Aalto University
School of Business

Effects of Enterprise Digital Assistants in Medication Dispensing Operations

Case Hospital Pharmacy

MSc program in Information and Service Management

Master's thesis

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2015

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Abstract of master's thesis

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Title of thesis Effects of Enterprise Digital Assistants in Medication Dispensing Operations – Case Hospital Pharmacy

Degree Master of Science in Business Administration

Degree programme Information and service management

Thesis advisor(s) Professor Markku Kuula, Docent Vesa Kämäräinen

Year of approval 2015 **Number of pages** 89 **Language** English

OBJECTIVES OF THE STUDY

In this thesis, I study the effects of introducing automation in the form of barcode-reader enabled Enterprise Digital Assistants and their impact on work efficiency and medication safety in a hospital pharmacy setting. The goal is to determine whether the efficiency of the process can be improved without compromising medication safety. In addition to the quantitative objectives, employee perceptions on the likelihood of success of the implementation are studied to include a more qualitative approach on the subject.

DATA AND METHODOLOGY

The data include information on different phases of the medication dispensing process taking place in the HUS Hospital Pharmacy in Helsinki, Finland. My sample consists of 80 341 orders processed on 143 days between July 2014 and April 2015. I use statistical analysis to calculate pre- and post-implementation process throughput times and error rates. Employee perceptions are measured with a questionnaire and interviews.

FINDINGS OF THE STUDY

It is possible to improve the efficiency of the order-picking process by automating the pharmaceutical inspection phase with the EDAs without increasing the dispensing error rate. Firstly, The efficiency of the order-picking process improved by 34% from 1.40 rows per minute to 1.87 rows per minute. Secondly, the EDA implementation bears potential for further process streamlining, as the pharmaceutical inspection could be performed without an additional hospital pharmacist, freeing resources to perform more knowledge-intensive work tasks.

The questionnaire and employee interviews revealed that employee perceptions on the usefulness and the ease-of-use of the implementation would seem to affect positively on the perceived likelihood of success of the implementation. Even though the implementation project had faced several difficulties, the employees considered that the devices are useful and thus have faith in the success of the implementation.

Keywords barcode technology, enterprise digital assistant, hospital pharmacy, healthcare operations management, dispensing, order-picking, medication safety, warehouse management, ICT implementation

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Gradutiivistelmä

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Otsikko Kannettavien keräilylaitteiden käytön vaikutukset lääkejakelussa- Case Sairaala-apteekki

Tutkinto Kauppatieteiden maisteri

Ohjelma Tieto- ja palvelutalous

Ohjaaja(t) Professori Markku Kuula, Dosentti Vesa Kämäräinen

Hyväksytty 2015 **Sivumäärä** 89 **Kieli** Englanti

TUTKIELMAN TAVOITTEET

Tutkin pro gradu –tutkielmassani automatisaation lisäämistä lääkekeräilyprosessissa kannettavien keräilylaitteiden avulla, ja laitteiden käyttöönoton vaikutusta työn tehokuuteen ja lääkitysturvalliseen sairaala-apteekkiympäristössä. Työn tavoitteena on tutkia voiko lääkekeräilyprosessin tehokkuutta parantaa laitteilla vaarantamatta lääkitysturvallisuutta. Sisällyttääkseni työhön myös kvalitatiivisen näkökulman, tutkin kvantitatiivisten tavoitteiden lisäksi henkilökunnan näkemyksiä implementaation onnistumisen todennäköisyydestä.

DATA JA METODOLOGIA

Data sisältää tietoa lääkekeräilyprosessin eri vaiheista HUS Sairaala-Apteekista, joka sijaitsee Helsingissä. Otokseni koostuu 80 341 lääketilauksesta jotka on käsitelty 143 päivänä aikavälillä heinäkuusta 2014 huhtikuuhun 2015. Käytän tutkielmassa tilastollista analyysia laskeakseni lääkekeräilyprosessin keskimääräisiä läpimenoaikoja sekä keräilypoikkeamien määrää ennen ja jälkeen laiteimplementaation. Työntekijöiden näkökulmia on mitattu kyselyllä ja haastatteluin.

TULOKSET

Keräilyprosessin tehokkuutta voi parantaa automatisoimalla farmaseuttisen tarkastuksen kannettavilla keräilylaitteilla ilman että toimituspoikkeamien määrä kasvaa. Keräilyprosessin tehokkuus kasvoi 34% 1.40:stä rivistä minuutissa 1.87:aan riviin minuutissa. Laitteet voivat parantaa prosessin tehokkuutta entisestään, sillä farmaseuttisen tarkastuksen suoritettaessa laitteilla vapautuu työntekijäresursseja tietointensiivisempiin työtehtäviin lähemmäs potilaita.

Kysely- ja haastatteluvastausten perusteella voidaan sanoa että laitteiden hyödyllisyys ja käytettävyys vaikuttavat positiivisesti työntekijöiden näkemyksiin hankkeen onnistumisesta. Vaikka implementaatioprojekti oli kohdannut useita hankaluuksia, työntekijät pitivät laitteita hyödyllisinä minkä johdosta he uskoivat hankkeen onnistumiseen ongelmista huolimatta.

Avainsanat viivakooditeknologia, kannettava keräilylaite, sairaala-apteekki, terveydenhuollon tuotantotalous, jakelu, keräily, lääkitysturvallisuus, varastonhallinta, ICT-implementaatio

Glossary

ADE	Adverse Drug Event
APCS	Automated Pharmacy Carousel System
BCMA	Barcode-assisted medication administration
CAH	Critical-Access Hospital
EDA	Enterprise Digital Assistant, a hand-held device
EMAR	Electronic Medication Administration Record
Eksote	Hospital District of Southern Carelia
ERP	Enterprise Resource Planning
Fimea	Finnish Medicines Agency
HHP	Helsinki and Uusimaa Hospital District Hospital Pharmacy
HIT	Healthcare Information Technology
HUCH	Helsinki University Central Hospital
HUS	Helsinki and Uusimaa hospital district
ICU	Intense Care unit
LASA medications	Look-alike/Sound-alike medications
LMI	Lean Management Initiatives
PDA	Personal Digital Assistant
PEOU	Perceived Ease-of-Use
PU	Perceived Usefulness
RFID	Radio-frequency identification
SCM	Supply Chain Management
TAM	Technology Acceptance Model
TPB	Theory of Planned Behavior
TTK	Työturvallisuuskeskus, Center for Occupational Safety
UTAUT	Unified Theory of Acceptance and Use of Technology
Vnr	Nordic Article Number
QI	Quality Improvement

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1. Introduction

Hospital pharmacies supply hospital wards with their daily medication needs. Although the personnel in hospital pharmacies are not in direct contact with the patients, their role in medication safety is nonetheless important. With the steady increase in the number of available medications, the potential for medication errors has consequently increased (Kanse et al. 2006). By dispensing the correct medications to the hospital wards, the hospital pharmacy contributes to the overall medication safety of the hospital. However, human error is natural, which is why technology safeguards are commonly used in several industries. Likewise, technology is often harnessed in order to increase the productivity and efficiency of work. In this thesis I study the effects of implementing Electronic Digital Assistants (EDAs) in a hospital pharmacy environment, with special emphasis on their impact on work efficiency and medication safety. The empirical part of the study is undertaken in the HUS Hospital Pharmacy, located in Helsinki, Finland.

HUS Hospital Pharmacy (HHP) is responsible for delivering medication and related supplements to hospitals and other relevant actors in the Helsinki and Uusimaa hospital district (HUS). HUS covers 24 municipalities in Southern Finland and offers specialized healthcare to over 1.5 million people (HUS, 2014). In addition, Helsinki University Central Hospital (HUCH) that works as a part of HUS offers demanding and rare disease care to the whole Finnish population. The hospital pharmacy works as a central warehouse and a logistics hub for the surrounding hospitals, health centers and other institutions in the area, distinguishing its operating model from retail pharmacies that mainly serve consumers. In addition to medicine deliveries, the hospital pharmacy's responsibilities include manufacturing, compounding and preparing selected pharmaceuticals, patient-specific mechanical dose delivery service, clinical trials, research, and chemotherapeutical agents' laboratory services. The HUS Hospital Pharmacy has locations in Helsinki, Vantaa, Espoo, Hyvinkää, Lohja and Porvoo. In this thesis, the term "HUS Hospital Pharmacy" refers to the central warehouse in Meilahti, Helsinki.

1.1. Background

The concept of supply chain management (SCM) has recently gained ground in the field of healthcare as a tool of increasing productivity and efficiency and improving the quality of the operations (Lega et al. 2013). The aim of this study is to find out if the efficiency and quality (i.e. ensuring medication safety) of a warehouse order-picking process can be improved by introducing automation in the form of Enterprise Digital Assistants (EDAs). EDAs are handheld computers that are adapted for use within small and medium enterprises and enterprise business applications for data capturing use. They can be extended with e.g. barcode scanners, printer carry cases or RFID panel antennas (Bezboruah, 2010). Common uses for the EDAs are, for example, warehouse management and inventory control. Consequently, the academic discipline to which this study relates to is *warehouse management*, which is a key part of supply chain management and logistics (Figure 1).

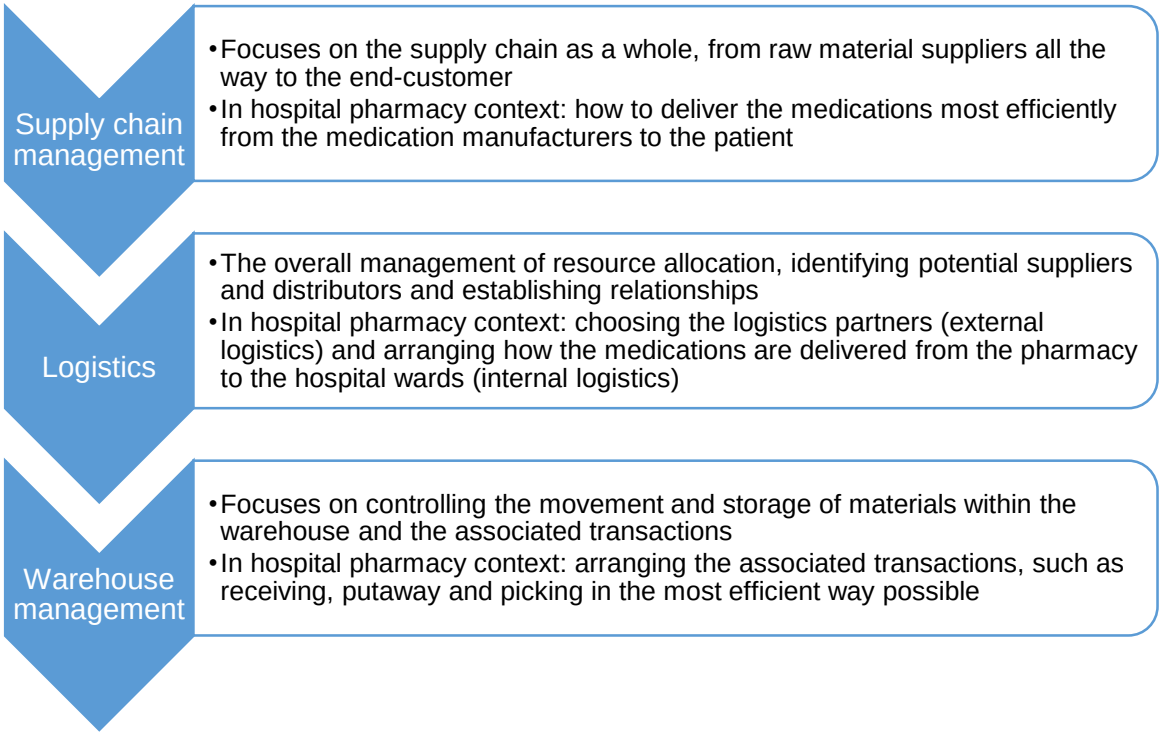

Figure 1 - Positioning the study within the academic discipline

In this study the daily operations of a hospital pharmacy are observed. However, the research setting may be applied to other similar warehouses as well. The use of EDAs has recently become more common in Finland, with a number of other hospital pharmacies, including

hospital pharmacies in KYS (Kuopio), Eksote (Lappeenranta), TAYS (Tampere) and TYKS (Turku), taking EDAs or similar devices into use. The proliferation of these types of devices calls for a comprehensive study on the factors that define the success of such an implementation.

The EDAs are handheld digital devices that are similar to Personal Digital Assistants (PDAs) used in many aspects of business in different companies. Their technical aspects are introduced in more detail in Appendix 4. In this thesis, efficiency relates to the amount of resources required to deliver medications to the customers of the hospital pharmacy. The order-picking process is labor-intensive, meaning that the associated costs consist mostly of wages of the order-picking staff. There are two points during which medication errors can occur in a hospital pharmacy: firstly, during *order-picking*, when the pharmacy employees pick the medications from the shelves. Although a considerable hindrance, an order-picking error is not a great concern if the error is noticed during the pharmaceutical inspection. In these kinds of occasions the incorrectly picked medications are simply replaced with correct ones by the pharmacist. However, if the incorrect medication slips past the pharmacist, a *dispensing error* is produced, which means that incorrect medications are sent to the hospital wards. To clarify this division, the following definitions are used in this thesis:

Order-picking error: A hospital pharmacy employee picks the wrong medication from the shelf

Dispensing error: An order-picking error goes unnoticed by the pharmacist and incorrect medication is sent to the hospital ward

Quality in hospital pharmacy operations relates to the accuracy of the order-picking process, and the number of dispensing errors that may in worst cases compromise patient safety. Figure 2 illustrates the role of dispensing errors as a component of patient safety:

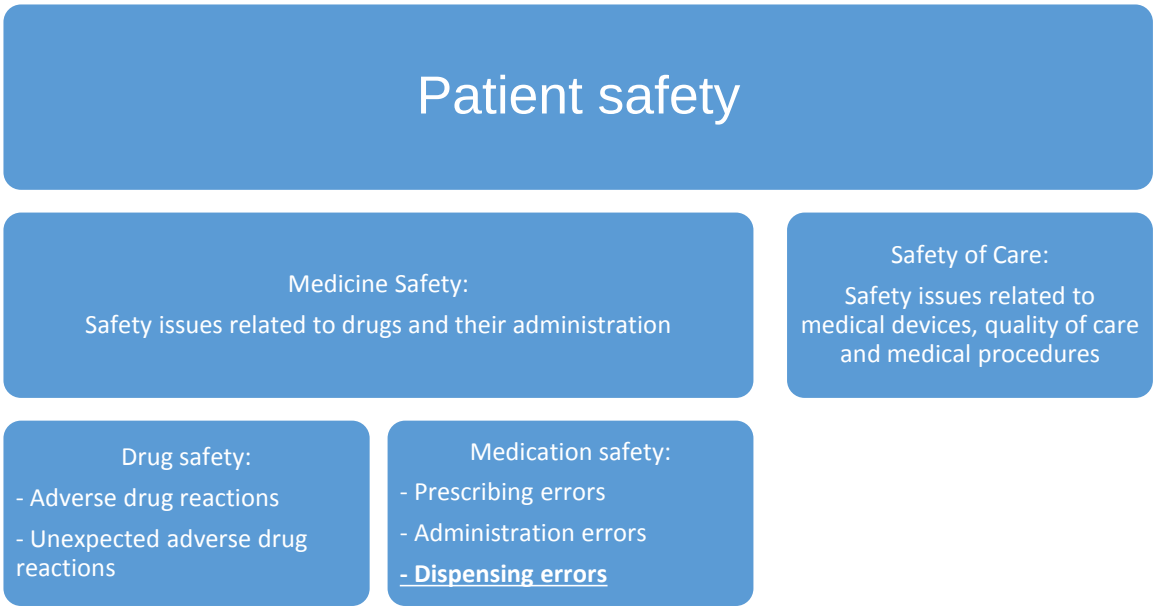

Figure 2 - Dispensing errors as a component of patient safety (modified from Stakes, 2006)

Reducing the number of medication errors and improving work efficiency in the hospital pharmacy are general problems addressed in academic literature. Previous research on the subject has been performed especially in the United States. Similar studies focusing on medication delivery in hospitals include for example those by Oswald & Caldwell (2007), Poon et al. (2006), DeYoung et al. (2009) and Samaranayake et al. (2014). Many previous studies focus solely on the quality and accuracy aspect, i.e. medication safety. A few previous studies that do address work efficiency in EDA-enabled order-picking operations include those by De Koster et al. (2007) on a general level and by James et al. (2013) in a hospital pharmacy setting.

