goods. It has also been found that most environmental benefits of using drones arise when light packages are delivered with drones, whereas heavier packages are delivered with road-based vehicles (Stolaroff et al., 2018). Another advantage of lightweight goods for drone deliveries is that they pose less risk to damage objects or people on the ground if they crash, compared to drones with heavier payload.

Based on the time saving potential that drones offer, the greatest benefits are obtained for drone deliveries of urgent needed medical products and time sensitive goods (Mion, 2018; NESTA 2019a). The most time critical goods transported between the SU hospitals are healthcare laboratory samples and blood supplies. Deliveries of research laboratory samples can be urgent but are not critical from a patient safety perspective. Although a destroyed or lost research laboratory sample might cause issues in a particular research study, it does not affect the patient from whom the sample was taken. However, delays and faulty deliveries of research laboratory samples can have consequences from a societal perspective since the society could have benefited from the results of the research. Medical devices and sterile goods are usually not directly time critical from a patient's perspective. However, delays of deliveries of these goods might result in that surgeries are delayed or cancelled, which causes wait that should be avoided from a patient safety perspective (Vincent, 2010). Delayed or cancelled surgeries are also a cause for increased healthcare queues, which has been seen at Nya Karolinska (Gustafsson, 2019). However, the need of urgent deliveries of medical devices, sterile goods and pharmaceuticals between the SU hospitals are rare.

Mion (2018) further concludes that goods that have low risk of theft or monetary loss are suitable for drone deliveries, why biological products are more suitable than pharmaceuticals, medical devices and sterile goods. Additionally, it was found in the study by NESTA (2019a) that medical goods delivered in high frequency and in low volumes are suitable for drone deliveries, which is the case for most on-demand deliveries of medical goods within VGR, particularly blood supplies and laboratory samples. Regular deliveries usually carry less time critical goods in high volumes and high weight, hence, we argue that these deliveries are not suitable to be replaced by drone deliveries in an initial state.

All risks should be avoided or at least reduced (Vincent, 2010), hence, we argue that replaceable products are more suitable for drone deliveries than non-replaceable products in an initial state. In general, biological products are not replaceable and constitute a higher risk than non-biological products. Mion (2018) argues that laboratory samples are suitable for drone deliveries due to the low weight, small size and low monetary value and further argues that sampling could be repeated in case a sample is destroyed or lost. The latter is contradictory to our findings since this study shows that resampling should be avoided to the greatest extent and that there are samples that are not even possible to retake, such as samples that aims to reflect a patient's medical state at a given time or when a sample is taken from a newborn. Thus, there can be harmful consequences from a patient safety perspective if these types of samples are lost. However, blood supplies are stored and can be replaced in terms of function, hence, these products entail less critical consequences than healthcare laboratory samples from a patient safety perspective. In addition, BAS-test samples belong to the type of samples that can be retaken. Another benefit is that blood supply deliveries rarely are extremely acute due to that the surgeries at MS are planned in advance and that there is a stock of universal blood that constitutes a safety margin.

Concluding, we argue that urgently needed replaceable medical goods with low economic value and low risk of theft, which are lightweight and frequently delivered in-demand in low volumes between facilities, are suitable for drone deliveries. In the VGR delivery system, blood supplies and healthcare laboratory samples are delivered urgently on-demand and have characteristics that match these criteria, whereas healthcare laboratory samples imply a higher risk from a patient safety perspective than blood supplies do today due to their irreplaceability.

5.3 Logistics design aspects

The design aspects for a logistics system including drones, span from technical solutions such as the attributes of the boxes in which the goods are transported, the choice of type of drone and navigation system, the layout of take-off and landing stations to more operational decisions such as handling of goods, flight routes, and air traffic control. As mentioned by Johannesson (April 5, 2019) and Forskningsrådet (2019), internal solutions, such as IT systems, working schedules, facilities and processes, must be adapted in order to realize the full potential of drone deliveries. Since this study is focused on the strategic aspects of using drones as a mode of transport, these more operational aspects will not be discussed in depth. However, we want to highlight some crucial aspects that are likely to impact the outcome of a drone delivery system.

For instance, since the use of drones for medical good deliveries is explored in several projects around the world, we argue that it is beneficial to make use of the existing knowledge when designing a drone-based delivery system. However, it is important to have in mind that although the similarities between the urban projects allow for benchmarking, there are distinctive prerequisites for each project. For example, compared to Switzerland where a current drone-based delivery system is up and running, weather conditions in Gothenburg are very different. The drones suitable for deliveries of medical goods between the hospitals in Gothenburg should be able to operate in strong winds, humidity, coldness and the drones should not be vulnerable for frost formations, which today constitutes a risk (Johannesson, 2019; Sällström, 2019). The drones used in similar healthcare projects, but in other weather conditions, are thus not necessarily suitable for deliveries of medical goods in Gothenburg.

Regardless of size and payload, the future drone delivery boxes in the healthcare sector should be designed to meet the requirements for the condition the medical goods need to be transported in, such as controllable temperature, stability or as the third layer in a three-layer sterile package. Furthermore, it is crucial that the drones are equipped with a safety system that minimizes the consequences of an unpredictable crash, where the safety system used in Switzerland (Furer, 2019) could constitute an example. Due to the fact that the security system for medical goods within VGR today is based on a trust system, every security factor added to a drone delivery system is an improvement. Security factors could, for instance, be to code personal information on the goods during transport in order to avoid the risk of dissemination of personal information, to use lockable boxes and require authorization in order to open the boxes in which the goods are sent. We argue that all these solutions would improve the overall security in the logistics system within VGR and that a logistics system including drones should be designed according to the need of the organization rather than pushed by available technology.