Sakowski & Ketchel (2013) calculated the costs and benefits of introducing barcode technology in the medication supply chain. Furthermore, many studies focus on the Barcode-Assisted Medication Administration (BCMA) applications that consist of all the phases of medication administration, from the prescribing and dispensing phases all the way to the administration phase at the patient bedside. However, this study focuses more closely on the dispensing process that takes place within the hospital pharmacy to better explain the effects of introducing automation in that particular point in the supply chain. The major contribution of this study to the existing literature is to complement the research of the occurrence of medication errors in the hospital pharmacy by also measuring the effects of preventive technology on work efficiency and employee perceptions, i.e. by providing a synthesis of these three, previously separately discussed views.

1.2. Research questions

The goal of this thesis is to evaluate the effects of introducing EDAs in terms of improving efficiency and medication safety in an order-picking process. A case study will be performed in the Central HUS Hospital Pharmacy located in Meilahti, Helsinki. The following research questions are formulated to construct a meaningful approach to measure both the quantitative and qualitative aspects of the EDA implementation:

(1) *"How will the introduction of enterprise digital assistants affect the efficiency and medication safety of the order-picking operations at a hospital pharmacy warehouse?"*

(2) *"How will employee perceptions on the usefulness and the ease-of-use of the EDA implementation affect the perceived likelihood of success of the implementation project?"*

While the research questions are quite specific in nature, they can be linked to a broader academic discussion. Seeking improved quality and efficiency of operations is a common goal in the healthcare sector, as is implementing automation in various types of warehouses. Furthermore, there is ongoing discussion and research on automating the pharmaceutical inspection in hospital pharmacies performed by Fimea (Finnish medicines agency), to which this study can contribute.

1.3. Focus and limitations

Although the medication delivery chain reaches all the way from the drug manufacturers to the nurses administering the medications to the patients at their bedside, this study will focus only on the dispensing phase performed in the hospital pharmacy. Moreover, to determine how many of the dispensing errors actually lead to a patient taking the wrong medication, producing an adverse drug event (ADE), the full-time labor input of one or more ward pharmacists would be required. For these reasons I opt to study only the number of order-picking and dispensing errors and their indirect effect on medication safety.

Moreover, the empirical part of this study is performed during a preliminary test phase at the HHP. The EDAs are used to pick the orders of only a few of the customers, or hospital wards. The implementation project has faced a number of drawbacks regarding the software integration, as well as a number of hardware problems. Thus, the full-scale implementation of the EDAs has been postponed on several occasions also during the research process. It was also in the will of the case organization as well as the legislator (Fimea, Finnish Medicines Agency) that the EDAs are not yet taken into use with all of the daily orders before their effects have been adequately studied, which this thesis sets out to do.

Furthermore, a number of other factors may affect the efficiency and safety of the order-picking process. While environmental factors can be ruled out as the pre- and post-implementation research setting are the same, human factors such as staff motivation and attitudes towards the implementation project may change during a long research process.

1.4. Content and structure

In this thesis, Chapter 2 will include a review of previous literature on the effects of barcode-assisted medication administration on work efficiency and medication safety, as well as effects of barcode technology in different parts of the medication supply chain. The learnings from the previous literature will be used to develop a theoretical framework that will be used to answer the research questions. In Chapter 3, the research environment, as well as the structural effects of the EDA implementation on the medication dispensing process are presented in more detail. Chapter 4 will discuss the research process, data collection and methodology used to attain results and findings from the data. Chapter 5 will present the results of the data analysis and the findings from the questionnaire and interviews. Conclusions and managerial implications are presented in Chapter 6, as well as the limitations on the interpretability of the results of the study and avenues for future studies. Chapter 7 provides discussion on the results and additional observations made during the research process.

2. Literature review and theoretical framework

This chapter discusses academic literature covering the principles of supply chain management, quality improvement, logistics and warehouse management both on a general level and in healthcare organizations. The literature consists of articles discussing supply chain management, performance measurement, quality improvement, warehouse management, and change resistance in IT implementations, with most of the articles visiting these topics from the viewpoint of the health care industry in particular. Literature on medication safety and barcode-assisted medication administration will also be thoroughly reviewed.

First, previous literature on supply chain management is discussed to form a general idea of the principles that apply within the SCM discipline. Next, quality improvement in health care organizations will be studied, with special emphasis on Lean and Six Sigma projects. Existing studies on hospital pharmacy warehouse management covering the use of barcode technology will be visited to establish benchmarks for the results of the empirical part of this thesis. Lastly, previous literature on change management in IT implementations will be studied to include a more human-centered view to provide suggestions for the successful deployment of the EDA devices (for more information on the devices, see Appendix 4). To conclude, selected theories are used as a base of the theoretical and conceptual frameworks presented at the end of this chapter.

2.1. Supply chain management and performance measurement

Supply chain management and performance measurement are widely visited topics in academic literature (see e.g. Banomyong & Supatn 2011; Shepherd and Günter 2006; Swinehart & Smith 2005). One often cited article is by Neely et al. (1995), which defines performance measurement as "the process of quantifying action, where measurement is the process of quantification and action leads to performance". The terms efficiency and effectiveness are also defined in the article. Effectiveness is defined as "the extent to which customer requirements are met", whereas efficiency is "a measure of how economically the firm's resources are utilized when

providing a given level of customer satisfaction." In the context of a central hospital pharmacy, customers are the surrounding hospitals and individual wards where medications are delivered. Thus, customers are mostly internal, in a sense that they all represent the same hospital district. A hospital pharmacy's resources consist of its facilities, staff and equipment. The economical use of these resources while meeting customer requirements in a satisfactory way leads to a high level of efficiency. Meeting customer requirements, or the goal of effectiveness, means supplying the medicine according to the five rights of medicine administration: the right patient, the right drug, the right dose, the right route, and the right time (Smaling & Holt 2005). In other words, effectiveness equals patient safety, which is the measure of quality for a hospital pharmacy's operations.

According to Banomyong & Supatn (2011), supply chain management addresses long-term strategic alliances, supplier-buyer partnerships, cross-organizational logistics management, joint planning, control of inventory, and information sharing. Shepherd and Günter (2006) state that understanding supply chain performance can help improve business capability by enhancing understanding and cooperation between supply chain members. Moreover, Shepherd and Günter (2006) identify cost, quality and time as the most common measures of supply chain performance in academic literature. These measures apply well to the case organization, HUS Hospital Pharmacy, whose operational goals are providing the hospital wards with the correct medication on time and with as low costs as possible while maintaining sufficient service levels. In order to achieve these goals, the hospital pharmacy has to share information and plan the medication assortment in co-operation with their partners, i.e. the hospital wards and the medication suppliers. Also, they have to be constantly scrutinizing their internal supply chain to locate work phases where efficiency could be improved in collaboration with their partners.

Manzini et al. (2005) discuss Order-Picking Systems (OPS) in their article. They divide OPS in two categories: Picker to part OPS and Part to picker OPS. In Picker to part OPS, the order-picking personnel have to move between the warehouse shelves to pick the products. In Part to picker OPS, there is an automatized system that does the picking. Thus, the enterprise digital assistants represent a Picker to part OPS; an example of a Part to picker OPS would be a fully automated warehouse robot or a carousel. De Koster et al. (2007) conclude in their literature review that even though picker-to-parts OPS are far more common in practice, they have received less research attention compared to Parts to picker OPS – a research gap that this study sets out to cover.

2.2. Health care supply chain management and logistics

In the healthcare sector, supply chains normally consist of raw material suppliers, manufacturing companies, wholesalers, retailers (the hospitals) and consumers (the patients) (Kim 2005, see Figure 3.) The same supply chain structure applies for the medication industry, the manufacturers being pharmaceutical companies and the retailers being both hospital pharmacies and retail pharmacies with wholesalers working in between the manufacturers and the retailers. In this thesis, the focus is on the internal logistics and warehouse management within the hospital pharmacy warehouse, and the effects of those logistics on patient safety (the two actors on the far-right of Figure 3).

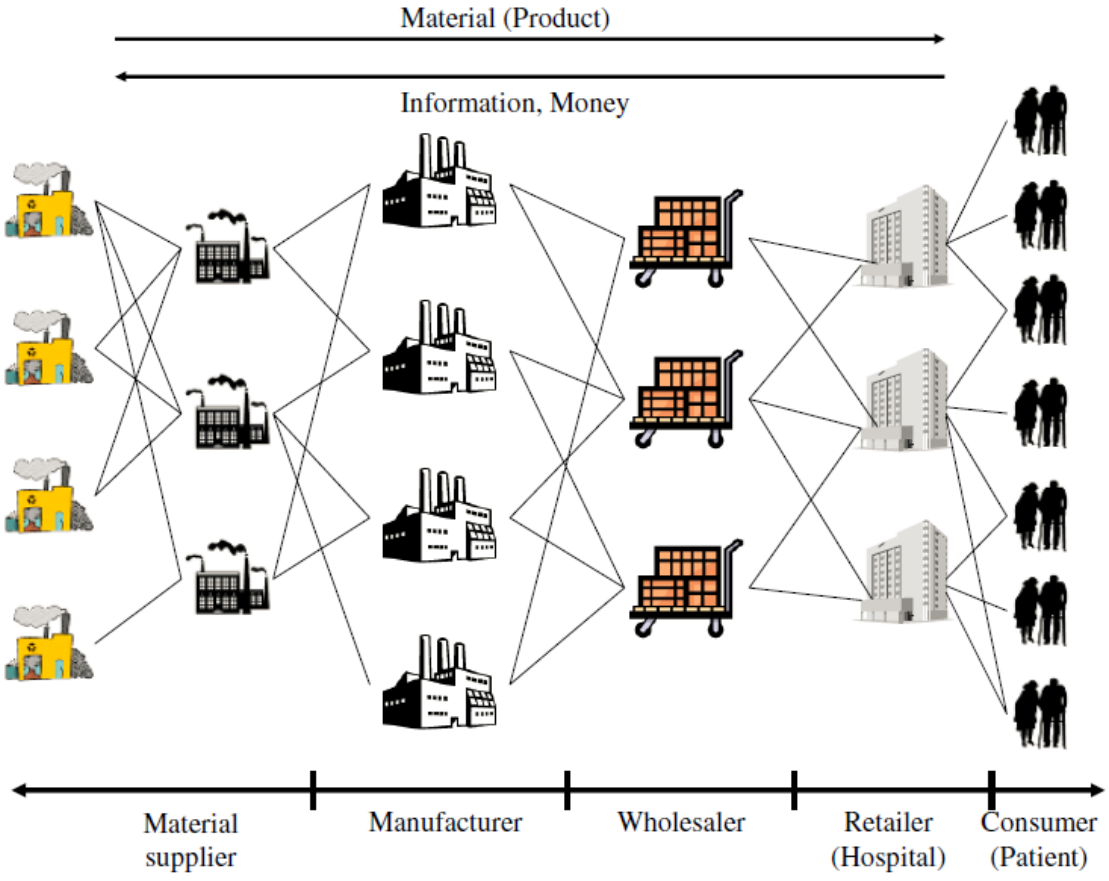

Figure 3 - Composition of the healthcare supply chain network (Kim, 2005)

Serafim et al. (2010) state that hospital units have high and increasing operational expenses that cause constant pressure for increased quality and productivity without increased costs. Logistics

planning, especially in the pharmacy, is fundamental to guaranteeing the supply of medicines and therefore it is imperative to use a rational system for the distribution of medications. According to Lega et al. (2013), there is pressure to improve the performance of public services, which is one of the reasons to the recent rise of supply chain management in the public healthcare sector. Two key supply chain processes – purchasing and logistics – are economically significant and considered to be of paramount importance to the improvement of healthcare organization performance. Swinehart and Smith (2005) state that as passing increased costs to the external customers is no longer a viable solution in the health care industry, cost control becomes a practical strategy to maintain competitiveness. Consequently, improving internal customer relationships and interactions to increase efficiency and satisfaction and to reduce redundancy, as well as making the relationships more economical, can be considered a notable tool in cost reduction efforts.

Runy (2008) states that health care organizations typically have a twofold purpose when automating the pharmacy. Firstly, improving the medication administration process to eliminate errors to improve patient safety. Secondly, streamlining the supply chain to enhance efficiency and achieve cost-savings. Patient safety can thus be seen as a measure of quality for a hospital pharmacy (see Figure 2).

As in many other industries, there may exist a contradiction between maximizing quality and cutting down costs. Patient safety can only be improved within the limits of a hospital's budget. Therefore, it's important to identify the investments that have the best yield in terms of patient safety and costs. However, it may also be possible to find investments that improve both effectiveness and efficiency simultaneously (Banomyong & Supatn, 2011). In the case of a hospital pharmacy, this would mean improving patient safety while decreasing costs at the same time. In this study, the assumption is made that increased efficiency leads to decreased costs in the long run, as less resources are required to perform the same amount of work.

According to a questionnaire study by Baker & Halim (2007), companies believe that automation can meet both cost and service requirements, given the correct circumstances. They discovered that the most common reasons for introducing automation in a warehouse are (in the following order): accommodating growth, reducing operating costs, improving customer service, reducing staffing levels, consolidating inventories, improving accuracy, increasing stock rotation and improving image. Most of these goals correspond to HHP's current situation well. The hospital pharmacy has faced considerable growth in the number of order lines in the

previous year, as is pointed out by the 18% growth in order quantities after the shutting down of Töölö hospital pharmacy and integrating its operations to the Meilahti pharmacy (Figure 4). Reducing operating costs is also a current goal at any public institution, but it should not be pursued at the cost of work quality. This is something that automation aims to help with. Although most of HHP's customers are internal, it is important to maintain and try to improve customer service levels. Improving order-picking accuracy would mean – in addition to improving patient safety – that the hospital pharmacy could better serve their customers by providing them with the correct medications they have ordered.

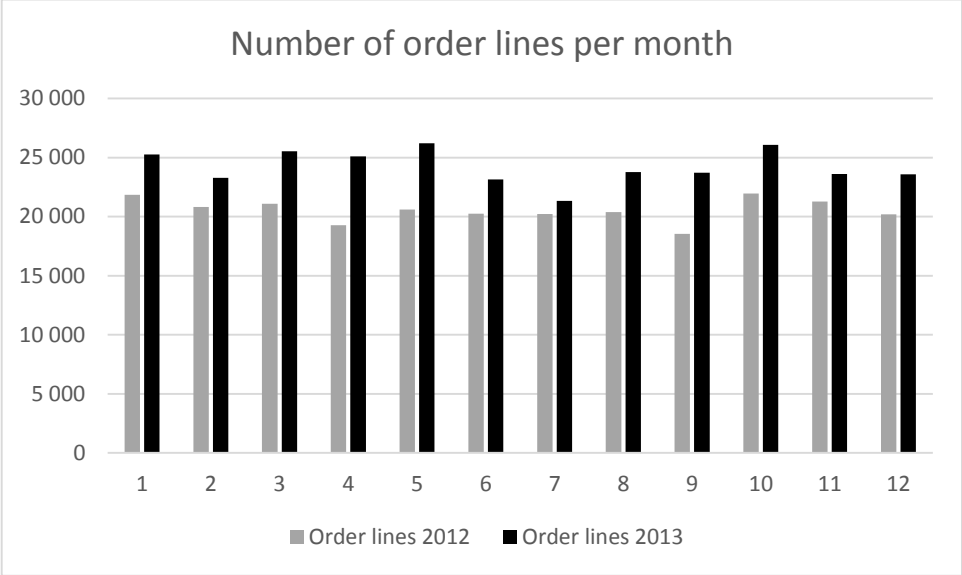

Figure 4 - Order quantities per month, 2012 - 2013

2.3. Quality Improvement and Six Sigma in the hospital pharmacy

Reducing process variability and standardizing outcomes with the help of statistical methods has been popular in operations management for decades. According to DelliFraine et al. (2010), even though evidence-based management has been popular in manufacturing for some time already, it is still an evolving practice in healthcare. The authors state that evidence-based management is especially important in the area of Quality Improvement (QI) to improve quality of care. Out of the myriad of tools affiliated with QI, the authors state that Six Sigma and Lean are particularly popular.

Six Sigma is an improvement concept that focuses on the reduction of errors by establishing coherent measures for quality. Statistical and empirical methods, specific project methodologies (such as DMAIC – Define, Measure, Analyze, Improve, Control) and a special infrastructure of people within the organization (quality "champions", "black, yellow and green belts") are commonly used drivers to reach the quality goals of a Six Sigma project.

The origin of Six Sigma is derived from previous quality schemes in which a process was considered to produce quality results if 99.74% (+- three sigma) of the products' (or services') attributes were within specification limits. However, for certain industries, such as the pharmaceutical industry, such standards are unacceptable, as this would signify 2 600 out of every 1 000 000 medications to be defective. Adopting Six Sigma raises the standard of quality to 99.99966%, or 3.4 defective medications out of 1 000 000 (Revere et al. 2004.) In industry segments like hospital pharmacy where errors may incur additional costs through e.g. prolonged patient episodes, reducing the number of errors could lead to cost savings for the hospital. For example, in a study by Tyynismaa et al. (2013), it was estimated that medication errors in total amount to at least €1.8 million in additional costs in the HUS region. The standard measure for calculating the sigma level is defects per million opportunities (DPMO), which is calculated with the following formula:

$$DPMO = \frac{1\,000\,000 * Number\ of\ defects}{Number\ of\ opportunities * Number\ of\ units}$$

Where the number of opportunities is everything that could be wrong with the product that is also important to the customers, and the number of units is the number of dispensed medications. Consequently, the dispensing error rate is a component of the DPMO formula:

$$Dispensing\ error\ rate = \frac{Number\ of\ dispensing\ errors}{Number\ of\ dispensed\ medications}$$

Calculating DPMO for the medication dispensing process is difficult as there are various different classifications for the number of opportunities in previous studies. For example, Poon et al. (2006) identified 4 different types of *target dispensing errors* which the BCMA implementation under study could have effect on; Revere & Black (2003) also identified 4 different types of dispensing errors; Tyynismaa et al. (2013) identified 10 different types of dispensing errors in their study based on self-reporting medication errors in HUS; Cheung et al. (2009) identified 12 different categories of dispensing errors based on previous studies with the addition of three categories of their own. The different categorizations vary in regards to

the level of granularity that dispensing errors are identified on, as well as in regards to the view of who is responsible for dispensing errors. For example, Cheung et al. (2009) identified "Wrong dosage form" and "Wrong drug strength" as separate error categories, whereas Poon et al. (2006) identified "Wrong dosage/strength" as only one type of error. Moreover, Cheung et al. (2009) included error categories such as "incorrectly compounded medicine" (compounding in pharmacy), "medicine of inferior quality" (pharmaceutical companies) and "dispensing with the wrong verbal information to the patient or representative" (which is the responsibility of the ward staff) in their classification. To conclude, the same percentage of dispensing errors might produce different DPMO measures depending on the categorization of different errors.

Revere et al. (2004) studied Six Sigma levels in various aspects of healthcare services in the US. Examples of the various estimates include the use of beta blockers (sigma level of 1.0, or 691 600 DPMO), identifying and treating depression (sigma level of 2.0, or 308 538 DPMO), antibiotics misuse (sigma level of 3.0, or 66 800 DPMO), and treatment of injuries (sigma level of 4.0, or 6 200 DPMO). Needless to say, these numbers are by no means sufficient. The authors consequently suggest that many areas of patient care could benefit from the process improvement outcomes achievable by introducing Six Sigma.

In their previous study, Revere & Black (2003) studied six sigma levels of medication errors. Their results showed that medication errors have a lower error rate compared to other healthcare services: 439 DPMO for prescribing medication (sigma level of 4.7), 70 DPMO for dispensing medication (sigma level of 5.4) and as low as 28 DPMO for administering medications (sigma level of 5.5). However, as stated previously, it has to be kept in mind that the DPMO measures and the consequent Sigma levels depend on the classification of medication errors, i.e. how many different types of errors are defined. Consequently, it is not viable to compare Sigma levels attained as results from different studies.

Esimai (2005) developed Lean error reduction solutions by combining Lean and Six Sigma techniques in the error reduction process of an anonymous mid-sized US hospital. Lean methods aim at identifying and incrementally reducing waste in the process, in this case in the form of medication errors. The process under scrutiny was the medication administration process consisting of the medication order entry and the related logistics and communication between the hospital pharmacists and the nurses in the hospital wards. In total, the project team identified 10 different kinds of error types: additional instructions, wrong dose, wrong drug,

duplicate order entry, discrepancies in medication order frequency, omissions, discontinuation order not carried out when received, order not received, wrong patient and wrong route (e.g. intravenous vs. intramuscular). The problems related to the process were then thoroughly analyzed and the process was consequently re-designed to fix these problems. The error reduction solutions included the institution of a high performance standard through instruction and supervision, facility-wide implementation of computerized physician order management (as opposed to faxing the orders), installation of a system to separate the fax and phone lines as an interim to reduce the faxing problems, unit based pharmacists and agreement on standard times of medication administration among hospital nurses and pharmacists, monthly meetings to foster better relationships between the two parties, and the designation of a pharmacy employee to serve as a telephone operator for all external calls.

With these process re-organization measures, the hospital was able to decrease the occurrence of all of the error types, reducing the total number of errors by 55% (from 0.33% to 0.14%) in five months. Even though the scope of the project was different than that of this study and thus the results are not comparable, it provides good insight on how Lean projects can be implemented to reduce medication errors. In another study by Gowen et al. (2012), it was also found that the use of Lean Management Initiatives (LMI) is effective for improving patient safety results.

2.4. Medication safety and barcode-assisted medication dispensing and administration

This chapter will present previous literature on barcode-assisted pharmacy automation and its effects on medication safety. The results from previous studies presented in this chapter will be used to reflect on the empirical part of this study. Since barcode-assisted medication administration has been used for nearly two decades in the US, a large number of related literature can be found. However, automation projects focusing only on dispensing applications were found to be rare – a research gap that this study sets out to fill.

2.4.1. Occurrence of medication errors

Serafim et al. (2010) state that dispensing medications has a considerable impact on the management of the hospital pharmacy, and that the choice of a medication distribution system should be based on the structural and assistential profile of the hospital pharmacy to guarantee an efficient, effective, economic and safe supply of medications. Delivering medications to patients is a process consisting of three major phases: (1) practitioner ordering or prescribing; (2) dispensing, including order verification and drug packaging by a pharmacist; and (3) medication administration, including monitoring for therapeutic and undesirable effects (Wulff et al. 2011). Correspondingly, medication errors consist of (1) prescription errors; (2) dispensing errors; and (3) administration errors. Due to factors such as data availability and time restrictions, the empirical part of this thesis will focus solely on the second phase of the process, i.e. medication dispensing that takes place within the hospital pharmacy. Nevertheless, to attain a systematic view of all of the factors that contribute to medication safety, this theoretical part will also cover literature regarding other phases of the supply chain of the medication delivery process. Through broader understanding of the whole medication delivery process, further suggestions can be made to improve medication safety and prevent prescribing, dispensing and administration errors.

The medication process today is an ever more important target for safety measures due to the steady increase in the number of available medications and the subsequent increased potential of medication errors (Kanse et al. 2006). The steady increase in the number of available medications has been likely to add to the number of LASA ("look-alike and sound-alike") medicines. Approximately 25% of medication errors have been contributed to orthographic (look-alike) and phonetic (sound-alike) similarity between drug names and confusable packaging (Emmerton & Rizk, 2012). As LASA medicines are a major contributor to dispensing errors, the authors propose that the introduction of barcode scanners, along with other technological applications such as automated alerts, could offer a solution to the problem if applied correctly.

Estimates on which part of the medication supply chain errors occur most often vary slightly between different studies. According to a study by Yang et al. (2002) 39% of Adverse Drug Events (ADEs) occur during ordering, 38% during medication administration and 13% during transcription and dispensing. Revere & Black (2003) calculated Six Sigma levels of the

medication dispensing process with the assumption that approximately 35% of all medication errors are the result of prescribing errors, approximately 30% are caused by dispensing errors, and another 35% by administration errors. In a more recent study by Samaranayake et al. (2012), results showed that 53.4% of medication errors occurred during prescribing, 29.0% during administration, and 17.6% during dispensing. The authors used a 'Swiss Cheese Model' to study the interception of medication errors during the medication supply chain. Although the Swiss Cheese Model is not as specific as root cause analysis or failure mode effect analysis, the authors argue that it is a simple and useful generic tool to understand the magnitude of a problem before embarking on more detailed analysis. The model is used to recognize problems in systems that are caused by errors that are aligned in different layers of the system. To prevent these problems, the defensive layers have to be designed so that no errors can pass through the whole system. The defensive layers refer to the prescribers in the prescribing stage, pharmacy staff at the drug dispensing stage and nurses at the drug administration stage. In addition to the staff members, different technologies at their disposal, such as barcode-readers, can be seen as assistive defensive layers. Consequently, it can be concluded that in previous academic literature there exists no uniform view on how much each part of the medication delivery process contributes to the occurrence of medication errors.

According to a systematic review by Keers et al. (2013), error-provoking conditions influencing administration errors include: inadequate written communication, problems with medicines' supply and storage (including pharmacy dispensing errors), high perceived workload, problems with equipment, patient factors, staff health status (fatigue, stress), and interruptions/distractions during drug administration. The pharmacy department contributed to errors and violations through delayed deliveries, incorrect dispensing, and unavailable stock. Ashcroft et al. (2004) identified errors related to drug selection in 35 community pharmacies in the UK. Causes for identified near-miss (any incident that was detected up to and including the point at which the medication was handed over to the patient) and dispensing errors (incidents that were detected after the patient had acquired the medication – note the different definition from the one used in this study) included: similar drug name, packaging, picking the next medicine in shelf, medicines misplaced in the shelf, busyness, staffing and distractions (such as telephone interruption or staff query). In other words, the results were consistent with those presented by Emmerton & Rizk (2012). The authors state that many of the observed problems involved selecting products with similar drug names or similar packaging without the help of

barcode technology, and that introducing such technology could help reduce the level of dispensing errors.

Cochran et al. (2013) concluded in their study of 9 rural US hospitals that pharmacists and bedside barcode systems are important safety systems used by these hospitals. Medication error rates were lower in critical access hospitals (CAHs) with more onsite pharmacy support. They also noted that medication errors occurred less frequently in small hospitals (1.0% of all dispensed medicine) compared to studies undertaken in larger hospitals (that reported median error rates ranging between 8% and 19%), even though smaller CAHs lack technology, quality-improvement resources and regulatory drivers. The authors contributed the results to differences in patient acuity, less complex medication regimen, lower patient:nurse ratios (2.5 compared to 4.7 – 7.2 in larger hospitals) and smaller number of interruptions and distractions. Wrong-time errors were notably fewer in smaller hospitals, likely due to shorter delivery times between the medication room and the patient areas. A conclusion can be derived from the results that the implementation of barcode systems is a more acute solution in large hospitals rather than small ones.