It is also desirable that the whole process should be automated as far as possible in order to minimize the risks of human errors (Vincent, 2010) and to reduce the amount of time healthcare or laboratory personnel spend on activities that do not add value to the patients (Modig & Ahlström, 2012). We claim that reduced physical lead time through the use of drones should not result in increased administrative lead time or time of handling, and it is important to have in mind that the drivers of road-based deliveries today constitute an important function in the delivery system today as they provide the last leg deliveries to and from each unit. Therefore, we argue that the drones suitable for delivering medical goods should be totally autonomous and the need of a human operator should be minimized, both in connection to take-off, landing and handling the medical goods to and from the drone stations. In the Swiss project, where drones today deliver laboratory samples on a daily basis, the flight routes are autonomous except for the take-off and landing where an operator currently is needed (Mion, 2018), and we stress the importance of resolving this issue. It also implies the importance of the decision of placement of the drone stations in order to minimize handling time, and to maximize the utilization of the drones. As suggested in 5.1.3, we argue that within VGR, it is beneficial to place drone stations in connection to CC MS and the blood center at SS.

6. Conclusion

This study intended to combine findings in healthcare and logistics, and assess the potential benefits of drone deliveries of medical goods to support patient safety. Through a literature study on patient safety, centralization and the state of the art of drones, together with a comprehensive current state analysis of the urban delivery system of medical goods within VGR, key potential benefits and challenges related to a drone-based delivery system have been addressed. In addition, characteristics of medical goods have been mapped in order to investigate the compatibility with drone deliveries based on the current need for deliveries between healthcare facilities today. By translating patient safety aims to logistics performance indicators, it is clear how drones allow for patient safety improvements.

This study shows that the potential benefits of a drone-based delivery system, compared to a road-based delivery system, are first and foremost related to time savings and the possibility to reduce the delivery lead time of medical goods between urban healthcare facilities. For instance, the total delivery lead time for on-demand deliveries between the blood center SS and CC MS can be reduced with at least 50 %, which corresponds to 24 hours per month. From the case study it is concluded that extensive logistics solutions including both regular and on-demand deliveries, are needed in order to handle the deliveries of medical goods that arise from centralized and specialized units. A potential patient safety benefit of shorter delivery lead times is less wait for patients and healthcare personnel, which results in higher flow efficiency where value-adding activities in relation to the total throughput time increases. Shorter lead times are additionally connected to benefits such as faster test results and medical care to patients, directly adapted to their medical status. Faster test results as a result of faster deliveries allows for, for instance, the possibility to adjust the frequency and dose of medications, such as antibiotics, earlier. In addition to time savings, road-based transports can be reduced with associated environmental benefits. Only by considering the on-demand deliveries between the blood center SS and CC MS, savings of 1607 km of fossil fuel driven deliveries per month can be achieved.

Another benefit of a drone-based delivery system, found from this study, is improved reliability due to more predictable lead times, which simplifies planning and performing of activities at better accuracy. Therefore, utilization rates of resources, such as facilities, healthcare professionals and medical equipment, could increase through the use of drones as a mode of transport. A drone-based delivery system also results in a more effective, and therefore more patient safe, logistics system where the capacity of transports is easier to match with demand for deliveries. Additionally, autonomous drones improve the flexibility of deliveries in terms of both time and location due to automatization of delivery processes and reduction of labor. The risks associated with drone deliveries should be put in relation to deviations that occur in a road-based delivery system. From this case study, it is shown that deviations such as faulty delivered or lost goods have occurred partly due to human errors that could be avoided through the use of drones. Additionally, drones enable for traceability and security to be improved and consequences of deviations to be mitigated.

This study further concluded which medical goods that are most suitable for drone deliveries in an initial state from a patient safety perspective. The characteristics of goods most suitable for drone deliveries are urgently needed small and lightweight goods, delivered in low volumes at a high frequency on-demand. The goods should also have low economic value and preferably be replaceable. From the case study on deliveries of medical goods between the SU hospitals, it was concluded that blood supplies and laboratory samples are the goods that are most suitable for drone deliveries based on these criteria. Of these two, blood supplies have the advantages of being replaceable and require less complicated transport conditions in a less complex delivery system compared to laboratory samples. In addition, the current delivery system of blood supplies from SS to MS indicates the importance of the availability of fast on-demand deliveries of blood supplies, but the solution used today is both inefficient and costly. Concluding, most benefits from a patient safety perspective can within SU be obtained from drone deliveries when applied on a blood supplies logistics system.

The findings from this study are applicable to most urban healthcare organizations where there is a need for deliveries of medical goods between facilities, especially those that make use of a centralization strategy, but the potential benefits of using drones have only been theoretically proven. In order to realize the full potential of drone deliveries, internal solutions must be adapted and a solution for fully autonomous take-off and landing must be developed. There is also a need to investigate whether the technical attributes of existing drones can handle the local weather conditions. Additionally, there are regulatory hinders that must be investigated and overcome. This study mainly focuses on the strategic aspects of drone-based distribution systems in urban healthcare. Therefore, further research should seek to find operational fully scalable solutions and investigate the feasibility through cost-benefit analyses.

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