2.4.2. Barcode-assisted medication administration (BCMA) systems

Barcode-assisted medication administration (BCMA) systems are Health Information Technology (HIT) applications. BCMA systems consist of barcode readers, portable or desktop computers, software, and a wireless network to link the different components. These kind of medication administration technologies are designed to reduce errors and ADEs by improving adherences to the five rights of medicine administration in all of the three phases of delivering medication to patients (Smaling & Holt 2005). The five rights of medicine administration (the right patient, the right drug, the right dose, the right route, and the right time), have since been added with two more rights: the right reason and the right documentation (Schaeffer, 2009). To improve adherences to the aforementioned rights, BCMA technology aims to decrease e.g. the following error types: unauthorized drug, wrong form, wrong dose, wrong route, extra dose, and omission (Helmons et al. 2009).

As of 2006, the US Food and Drug Administration has mandated bar-coding of most medications used in all of the hospitals in the country (Poon et al. 2005). The impact of BCMA and electronic medication administration records (EMAR) have been widely studied by direct-observation techniques and have shown a positive impact in reducing medication errors (e.g. Paoletti et al. 2007, DeYoung et al. 2009). Moreover, in a study by Pedersen et al. (2012), estimates showed that 33.9% of all hospitals in the US use machine-readable coding in the inpatient pharmacy to verify doses before dispensing (with or without a dispensing robot). The practice is considerably more common in larger hospitals compared to smaller ones (see Appendix 2). Fimea, the corresponding legislator in Finland, has not yet mandated bar-coding medications, which might have mitigated the diffusion of bar-code technology among Finnish hospital pharmacies.

2.4.3. Dispensing errors and barcode-assisted systems in the hospital pharmacy

Most of the aforementioned BCMA studies cover the whole medication supply chain in the hospital, from dispensing in the pharmacy to administration in the hospital wards. When considering the whole medication supply chain, the role of medication administration performed by nurses is most significant and most often studied from the viewpoint of medication safety (Keers et al. 2013). However, the empirical part of this thesis focuses more on the previously less-studied dispensing phase of the medication delivery process, where the baseline error rate is often lower. Nevertheless, due to the large volumes processed in the hospital pharmacy, the total number of dispensing errors is still a considerable issue for medication safety (Cheung et al. 2009).

In an early questionnaire study by Schumock et al. (2003), 26.8% of US pharmacies had implemented, and 25% were planning on implementing, PDAs (personal digital assistants or enterprise digital assistants) used by pharmacists for drug information and clinical documentation. Out of the respondents that reported that they had PDAs in use, 40% saw that the occurrence of medication errors had decreased after the implementation whereas another 40% saw that there was no change in the occurrence of medication errors. 20% of the respondents were not sure. In comparison with other medication safety technologies, such as

robots and electronic medication administration records, PDAs were seen to have the least effect on medication safety. However, the results of the study are solely based on the attitudes and perceptions of hospital pharmacy managers. No data were provided regarding the true effect of each of the technologies on medication errors.

Poon et al. (2006) studied the impact of barcode technology on medication dispensing errors and potential adverse drug events (ADEs) in the same hospital as Maviglia et al. (2007) performed cost-and-benefit calculations a year later, Brigham and Women's Hospital in Boston, MA. As currently in the HUS Hospital Pharmacy in Helsinki, the selection of medication (order-picking) and verification of accuracy (pharmaceutical inspection) were performed manually by the pharmacy staff before the deployment of barcode technology. After the deployment, each dose was bar-coded and electronically scanned to verify its accuracy, as is planned in HHP. There were three different technological configurations: one with carousel fill (machine-directed retrieval) and two with manual retrieval (one where 1 dose per batch was scanned and another where each dose was scanned on retrieval, when applicable). The authors defined *target dispensing errors* as dispensing errors that the bar code technology was specifically designed to address. Some errors, such as dispensing incorrect quantity or neglecting "do not refrigerate" labels, were not considered a target for bar code technology implementation. A similar classification was used also by Seibert et al. (2014). The following errors were considered target dispensing errors:

- Wrong medication (e.g. intravenous nafcillin was ordered, but intravenous vancomycin was dispensed)
- Wrong dose/strength (e.g. 25mg of metoprolol was ordered, but 50mg of metoprolol was dispensed)
- Wrong formulation (e.g. 25 mg of long-acting metoprolol was ordered, but 25 mg of short-acting metoprolol was dispensed)
- Expired medication

Additional error categories were introduced by Cheung et al. (2009):

- Wrong patient
- Wrong time (the medication was dispensed too early or too late)
- Omission (i.e. failure to dispense, excluding instances where the medication is out of stock)

- Incorrectly compounded medicine (relates to compounding performed in the hospital pharmacy)
- Dispensing with the wrong information on the label (e.g. instruction, patient name, quantity, warnings)
- Dispensing with the wrong verbal information to the patient or representative

Out of the aforementioned error types, only three could be observed and recorded in this study: wrong medication, wrong dose/strength and omission. The rest of the error categories were not inspected in this study as they were not considered relevant; the compounding performed in the hospital pharmacy as well as labeling the medications at the medication suppliers' premises, which could lead to the other errors, fall outside the scope of this study.

In Brigham, each dispensing error was further reviewed to determine whether it represented a potential ADE, and if so, the severity of the ADE (significant, serious, life-threatening). The 735-bed hospital with 6 million doses of medication dispensed per year managed to reduce the rate of *target dispensing errors* by a notable 85% from 0.37% pre-implementation to 0.06% (chi-squared test, $p<0.0001$), while the rate of all dispensing errors was reduced by 36% from 0.88% to 0.57% (chi-squared test, $p<0.0001$). Moreover, the number of *target potential ADEs* was reduced by 74% from 0.17% to 0.04%, while the rate of all potential ADEs was decreased by 63% from 0.19% to 0.069% (chi-squared test, $p<0.0001$). This summed up to 13,000 dispensing errors and 6,000 potential ADEs avoided per year. (Poon et al. 2005.)

Oswald & Caldwell (2007) studied the effects of introducing an automated pharmacy carousel system (APCS) on filling and dispensing errors in the hospital pharmacy. The study was conducted in a 613-bed acute and tertiary care university hospital. A pre- and post-implementation direct observational study was performed during 2004 and 2005. Although the APCS uses barcoding as a way of identifying the medication, the level of automation is higher compared to the Enterprise Digital Assistants implemented in HHP. Even though the results of the study show a decrease in dispensing errors after the implementation of the APCS (0.4% before implementation, 0.3% post implementation), it has to be noted that because of the evaluative nature of the study and the low baseline dispensing error rate (4 dispensing errors out of 1 112 orders observed) statistical analysis was not performed.

The following table sums up the results of previous studies that can be used to benchmark the results of the empirical part of this thesis. The most interesting results are presented in the last column, "Dispensing errors Without/With BCMA", as preventing dispensing errors is within

the scope of this thesis. Medication errors related to the rest of the medication delivery chain, i.e. prescribing and administration errors, are presented to provide insights on the possible improvements that could be achieved with a larger-scale automation project. The one study that stands out where dispensing errors increased after a BCMA implementation (Samaranayake et al. 2014) will be examined in closer detail.

STUDY	All Medication errors Without/With BCMA	ADEs Without/With BCMA	**Dispensing errors** Without/With BCMA
Ashcroft et al. (2004)*	N/A	0.02% / N/A	0.26% / N/A
Poon et al. (2005 & 2006)	N/A	0.19% / 0.07%	0.88% / 0.57%
Oswald & Caldwell (2007)	N/A	N/A	0.04% / 0.03%
Paoletti et al. (2007)	1.6 – 6.3% / 1.6 – 2.9%	N/A	N/A
DeYoung et al. (2009)	19.7% / 8.7%	N/A	N/A
Helmons et al. (2009)	8% - 10.7% / varying levels of improvement up to 58%**	N/A	N/A
James et al. (2013)	N/A	N/A	0.64% / 0.28%
Cochran et al. (2013)	1.49% - 3.27% / 0.53%	0.81% - 3.07% / 0.35%	N/A
Sakowski & Ketchel (2013)	1.1% improvement	0.01% improvement	N/A
Samaranayake et al. (2014)	N/A	N/A	0.4% / 3.20%
Eksote (2014)	N/A	N/A	N/A / 0.23%
This study (2015)	N/A	N/A	STUDIED

* Ashcroft et al. studied community pharmacies, whereas other studies focused on hospital pharmacies

** Helmons et al. reported up to 58% improvement in medication errors excluding wrong-time errors in medical-surgical units. On the contrary, medication errors increased in an ICU setting

Table 1 - Previous research on medication errors and effects of BCMA

As can be seen from Table 1, there is notable variability between the reported error rates in previous studies. This could partly be contributed to the differences in the categorization of medication errors, as pointed out in Chapter 2.3. Thus, one has to be skeptical about these results and try to understand what the true causes behind each outcome are. DeYoung et al. (2009) attribute variability in error-reduction results mostly to the error-detection method used (i.e. direct observation versus voluntary reporting or medical chart review). Of these error-detection methods, direct observation is considered more accurate than voluntary reporting (Flynn et al. 2002). Whether the errors are reported as proportion of all dispensed medication doses or patient-days may also cause variation in the results, as well as the patient population evaluated (e.g. medical, surgical, elderly or pediatric patients). The definitions of preventable/non-preventable medication error and/or (potential) adverse drug events may also cause differences in the reported results. Moreover, the hospital ward where the implementation takes place may have significant effect on the results of the BCMA implementation, as can be noted e.g. in the study by Helmons et al. (2009). Most studies focused on the medication administration part of the process that takes place in the hospital wards when the nurses give the medication to the patient. This part is most critical in a sense that it is the final phase in which a medication error may be noticed and potential risk to health may be prevented before the patient consumes the medicine. In the medication administration phase of the process, a bar-coded bracelet may be used to ensure that the correct patient receives the correct medication.

However, not many studies focus on the dispensing phase of the medication delivery process. The most significant studies from the medication dispensing viewpoint are the ones by Poon et al. (2005 & 2006), as well as the literature review by James et al. (2009). As previously stated, the empirical part of this study will focus on the effects of BCMA implementation on medication errors and work efficiency within the hospital pharmacy warehouse, i.e. barcode-assisted technology implementation that aims to prevent dispensing errors.

2.4.4. Costs and benefits of BCMA

Sakowski & Ketchel (2013) calculated the costs associated with implementing and operating a BCMA system in a community hospital setting and estimated the costs and savings per harmful error prevented. Costs of implementing a BCMA system included direct expenditures on capital, infrastructure, additional personnel, and the opportunity costs of time for existing

personnel working on the project (see Appendix 1). The costs were calculated based on BCMA implementation projects in 4 different sites in the US. The average cost for a 5-year project was $40 000 (range: $35 600 to $54 600) per BCMA-enabled bed. The improvement in drug safety resulted in a 1.1% increase in identification & interception of medication errors, 9% of which could have resulted in lasting harm. Consequently, the cost per adverse drug event (ADE) prevented averaged $2 000 (range: $1 800 to $2 600). When compared to estimates of the cost of one preventable realized ADE for the hospital (range: $3 100 to $7 400), the authors conclude that the BCMA investments in the hospitals subject to study were not only effective, but also financially justifiable.

Similar results were produced by a study by Maviglia et al. (2007), who calculated the total costs and savings of a BCMA implementation project undertaken in a 735-bed tertiary academic nonprofit medical center, Brigham and Women's Hospital in Boston, MA in the US. The total cost of the implementation during 5 years were $2.24 million in inflation- and time value-adjusted 2005 dollars, consisting of $1.31 million in 1-time capital investment and $342 000 in annual recurring costs. The study showed that 517 ADEs were averted annually post-implementation, corresponding to savings of $2.2 million annually. The system became fully active in year 3, accruing a cumulative benefit of $5.73 million during the 5-year period. The net benefit throughout the 5-year period was $3.49 million to the hospital, and the break-even point for return on investment occurring during the first year of operation. Furthermore, one-way sensitivity analyses were performed that showed little sensitivity to cost inputs. Two-way sensitivity analyses revealed some sensitivity by the primary and secondary outcomes to the assumptions that went into calculating benefits, such as the average savings from an averted potential ADE and prospective payment rates. Nevertheless, most 2-way analysis scenarios showed that the bar coding still eventually paid itself off by year 10 in the latest.

2.5. Barcode technology implementation barriers, limitations and risks

Even though the aforementioned results by Poon et al. (2006) are impressive, it has to be noted that the most improvement was achieved due to the automated retrieval carousel fill and the two-day fill, where less commonly used medications were retrieved by hand and all doses

retrieved in the process had to be scanned. In the alternate zone fill (the configuration most resembling the one planned in HHP), where medication doses were manually stocked and retrieved and only one dose per batch was scanned, the rate of dispensing errors decreased by only 60%, whereas the rate of potential ADEs increased 2.4-fold, of which the rate of life-threatening ADEs increased 2.8-fold. These results can be considered alarming from HHP's point of view, as they may be attributed to overreliance on technology. Moreover, the authors speculate that errors may occur from medications being mixed up on the stocking shelves because stocking did not require scanning.

2.5.1. Human barriers and risks

Other studies also support the claim that overreliance on computer systems may weaken human vigilance, "relocating" human factor problems rather than obviating them (e.g. McDonald 2006, Emmerton & Rizk 2012). Additional issues in the process included manually bypassing the barcodes that were difficult to read and mixing up medications after scanning if dealing with more than one medication at a time (Poon et al. 2006.) Similar observations were reported by Nanji et al. (2009) and Wulff et al. (2011): practitioners and pharmacy personnel frequently employed overrides to bypass rigid administration time limits and other restrictions imposed by the system, which negated the safety feature and increased the likelihood of medication errors. In a broad study by Koppel et al. (2008), 15 types of workarounds were found for 31 types of causes related to the technology, organization, tasks, patients and the environment.

In a recent study, Samaranayake et al. (2014) also attributed some of the decreased quality of the process to workflow changes, socio-technical and technical issues encountered by the pharmacy staff. A questionnaire and individual interviews were performed to analyze these changes. Among the interviewees, some of the nursing staff did believe that a stand-alone BCMA system could improve patient safety, however, most of them viewed that the drug administration process was slower when using it. Some also perceived an increase in the workload and work difficulty. The pharmacy staff also thought that the process was more difficult post-implementation. Moreover, only half of the pharmacy personnel considered the system to improve the safety of the drug dispensing process. While some participants reasoned that dispensing errors reduced as a result of more rigorous checking, others thought that the system didn't benefit the dispensing process without the support of computerized prescribing.

Similar observations were made by Ash et al. (2004), who state that errors can stem from situations where already heavily burdened professionals are faced with additional work tasks imposed by technology.

Staff resistance may also pose a prominent barrier. Resistance can be driven by three main factors: communication issues, changing roles, and negative perceptions about technology, as Nanji et al. (2009) noted in their study. The issue that the pharmacy staff had regarding communication was that they felt that they were led to believe that the new system would make their work a lot easier, when it in fact involved a lot of extra effort especially during the initiation phase. The authors state that clear and honest communication regarding the expected workload should be carried out to mitigate misunderstandings and the resulting staff resistance. Changing roles within the pharmacy were another issue that instigated staff resistance. The authors mentioned for example that the scanning system "eliminated the pharmacists' need to spend a significant proportion of time double-checking drugs that were manually dispensed" – a work phase that has been equally planned to be eliminated in the HUS Hospital Pharmacy. In the case report presented by Nanji et al. (2009) this problem was overcome by identifying champions – well-respected members of the staff who would show example to their colleagues and remind them of the benefits of the system in the bigger picture. Moreover, staff resistance was caused by negative perceptions about the technology. The authors identified three main negative perceptions through the interviews: overdependence on technology, potential for harm, and concerns about increased performance monitoring. They also state that the negative perceptions were mitigated by the technology's functionality (it provided the staff with previously unknown information) and the fact that it facilitated collaboration and teamwork.

2.5.2. Technology and process-related barriers and risks

Nanji et al. (2009) identified three main barriers to the implementation of a pharmacy bar code scanning system, as well as strategies to overcome them. The three main barriers were *resistance, process and technology.* The process barrier included issues such as training requirements and process flow issues. Even though the managers at the hospital pharmacy applied hands-on training for 1 year before full system deployment, some of the workers reported a desire to have more training available and made suggestions ranging from formal training sessions to simulation laboratories to "super-users"; peers who receive focused training

and would provide ongoing informal support to others (see also Douglas & Larrabee 2003). An example of a process flow issue was that the pharmacy technicians preferred to use their laptops and scanners in central pharmacy locations rather than in the individual areas where each medication was stored. By allowing the technicians to optimize their own workflow, the pharmacy managers overcame this challenge and fostered a collaborative working environment.

Nanji et al. (2009) also reported technology barriers during the bar code system implementation. These included both hardware and software problems, as well as the role of vendors. Hardware problems included bar codes not scanning and the wireless battery draining too quickly due to pharmacy technicians constantly holding down the scanning button. These problems were solved through re-education and changing manufacturers to ones whose bar codes were easier to scan, as well as establishing a process whereby technicians could easily report all un-scannable products. The vendor problem was solved by choosing vendors that provided long-term on-site formal support and had the resources to make specific changes to its system as difficulties arose. Neuenschwander et al. (2003) state that staffing challenges, fears of introducing errors, new work areas, capital outlays for equipment, variations in pharmaceutical manufacturers' practices as well as their reluctance to redesign their packaging processes may affect hospitals' ability to implement bar-code systems.

Samaranayake et al. (2014) assessed the effects of a BCMA system without the support of computerized prescribing on the dispensing process and its users in one medical ward in a tertiary-care hospital in Hong Kong and its separate pharmacy. The research showed an increase in the average time to dispense one drug item by one staff personnel from 0.8 (standard deviation 0.09) minutes pre-implementation to 1.5 (standard deviation 0.12) minutes post-implementation. Moreover, a notable increase in the proportion of potential dispensing errors (0.4% pre-implementation vs. 3.20% post-implementation, $p < 0.001$) was observed. The most frequently observed errors post-implementation were 'procedural errors' and 'missing drug items'. The increase in both of the statistical measures was likely due to the increased number of dispensing steps before (5) and after (8) the implementation. The additional steps included in the post-implementation setting included data entry to the computer, checking the data entry, printing 2D-bar code labels at another computer and using the automated dispensing machine to prepare some drugs. The first three of the mentioned steps were included in one step during the pre-implementation phase. The increased number of dispensing errors could not be contributed to the users familiarizing themselves with the system, as the post-implementation analysis and observation were performed 8 months after the implementation.

Additional studies have reported problems in the implementation of BCMA software. Wideman et al. (2005) depict in their report how a March 2000 implementation of a BCMA software faced difficulties in the 118-bed Harry S. Truman Memorial Veterans Hospital ICU ward. Due to problems in the software's limited ability to document intravenous fluid administration, the system had to be forfeited only 8 months after its implementation. Additionally, Wulff et al. (2011) suggested in their study that inappropriate warnings, which accounted for 70% of all system warnings, encourage users to ignore and override system warnings, which can lead to medication administration incidents. Moreover, Smaling & Holt (2005) state that while full implementation of a BCMA system is not required to achieve patient safety benefits, the absence of one or more of the components leaves opportunities for error. Although full automation brings integration challenges and may introduce other errors due to its complexity, the benefits gained from increased medication safety outnumber the risks. However, it has to be kept in mind that automating the whole medication loop bears considerable costs. While the benefits of BCMA and other medication administration technologies seem promising, the implementation of HIT can also produce unintended consequences and new types of errors (Poon et al. 2006). Even with the development of effective error prevention measures, ruling out all errors is likely impossible. Hence, it is useful to also consider safety measures supporting error recovery (Kanse et al. 2006). These are some issues that the management at HHP should take into consideration when implementing the barcode-assisted dispensing system.

Even though the implementation at HHP is planned to reduce the number of dispensing steps, these studies present many lessons to be learned from for the managers in HHP, e.g. how the scope of the implementation can affect the outcome from the medication safety point of view, as well as how the socio-technical and workflow issues should be taken into consideration – the perceptions of the pharmacy and nursing staff showed many 'job relevance' and 'perceived usefulness' issues. In order to prevent these kinds of issues, employee perceptions will be surveyed and recommendations will be made based on the framework by Burchell (2011).

2.6. Supply chain management risks

Baker & Halim (2007) state that automation projects may involve flexibility risks and service level risks, and that these risks need to be fully addressed already during the planning phase.

According to their survey, the projects that faced most severe difficulties were the ones that had given "reducing operating costs" and "reducing staffing levels" as reasons for implementing automation. Accordingly, Smaling & Holt (2005) state that improving medication safety should always be the outspoken goal of restructuring the operating process, as opposed to positioning the project as a way of saving nursing time.

Naish and Baker (2004) state that warehouse automation projects may lead to falling service levels in the short term. They offer guidelines to companies and institutions planning automation projects to avoid such shortcomings: emphasis should be put on gaining commitment from project stakeholders. Secondly, it is important to analyze all of the relevant data and agree on the performance targets, customer service levels and other goals so as to ensure that everyone is working towards a common goal.

2.7. Change resistance

User resistance is the leading challenge for the implementation of new information systems and thus needs to be understood and managed correctly (Kim & Kankanhalli 2009). Implementing the EDAs will have a fundamental effect on the day-to-day activities performed in the hospital pharmacy. The goal is to redesign the dispensing process so that the pharmaceutical inspection and packaging can be performed by the order-picking staff with the help of new technology. Therefore, employee commitment is paramount to the success of the implementation project.

2.7.1. User resistance due to status quo bias

Kim & Kankanhalli (2009) leverage previous technology acceptance theories, such as the theory acceptance model (TAM), the theory of planned behavior (TPB), the unified theory of acceptance and use of technology (UTAUT), and the status quo bias theory to inspect user resistance and acceptance towards new information system implementations. According to TAM, usefulness and ease of use dictate a user's willingness to accept and use a new technology (Davis, 1989). According to TPB, human behavior is led by three types of considerations: *behavioral beliefs* about the likely outcomes of the change, *normative beliefs* about the

normative expectations of others and motivation to comply with these expectations, and *control beliefs* about the factors that may impede or facilitate performance of the behavior and the perceived power of these factors (Ajzen 1991). Thirdly, UTAUT attempts to explain how performance and effort expectancy, social influence and facilitating conditions predict user acceptance (Venkatesh et al. 2003). These theories are often applied to situations where the users have a choice on whether or not they adopt the new technology in use. However, they may as well be used in an attempt to predict the resistance caused by implementing new technology when the users ultimately have no choice but to take the new technology in use, as user resistance may hinder or slow down the pace at which the change can be undertaken.

Status quo bias theory, first introduced by Samuelson and Zeckhauser (1988), attempts to explain people's preference to maintaining the current situation. The authors describe status quo bias explanations in three categories: rational decision making, cognitive misperceptions, and psychological commitment. Rational decision making refers to users' assessment of the costs and benefits related to the change. The costs are divided in two types: transition costs and uncertainty costs related to the psychological uncertainty associated with the new alternative. Higher perceived costs than benefits lead to a status quo bias. Cognitive misperceptions of loss aversion mean that even small losses related to changing may be perceived higher than they actually are. Thirdly, psychological commitment to the existing situation can adhere with new IT implementations. Psychological commitment consists of three factors: *sunk costs* can refer to e.g. skills related to the existing way of working that cannot be applied in the new situation, *social norms* refer to the existing norms on the workplace that can either reinforce or weaken the status quo bias, and *efforts to feel in control* stem from individual employees' desires to decide on their own situation.

Leveraging the same theoretical framework as Kim & Kankanhalli (2009), the following topics were selected to anticipate how much change resistance the new EDA implementation and the consequent process re-engineering could face:

- How do the employees perceive the usefulness and ease-of-use of the new EDA device
- How do the employees perceive the new medication delivery process in terms of necessity and benefits
- Do the employees think they will face difficulties using the new device, and if so, what kind of difficulties

- Do the employees feel that their contribution has been taken into account during the design phase of the implementation
- Do the employees feel committed to the cause, do they believe that their colleagues are committed
- How do the employees perceive the likelihood of success of the implementation

2.7.2. Methods for dealing with resistance

In IT implementation projects, employee resistance may present a complex issue in organizational change (Burchell, 2011). In her paper, Burchell discusses dealing with employee resistance in IT-enabled organizational change using the seminal paper "Choosing strategies for change" by John P. Kotter and Leonard A. Schlesinger (1979, 2008) as a framework. Burchell states that in IT-enabled organizational change, new automation may cause a range of negative feelings and presumptions about the future of the work place. If automation leads to increased efficiency it may mean less people are required for the job, which may cause employees to fear for the loss of their job. Added efficiency may also present a threat of higher expectations from the management. Employees might experience difficulties in adapting to the use of new technology, which may result in a loss of status or lowered performance appraisals. On the other hand, employees might be too accustomed to old ways of working and develop certain ways of doing their tasks that they do not want to let go of. Moreover, employees might feel that the management doesn't have the required information to make valid assessments of the costs and benefits of the investment. In these cases, employees may resist because they feel that the change is not in their best interest or in the best interest of the organization (Burchell, 2011.)

Employees may also resist learning or using the technology altogether. This might be because they are confused or do not understand the reason for the change or the potential benefits of the change. Moreover, if the organization has a history of failed implementations it may cause employees to doubt the likelihood of future success or even lead to cynicism towards all organizational change (Reichers et al. 1997.)

Burchell also discusses methods for dealing with resistance, first introduced by Kotter & Schlesinger. These strategies include: education and communication, participation and

involvement, facilitation and support, negotiation and agreement, manipulation and co-option, and explicit and implicit coercion. Additionally, Kotter and Schlesinger (1979) presented the idea that change strategy should be viewed as a continuum where different situations call for different methods. On one end of the continuum are methods that require rapid change and implementation with a defined plan of action and little to no involvement of employees. On the other end of the continuum are methods that favor slower change that involve a less clear plan and more employee involvement. Methods that are more suitable for rapid change aim to *overcome* any resistance, whereas in slower change the goal is to *minimize* resistance. Key situational variables include the amount and type of resistance that is anticipated, the position of the initiators vs the resistors, the relevant data and energy required to implement the change, and the stakes involved. In an implementation project where the timetable from first announcement to final deployment spans over a year and that there is not much (outspoken) resistance, the appropriate methods are likely to be closer to the right side of the continuum (see Figure 5).

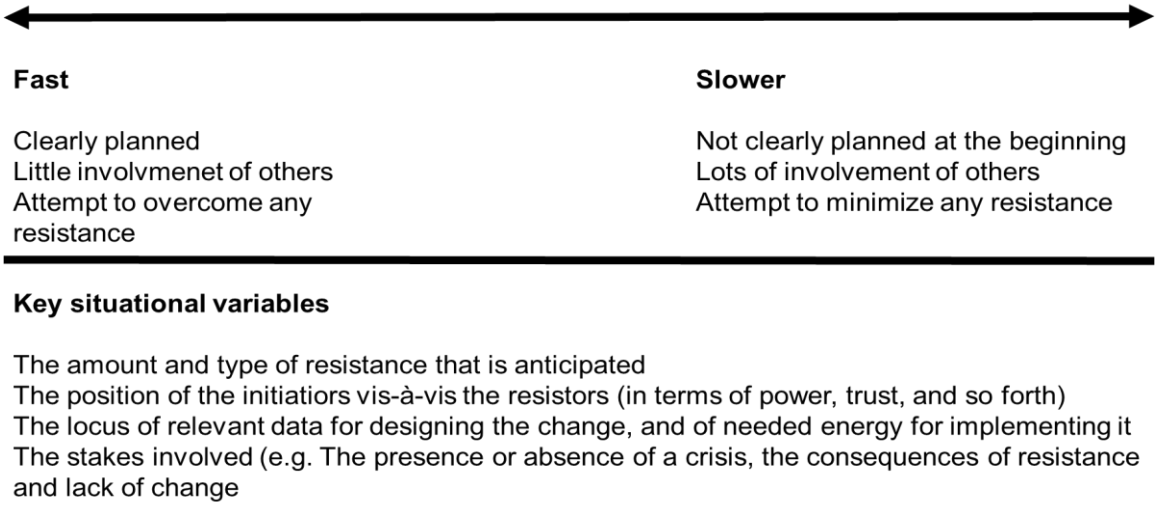

Figure 5 Strategic continuum for change management (Kotter & Schelsinger, 1979)

"Education and communication" would presumably be the most important method to support small-scale EDA implementations. It involves helping the employees learn how to use the new technology and understand its purpose. Truthful communication is required to mitigate the disappointment related to possible malfunctioning of the devices. This means that clear and honest communication should be carried out by the management regarding the expected work

load related to the implementation, as advised by Nanji et al. (2009). Participation and involvement would probably also be an appropriate method for change management in an EDA implementation project. According to Burchell (2011), it involves utilizing the stakeholders in the change process in order to facilitate the gathering of information or assistance in different stages of the implementation and testing. Consequently, participation and involvement signifies a deeper engagement of the employees than education and communication. In the case of an EDA or any other similar implementation, employees should be free to test the device and give feedback on its usability and functionality. Moreover, the feedback should be taken into consideration when designing the EDA user interface with the third-party software developers.

2.8. Theoretical framework

The theoretical framework of this thesis is related to the broader discussion of applying automation and barcode technology within the medication supply chain. The previous literature in this chapter have shown that if applied properly, BCMA can help hospitals improve their medication administration processes.

A more detailed framework is required to define a feasible scope for this study. The previous literature offer an approach to seek answers to the problems presented in the research questions. The research questions address two problems that may arise in hospital pharmacies that have not yet implemented barcode-assisted applications: how will the introduction of enterprise digital assistants affect the efficiency and medication safety of the order-picking operations at a hospital pharmacy warehouse, and how will employee perceptions on the usefulness and the ease-of-use of the EDA implementation affect the perceived likelihood of success of the implementation project.

The theoretical framework presented in this thesis aims to offer a structured approach that can be used to measure the success of an EDA implementation from the viewpoint of the research questions. Hence, it is based on a few key articles that have been presented in this chapter. The article by Runy (2008) presents the two goals that healthcare organizations usually have when automating operations: eliminating errors and streamlining the supply chain. Moreover, Banomyong and Supatn (2011) state that both effectiveness (quality, i.e. patient safety) and efficiency (achieving similar or higher service levels with lower costs) may be achieved with

the help of automation. The literature review by James et al. (2009) addresses in more detail the aspect of medicine safety and dispensing errors, whereas the later article by James et al. (2013) also includes the standpoint of workload and work efficiency. These goals correspond to the targets set for the empirical part of this study, and thus they form the base for the methodology that will be used in Chapter 5. The goal of the empirical part is to study whether these goals can be achieved with the help of the EDA device. As for the second research question, the articles on change management by Kim & Kankanhalli (2009) and on methods for dealing with resistance by Burchell (2011) form a part of the theoretical framework that seeks to answer how to address the possible employee change resistance issues that the implementation might face. Thus, the theoretical framework can be graphically formulated as follows:

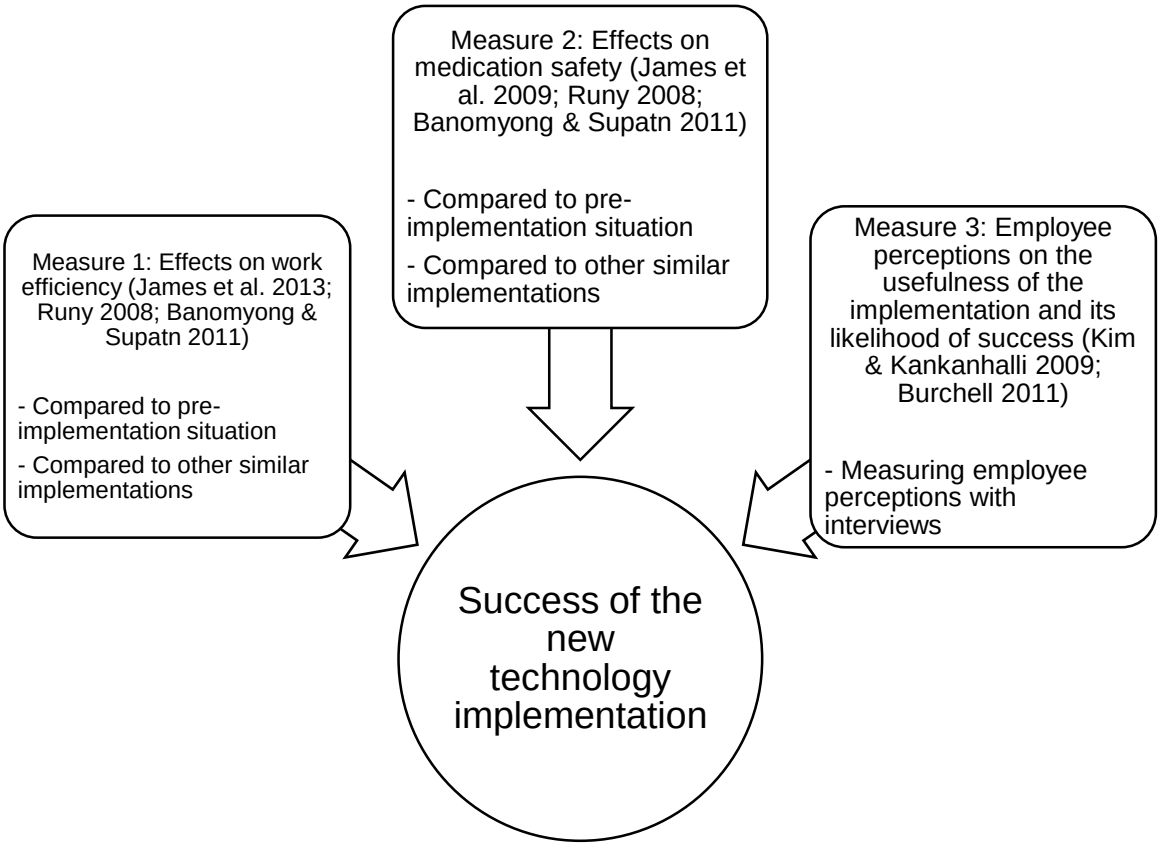

Figure 6 - The theoretical framework

The framework presented above addresses the three viewpoints that can be taken to answer the research questions. The first two measures seek answers to the first research question: "*How*

will the introduction of enterprise digital assistants affect the efficiency and medication safety of the order-picking operations at a hospital pharmacy warehouse?" The third measure takes a more qualitative outlook on the definition of success of the implementation as it measures the employee perceptions on the usefulness of the implementation and its likelihood of success to answer the second research question: "*How will employee perceptions on the usefulness and the ease-of-use of the EDA implementation affect the perceived likelihood of success of the implementation project?"*

In addition to measuring employee perceptions, more qualitative measures on employee acceptance of new technology have been presented by Keers et al. (2013) on the error-provoking conditions and by Nanji et al. (2009) and Wulff et al. (2010) on employee resistance in the form of overrides that employees have come up during previous studies on BCMA implementations. The occurrence of these overrides will not be included in the theoretical framework as such, however, should these issues arise in the questionnaire and interview answers they will be analyzed in the discussion chapter. The employees' perceptions on the usefulness of the EDA implementation will be surveyed to identify possible shortcomings that might provoke the users to apply overrides or to resist the change process.

As stated, the success of the implementation will be measured with statistical analyses by comparing pre- and post-implementation data on dispensing errors and throughput times. Moreover, additional studies presented in Table 1 can be used as a benchmark to compare the results of the data analyses with results from previous studies.

Another way to assess the research questions would be to approach them by using an existing theoretical framework, such as the Technology Acceptance Model (TAM, see Figure 7) by Davis (1989) or any of its expansions; TAM 2 (Venkatesh & Davis 2000) or Unified Theory of Acceptance and Use of Technology (UTAUT, Venkatesh et al. 2003). The theories are used to model how users (in this case, the employees) come to accept and use a new technology (in this case, the EDA). According to the theories, the main factors that contribute to the adaptation of a new technology are perceived usefulness (PU) and perceived ease-of-use (PEOU). Moreover, TAM 2 and UTAUT expand this view by contributing the intention to use to factors such as performance expectancy, social influence, job relevance, output quality, as well as demographical factors such as age and gender. By acquiring the information regarding these factors after the initial testing phase, the user acceptance could be forecasted and used to estimate how well the employees will adapt the new technology, and assume that the acceptance

would correlate with the success of the implementation. However, this viewpoint would not directly take into account the change in the number of dispensing errors or the effect on work efficiency, and as such would not serve the quantitative aspect of the research questions.

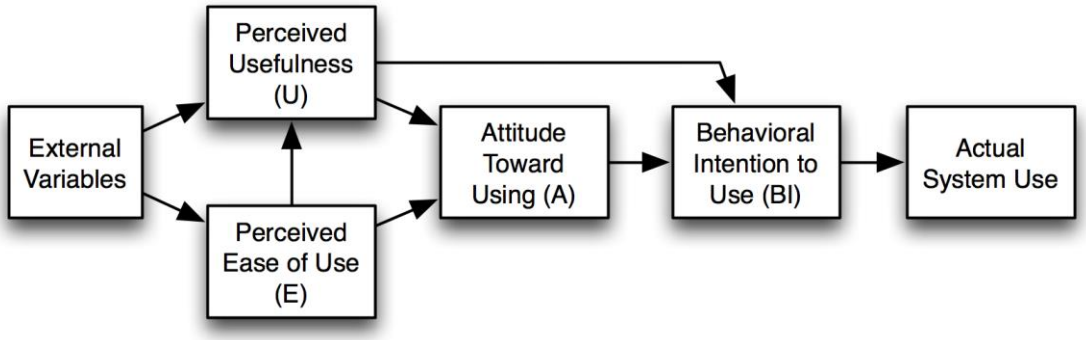

Figure 7 - Technology Acceptance Model (TAM), Davis (1989)

The key contributions of the theoretical framework are measuring the effect of introducing handheld EDAs to work efficiency and medication safety, and the synthesis of the results of the statistical analyses and the results of the interviews measuring qualitative aspects, i.e. employee perceptions. Most of the previous studies presented in this chapter focus on either the statistical, quantitative results of a BCMA implementation (decrease or increase in the number of medication errors and costs related to the dispensing process) or on the qualitative insights on employee perceptions. Moreover, the quantitative studies mostly focus on the effect of bar code technology on the occurrence of medication errors. There is a clear research gap regarding the effect of EDAs to work efficiency, which this thesis is set to fill. In this thesis, the success of the automation project will be measured both quantitatively and qualitatively. The relevant units of observation not only include the number of medication errors and the possible improvement in efficiency achieved by streamlining the order-picking process, but also employee behavior and how their perceptions on the value of their work will change after the implementation. Thus, the approach is more human-centered compared to the previous quantitatively focused studies.

3. Research Environment

This chapter introduces the research environment, HUS Hospital Pharmacy, and the medication dispensing process that takes place in the pharmacy. Different phases of the process are examined and their contribution to this study and answering the research questions related to efficiency and medication safety are discussed. On-site observations on each part of the process are made to provide general insights and suggestions for improvement.

HUS is a joint authority formed by 24 municipalities in the Helsinki and Uusimaa region. The population in the HUS area is 1 581 450 (31 Dec 2012, HUS). In 2013, 461 368 individuals used HUS services, and the whole hospital region hosted 209 017 inpatient days. In total, there are 2 831 hospital beds in HUS hospitals. Helsinki University Central Hospital (HUCH) functions as a part of HUS hospital district, treating patients with severe and rare illnesses and conditions calling for special expertise and technology nation-wide.

The HUS Hospital Pharmacy is a network organization operating within HUS, consisting of regional hospital pharmacy warehouses. The main warehouse located in Meilahti, Helsinki is the central hub with highest product volumes of all the hospital pharmacies. It is located in the premises of HUCH (Helsinki University Central Hospital), the largest hospital in Finland. It also has some outward traffic to the smaller regional hospitals, such as cytotoxic agents and pharmaceutical manufacturing products (depicted as dashed lines in Figure 8). However, the regional hospitals mostly place their orders to medication manufacturers independently.

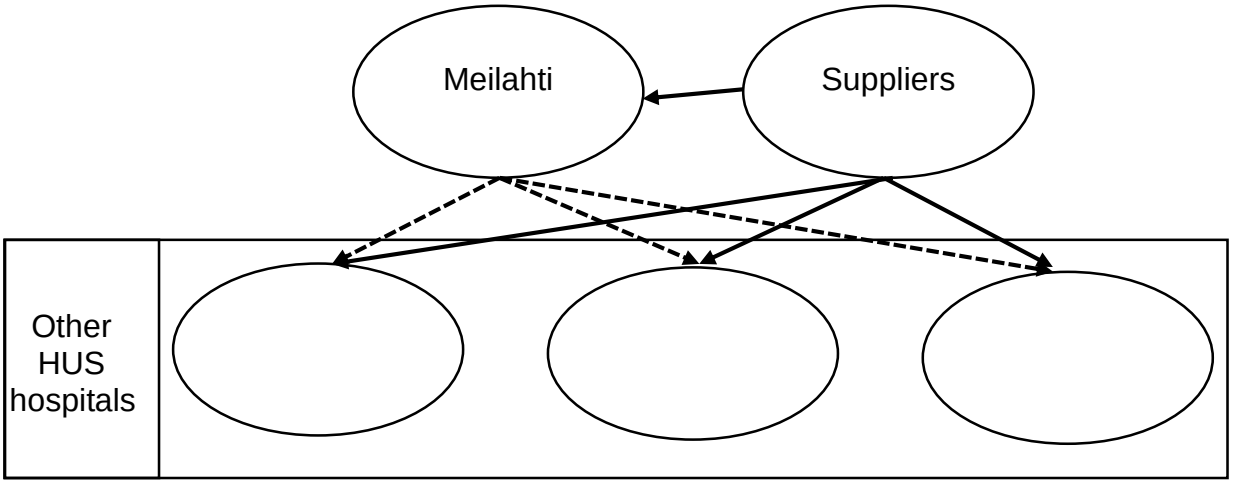

Figure 8 - The HUS Hospital Pharmacy supply network

Hospital pharmacies store large quantities of a wide assortment of medications. As opposed to retail pharmacies, their main function is to handle the medication needs of regional hospitals and their hospital wards. A very small portion of medications stored in HHP are delivered "over the counter" directly to the patients. Hospital pharmacies also stock more specialized and investigational (not yet approved by Finnish medicines agency, Fimea) medicines as well as compound sterile products such as cytostatics for the use of intense care units (ICUs) and other hospital wards. Moreover, hospital pharmacies' legal obligations include stocking the mandatory reserve supply to ensure the supply of medications in Finland in the occurrence of situations where the availability would otherwise be compromised. Thus, compared to retail or community pharmacies, hospital pharmacies are more like logistics hubs or warehouses specialized in medication storage.

3.1. Goods receipt phase

New orders arrive at the hospital pharmacy at least twice a day. Tamro and Oriola are the two major suppliers: Tamro's delivery arrives in the morning between 8:30 and 11:00, and Oriola's delivery arrives between 13:00 and 16:00. A normal delivery consists of 4 to 6 pallets. This often causes problems as the goods unloading area is only roughly 30m² by surface. At the back of the unloading area there is an additional room for storing flammable goods. This can at times cause through-traffic while the staff is unloading a delivery. In addition, reverse logistics are handled in the same area, and especially cold storage cases waiting for return delivery can take up plenty of room. Furthermore, a wider assortment of medications, including HUS Pharmacy's own medications and some highly specialized medications make the work in Meilahti more demanding compared to other locations. Consequently, with more traffic and more complex orders compared to other pharmacies in the HUS district and less space to operate, the main pharmacy at Meilahti, Helsinki is currently the most inefficient in terms of order receiving (see the results chapter for further details). The problem is acknowledged at HHP and contributed to the aforementioned problems regarding the more complex work environment.

The order lists are signed and the items registered as part of the hospital pharmacy inventory. This has traditionally been done manually. After the implementation of the EDAs, the

medications can be registered as part of the inventory by using the barcode reader. This would also further improve medication safety, as the expiration dates of each new batch of medications could be registered to the system in more accurate detail. Furthermore, some manual labor could be automated which should further improve work efficiency. Next, the pharmacy personnel take the medicine packages from the unloading area to the pharmacy warehouse on the same floor. At this point, the EDA can tell the staff member where each product is located on the shelves so they don't have to manually look it up from a binder. The mandatory reserve supply warehouse is located two floors down underground where some of the medications are taken. There is also traffic between these two warehouses to avoid drug expiration in the mandatory reserve supply. See Figure 9 for the delivery unloading process chart.

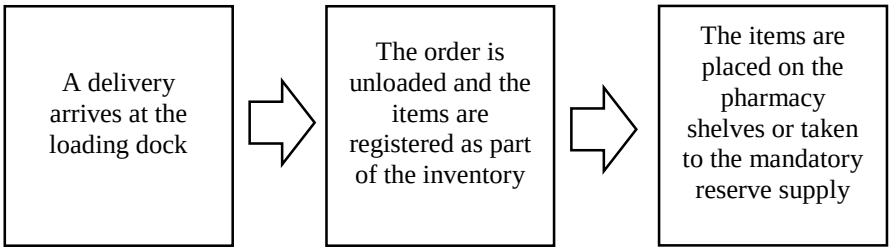

Figure 9 - The goods receipt phase

3.2. Order-picking phase

Hospital wards place their orders through WebMarela's electronic order system OSTi. Once an order arrives electronically through the system, a delivery list is automatically printed out, which the pharmacist checks to see if there are items that the pharmacy doesn't have in their inventory or if some of the items have to be delivered in a different quantity (e.g. if a hospital ward requested 5 units of a certain item but the item only comes in packages of 10). Next, the (corrected) delivery list is placed in a bin according to the time of the pick-up. The pharmacy personnel then take the lists and start picking the order from the pharmacy shelves on their trolleys. This constitutes the order-picking phase where *order-picking errors* may occur. One list can have anything between 1 and 50 order lines (according to observations based on the order lists received from the hospital pharmacy) so the order-picker may require several trolleys to handle one order. The lists or shelves do not currently have barcodes on them, meaning that

the order-picker has to match the item and the order by reading the name of the item and the VNR-code that dictates the shelf space. This can, at times, cause errors if the order-picker misreads the code and/or the name of the medicine. One of the outspoken goals of the automation project stated by the HHP organization is to improve order-picking accuracy at this part of the dispensing process with the EDAs.

3.3. Second pharmaceutical inspection and packaging

Once the members of the order-picking staff are done with an order list, they take the trolley and the list back to the center of the warehouse for a second pharmaceutical inspection, performed by a second pharmacist. The second pharmacist re-checks the list for any discrepancies between the listed items and the items on the trolley. To determine the baseline throughput times for this part of the process, the pharmacists wrote down the time they started and finished inspecting an order-list. As with the baseline throughput times for the order-picking phase, the time stamps were calculated and proportioned to the number of order-lines on each list. One of the goals of introducing the EDAs is making the second pharmaceutical check performed by the hospital pharmacist obsolete. Fimea (Finnish Medicines Agency) has not yet granted the hospital pharmacy a permission to perform the pharmaceutical inspection by any other means than a licensed pharmacist visually checking the hand-picked items. Thus, the results of this thesis could support validating the barcode-assisted pharmaceutical check as a reliable mean of automatically comparing the orders and the picked items for discrepancies, i.e. performing the pharmaceutical inspection. After the pharmaceutical inspection (and possible corrective actions if there are discrepancies), the items are placed in black plastic bags to protect them from sight during transportation, and the bags in metal baskets by the warehouse staff.

Cold-stored items in polystyrene foam containers and narcotics in paper bags are placed in the baskets right before the scheduled pick-up time. Lastly, the metal baskets are placed in a roll container to be picked up by the logistics personnel. Like the goods receiving facilities, the packing and forwarding space is also somewhat small for the purpose. See Figure 10 for a graphical presentation of the process flow

Dispensing errors occur when a member of the order-picking personnel picks the wrong kind of medicine and the pharmacist fails to notice this *order-picking error* during the pharmaceutical inspection. This leads to the wrong type of medication being sent to the hospital ward where it may end up being consumed by a patient. As pointed out in previous literature, this may be caused by factors such as LASA medications, stress, fatigue or carelessness. A dispensing error occurs even if a nurse notices the error before administering the medication to a patient. If the nurse also fails to notice the error, a dispensing error leads to a *medication administration error* which then can result in an adverse drug event (ADE). Hospital pharmacies dispense such large numbers of medications that even a very low dispensing error rate can lead to a considerable number of administration errors and consequent ADEs.

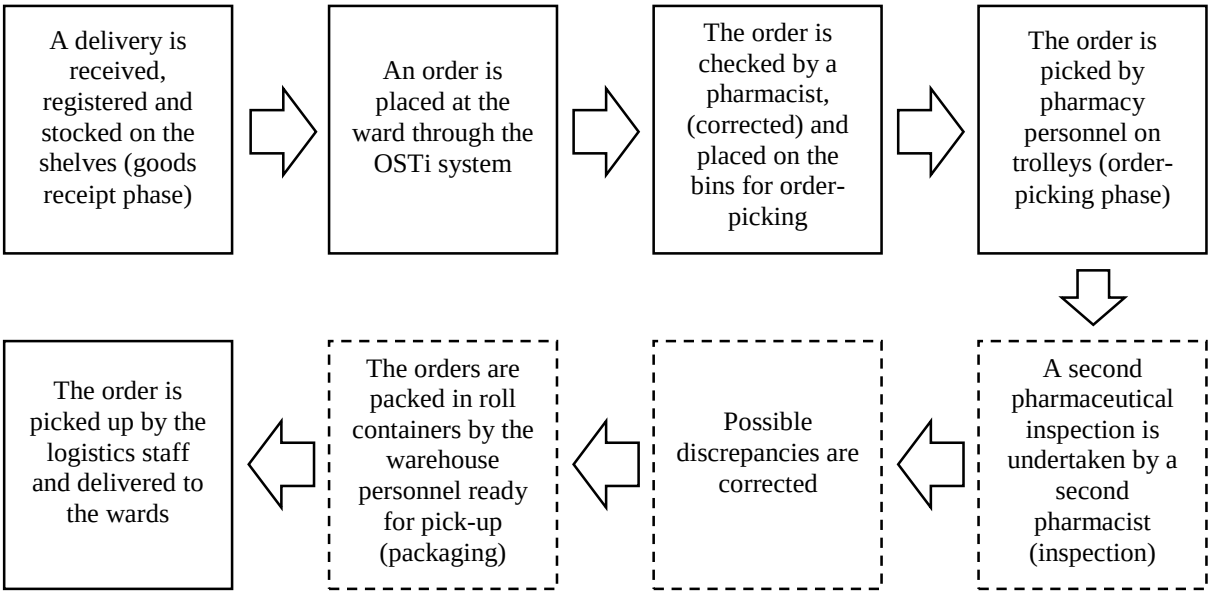

Figure 10 - The pre-implementation process chart for order-picking medication at the hospital pharmacy

3.4. Reorganizing the delivery process

The parts of the process highlighted with dash outline in Figure 10 are the ones that the hospital pharmacy management wish to streamline with barcode technology. The idea is that instead of visually checking the Vnr codes before picking the medicine from the shelves, the order-picking

personnel would be informed by the EDA which item to pick next, after which they would scan the correct medicine on the shelf before picking it. If the barcode doesn't match the given medication or the batch has expired, the device will give an error and prompt the order-picker to pick the correct item instead. This way a second pharmaceutical inspection wouldn't be needed, as it would be performed by the EDA during the order-picking.

In terms of medication safety, an *order-picking error* would be produced when an employee picks the wrong type of medicine and the EDA notices this, prompting the order-picker to pick the correct type or amount of the medication. Should the EDA for some reason fail to detect the error (e.g. it doesn't register that the medication is of wrong type or strength or that the batch is expired or an order-line is omitted without an error prompt) or the employee inputs that he or she picked the correct amount of medication while actually picking too much or too little, a *dispensing error* is produced. Consequently, the order-picking personnel could place the medications directly into the container boxes on the trolley. When they are done with an order, they could then insert the correct address tags on the boxes and place the boxes directly on the roll containers ready for pickup by the logistics staff. This way, the process could be streamlined by eliminating two or three phases of the process. Consequently, staff resources could be relieved from the second pharmaceutical inspection and packaging, which could incur cost-savings for the hospital pharmacy. Alternatively, the pharmacists who previously performed the pharmaceutical check could focus their resources on additional pharmaceutical work such as ward pharmacy. As for the goods unloading and shelving phase of the process, the EDA is simply planned to facilitate and improve the efficiency of the process.

4. Methodology and data

The empirical part of this thesis is performed as a case study at the HUS Hospital Pharmacy. The research methods used in the study include: (1) statistical analysis to measure the effects of the EDA implementation on the efficiency and accuracy of the order receiving, order picking and pharmaceutical inspection processes, and (2) gathering employee perceptions through structured interviews to determine the success of the implementation in regards to user adoption.

4.1. Research process

This research process started off by discussing with some of the managers and staff at the HUS Hospital Pharmacy in July 2014. The purpose of the meetings was to find out the strategic goals of the automation project deploying the Enterprise Digital Assistants (EDAs) in the hospital pharmacy. It became clear that even though the research process would be challenging, interesting results could be attainable and the potential implications useful both in theory and in practice. According to the discussions, improving medication safety can be seen as the main goal of the venture. However, other issues related to work quality, efficiency and accuracy arose during the meetings, discussions and on-site observations as well. Some parts of the facilities are cramped and hence somewhat inadequate for current operating levels of the hospital pharmacy. The order quantities of the hospital pharmacy grew by a notable 18% in 2013 compared to 2012 when the hospital pharmacy services in the nearby Töölö facilities were integrated to the Meilahti facilities' operations (see Figure 4).

One *order line* is the unit of observation used in this study. One order line consists of one type of medicine ordered by a particular ward. Hence, one order line can contain anything from a very small package containing only one single-packed medication to several carton boxes of IV (intravenous medicine) bags.

Next, the planning and gathering of data was initiated. Relevant data include medication throughput times within the delivery process. The following data were required:

- Throughput times for the receiving of goods,
- Throughput times for pharmaceutical inspections,
- Throughput times for order-picking,
- Throughput times for packaging,
- Number and type of order-picking errors daily

The number and type of order-picking errors in HUS are already recorded with HaiPro, a web-based reporting system for safety incidents in healthcare organizations provided by Awanic Ltd. However, in a study by Flynn et al. (2002), direct observation was proved to be the most efficient and accurate method for detecting medication errors, as opposed to reviewing charts or self-registering incident reports. Even though the self-reporting system is anonymous and does not seek blame, people might be inclined to report their own errors e.g. due to hurry or forgetting. In the study by Flynn et al. (2002), 457 errors were detected by a research pharmacist out of 2556 comparison doses, i.e. a true error rate of 17.9%. Direct observation detected 300 of the 457 errors and produced 73 false positives (14.6% detected error rate vs. 17.9% true error rate), chart review observed 17 of the 457 errors and 7 false positives (0.9% detected error rate vs. 17.9% true error rate), and report review detected only 1 error (0.04% detected error rate vs. 17.9% true error rate). In conclusion, direct observation detected 81.6% of the errors that occurred, while report review detected only 0.22% of all the errors that occurred during the examination period. Consequently, direct observation was chosen as the primary error-detection method for this study.

During this research process, the direct observation of the number of order-picking errors was performed daily by (1) the hospital pharmacists to check for order-picking errors made by the order-picking staff and (2) the hospital ward staff to check for dispensing errors that had managed to pass through the first check.

The throughput times for receiving the goods were chosen to be recorded by the pharmacy staff. Whenever an order was delivered by the supplier (Oriola Ltd), the pharmacy staff wrote down the time they started working on the delivery and the time they were finished. Distractions and other tasks that interrupted the work were not excluded from the measured time to achieve as realistic view of the process as possible. On few occasions the delivery was finished the following morning; in these cases time between 16:00 and 08:00 the following morning was excluded from the time stamp.

The throughput times for order-picking and pharmaceutical inspection were also recorded by the pharmacy staff during the research process. Stickers with space for time stamps were added to the order-picking lists, where the pharmacy staff wrote the time they started and finished working on an order list, as well as when the pharmacist would start and finish the pharmaceutical inspection. The order-picking and inspection times were recorded to the minute. These data were then used to analyze the efficiency and accuracy of the order-picking and delivery process before and after the implementation of the enterprise digital assistant.

4.2. Methodology

Based on the characteristics of the dispensing process presented in Chapter 3 and the previous literature and theoretical framework presented in Chapter 2, a methodology to perform the empirical part of the study is formulated. In order to calculate the potential benefits of the EDAs and the subsequent reorganizing of the delivery process, the effects of the implementation on work efficiency and process quality, i.e. medication safety, have to be measured.

After reviewing previous literature on warehouse management and efficiency measurement, "picks per person hour" (De Koster et. al 2007; James et al. 2013) was selected as the first measure of the success of the implementation presented in the theoretical framework. In this study, the term "row" is used instead of "pick", referring to the rows in the order list that represent the order lines that have to be picked. Moreover, for the order-picking process, the results are presented as "rows per minute" to differentiate them from the order-receipt "rows per hour" so as to achieve better interpretability and clarity of the results.

For the second measure of success presented in the theoretical framework, the EDAs' effect on medication safety, the number of dispensing errors was chosen as the numerator and the total number of items dispensed as the denominator. In a literature review by James et al. (2009), this was found to be the most common calculation formula in similar studies. To provide additional insights and to emphasize the connection between the process error rate and process quality, Six Sigma level measurements are also performed based on the same methodology as presented in a previous study by Revere & Black (2003).

As for the third measure, employee perceptions on the ease-of-use of the devices and the likelihood of success of the implementation, structured interviews were performed. The questionnaire includes questions on how well the employees think they've been included in the planning of the project, employee commitment, their views on the success of the project as well as their views on the ease-of-use and the perceived usefulness of the EDAs. The employees' perceptions are measured on a Likert-scale from 1-5 to make answers comparable. In addition, open-ended questions were presented to get any insights or comments that might bring up additional issues that should be taken into account during the deployment.

4.3. Data

The relevant data have been gathered from different parts of the medication delivery process. The data mainly include throughput times for different parts of the process, as well as order-picking and dispensing error data. The following process chart illustrates from which parts the throughput times (1), order-picking errors (2) and dispensing errors (3) have been recorded:

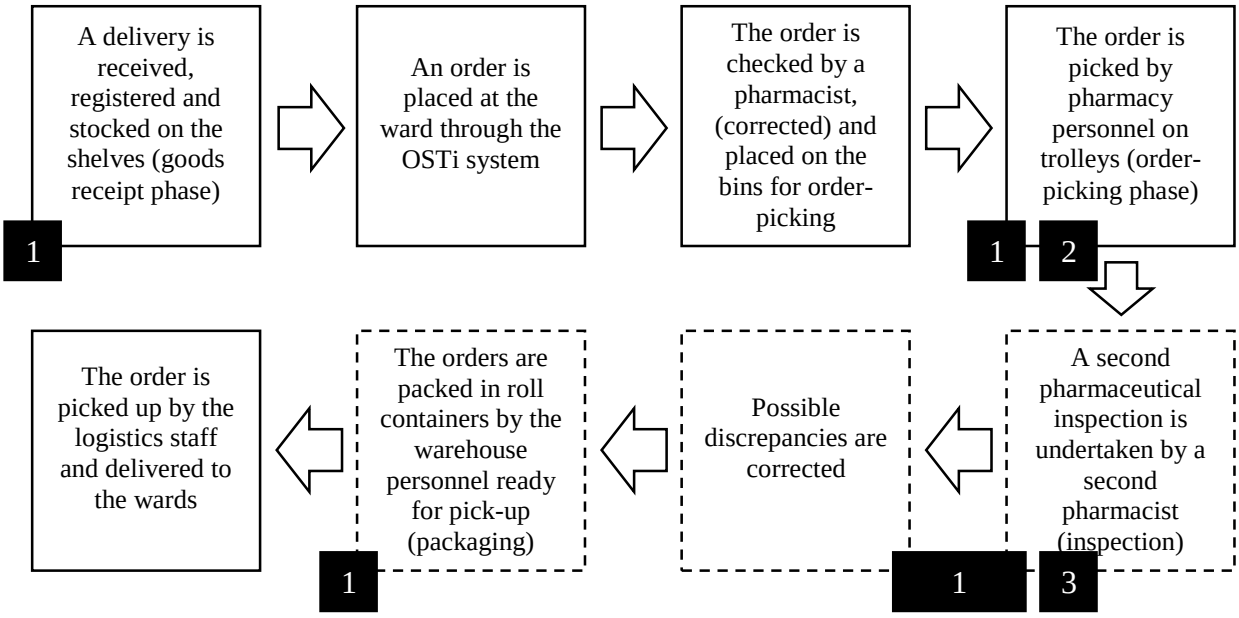

Figure 11 - Process phases subject to data analysis

In the post-implementation data collection phase, it is assumed that in the long run there would no longer be a separate pharmaceutical inspection once the EDAs have been implemented. Thus, data for throughput times have been collected only from the order-picking phase, and not the pharmaceutical inspection phase.

The data subject to analyses have been collected either manually by the hospital pharmacy staff or from the ERP system WebMarela (supplied by Affecto Ltd). The baseline throughput times and the corresponding order lines as well as the number of order-picking and dispensing errors have been recorded manually, whereas the number of order lines corresponding the number of errors have been collected from the ERP system. The data include throughput times for the receiving of goods, order-picking, and packaging parts of the process as well as the number of order-picking and dispensing errors. The applied method was direct observation as it was proven to be the most reliable method of detecting medication errors according to an article by Flynn et al. (2002). The HHP organization does have an ERP-based error reporting system – HaiPro supplied by Awanic Ltd – in use, however, according to a study by Tyynismaa et al. (2013) only 10 – 20% of errors are reported though the ERP system. Thus, recording the number of errors was chosen to be done manually both pre- and post-implementation to enforce consistency in reporting.

The baseline throughput times for the receiving of goods and order-picking have been recorded by the staff themselves, and for packaging by the author as on-site observation. The number of dispensing errors has been recorded by the HHP pharmacists, and the number of errors that passed the pharmacists have been reported by the ward staff. As stated previously, one of the limitations of the thesis is that the number of medication errors that reached the patient have not been observed or recorded.

Statistical analysis is conducted by comparing the throughput times, the number of order-picking and dispensing errors before and after the implementation of the EDAs. The pre-implementation (baseline) and post-implementation data have been collected as follows:

April-May 2014	June 2014	July 2014	August 2014
• Pre-implementation goods receipt throuhput times (11 days)		•Pre-implementation order-picking throughput times (10 days) •Pre-implementation order-picking and dispensing errors (17 days) •Packaging phase throughput times (2 days)	•Pre-implementation goods receipt throughput times (10 days) •Pre-implementation order-picking and dispensing errors (21 days)
September 2014	**October 2014**	**November 2014**	**December 2014**
•Pre-implementation order-picking throuhput times (9 days) •Pre-implementation order-picking and dispensing errors (22 days) •Packaging phase throughput times (1 day)	•Post-implementation goods receipt order lines and throughput times (16 days) •Post-implementation order-picking throughput times (8 days) •Pre-implementation order-picking and dispensing errors (18 days)	•Post-implementation order-picking throughput times (13 days) •Pre-implementation order-picking and dispensing errors (15 days)	•Post-implementation order-picking throughput times (11 days)
January 2015	**February 2015**	**March 2015**	**April 2015**
•Post-implementation order-picking throughput times (12 days) •Post-implementation order-picking and dispensing errors (5 days)	•Post-implementation order-picking throughput times (20 days) •Post-implementation order-picking and dispensing errors (20 days)	•Post-implementation order-picking throughput times (22 days) •Post-implementation order-picking and dispensing errors (22 days)	•Post-implementation order-picking throughput times (8 days) •Post-implementation order-picking and dispensing errors (8 days)

Table 2 - Data collection phases

As can be seen from the above table, there was some overlap between the pre-implementation and post-implementation data collection. The order-picking test phase for the EDAs commenced on October 2014 for the orders of one single hospital ward. From October to November, post-implementation order-picking throughput times were recorded from the test ward, while pre-implementation order-picking and dispensing errors were still recorded from the rest of the hospital wards' orders. This was done in order to ensure a large enough sample size for the error rate comparison. The test sample was expanded to include 8 wards in January

2015, and the recording of post-implementation order-picking and dispensing errors was started.

Unlike the baseline throughput times, the post-implementation data for the throughput times and the order-picking errors could be recorded with the EDAs and collected from the ERP system supplied by Affecto Ltd, excluding the goods receipt phase where throughput times have been recorded manually also post-implementation. The order lists that were picked with the EDA were still inspected by a pharmacist during the test period to monitor how many order-picking errors managed to slip past the EDA unnoticed.

All data were entered into Microsoft Excel for analysis. The results of the data analyses are presented in Chapter 5.

4.4. Employee interviews

Employee perceptions on the implementation of the EDAs and the consequent streamlining of the process have been measured with structured interviews. The interviews are based on a set of questions measuring the employees' perceptions regarding various aspects of the implementation project as well as related open-ended questions. The interviews were performed by the author so that the employee had the questionnaire (see Appendix 3) in front of them during the interview. As the number of employees included in the test phase is small (n = 8), no statistical analysis can be performed based on the answers. Instead, the answers to the open-ended questions provide the greatest insight on the subject. The questions are based on the measures of change resistance presented in the theoretical framework by Burchell (2011), and adopted to suit this particular case study. The interviews were performed in February 2015, when the EDAs had already been in test use with some of the customers. The time period was chosen so that the selected employees would already have some experience on the usability of the device so that they could evaluate the advantages and the disadvantages of the technology, yet before the full-scale implementation so that their feedback could be taken into consideration before the final deployment. The questionnaire covered the following aspects that can be used to assess the magnitude of change resistance:

- The usefulness of the EDA devices on the order-picking process
- Problems regarding the deployment of the devices

- Employee involvement during the implementation project
- The ease-of-use of the device and the installed software
- Employee commitment to the change project
- Employee perceptions on the likelihood of the success of the reorganization project

Employee perceptions on these questions are measured on a Likert-scale to achieve estimates of measurable results, and the open-ended questions were included after each of the questions to gather insights. The results and insights from the interviews are presented in Chapter 5.

5. Results and findings

This chapter will cover the results of the study. First, the two main measures presented in the theoretical framework are analyzed to answer the first research question: "How will the introduction of enterprise digital assistants affect the *efficiency and medication safety* of the order-picking operations at a hospital pharmacy warehouse?" The pre-implementation data are analyzed to calculate the *baseline order-picking and dispensing error rates* as well as the *baseline efficiency of the order-picking process.* These baseline rates are compared with the post-implementation rates. Second, additional data analyses are performed based on the goods receipt and packaging phase data to attain an estimate of how streamlining these work phases could improve the overall efficiency of the process. Third, the interview findings are analyzed to measure how the employees view the usefulness and the ease-of-use of the EDAs, and how these views affect their perception of the likelihood of success of the implementation, i.e. answers are sought to the second research question. Moreover, additional findings are presented regarding each of the phases subject to analysis to provide further insights outside the scope of the research questions.

5.1. Order-picking phase data analysis

The most key part of the medication delivery process that will be notably affected by the EDA implementation is the order-picking process. This section will study the effect of using the EDA in the order-picking process to identify the correct medication and to give information on each medication, for example where it is located in the hospital pharmacy. The pre-implementation analysis shows that the average order list consists of 5.27 order lines pre-implementation. The average time it takes the hospital pharmacy personnel to collect one order list is 0:03:45. There was no significant difference between the recorded average times in July (0:03:43) and September (0:03:47). Consequently, the average time to collect one order line pre-implementation was 0:00:43. The number of order lines per order list had some effect on the time it took the personnel to pick and inspect the order, as can be seen from Table 3:

Order lines per order list	Length of order-picking process/order line	n
1	0:01:29	409
2	0:00:57	235
3	0:00:51	191
4	0:00:50	164
5	0:00:42	128
6	0:00:41	96
7	0:00:40	91

Table 3 - Length of order-picking process/order line

The result is understandable in the sense that whether the warehouse staff member has one or several order lines on their order list, they have to walk to the shelves and back to the center of the warehouse to place the order in queue for the pharmaceutical inspection. In addition, they have to take the list and place it back into another pile. The actual time it takes to walk from one medicine's shelf-space to another is shorter than these extra activities. When calculating the efficiency of the process, the number of order lines per order list should be taken into account. Using the same methodology as De Koster et al. (2007) and James et al. (2013), "Rows per minute" is used as the measure of efficiency:

$$\overline{x} = \frac{\sum Rows}{\sum Minutes}$$

A total of 1 688 orders consisting of 8 843 order lines (rows) were observed during the pre-implementation phase, corresponding to 6 334 minutes of order-picking time. Thus, the rows per minute (RPM) efficiency measure for the pre-implementation phase is 8 843 Rows / 6 334 Minutes = 1.40 RPM. This constitutes the pre-implementation baseline efficiency rate of the order-picking process, or the *hypothetical population mean* (μ_0).

For the post-implementation process, 1 200 orders consisting of 9 269 order lines (rows) were recorded. The corresponding order-picking time was 4 956 minutes. Consequently, the efficiency measure for the post-implementation order-picking process is the post-implementation weighted average, or the weighted sample mean ($\overline{x}$):

$$\overline{x} = \frac{9269\ Rows}{4956\ Minutes} = 1.87\ RPM$$

Subsequently, the EDA would seem to improve the efficiency of the order-picking process by roughly 34% (1.87 / 1.40). Thus, the first research hypothesis of this study is formulated:

H1: Using the EDAs improves the efficiency of the order-picking process

Next, the research hypothesis has to be tested for statistical significance. I denote ($\alpha = 0.05$):

H_0: *The EDAs have no effect on the efficiency of the process, i.e.* $\mu_0 = \overline{x}$

H_1: *The EDAs improve the efficiency of the process, i.e.* $\mu_0 < \overline{x}$

In order to test this observation for significance the sample standard deviation (*s*) needs to be calculated using the formula:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

The sample standard deviation of the post-implementation order-picking process is 1.277. Next, the standard error of the sample mean ($\overline{x} = 1.87$) needs to be calculated using the formula:

$$SE_{\overline{x}} = \frac{s}{\sqrt{n}} = \frac{1.277}{\sqrt{1200}} = 0.04$$

With the sample mean ($\overline{x}$), the process baseline mean (μ_0), and the standard error ($SE_{\overline{x}}$) the Z statistic can be calculated:

$$Z = \frac{\overline{x} - \mu_0}{SE_{\overline{x}}} = 12.87$$

With Z-score 12.87, $p < 0.00001$ is obtained. The result is significant at $p < 0.05$; thus, H_0 can be rejected and the first research hypothesis can be accepted. To conclude, using the EDAs does improve the efficiency of the order-picking process.

5.2. Pharmaceutical inspection phase data analysis

The most interesting part of the medication delivery process in terms of the automation project is the pharmaceutical inspection phase. The goal of the HHP EDA project is to streamline the process so that the second pharmaceutical inspection phase could be eliminated by using the EDA to check the order list and the picked medications for discrepancies. Thus, one of the goals of this study is to find out how much this particular phase of the process requires resources and how much of those resources could be saved by performing the pharmaceutical inspection with the EDA device. On the other hand, it is paramount that the quality of the process, i.e. its contribution to medication safety, is not compromised at the cost of efficiency.

The analysis shows that the average time it takes the pharmacist to perform the pharmaceutical inspection on one order list was 0:03:28 or forty seconds per order line. Consequently, it can be noted that the order-picking process is slightly more resource-intensive when compared to the pharmaceutical inspection which takes 7.6% less time than the manual order-picking phase (0:03:47 vs. 0:03:28). Similar results were noticed in the relation between the number of order lines per order list and the throughput time as with order picking, as can be seen from Table 4 below:

Order lines per order list	Length of pharmaceutical inspection/order line	n
1	0:02:03	409
2	0:01:14	235
3	0:00:52	191
4	0:00:41	164
5	0:00:45	128
6	0:00:34	96
7	0:00:31	91

Table 4 - Length of pharmaceutical inspection/order line

As can be seen from Table 4, a pharmaceutical inspection performed on only one or two order lines takes longer than the order-picking process for as many order lines. However, as the number of order lines increases, the benefit of scale increases faster for the pharmaceutical inspection than for the order-picking phase. This is likely due to emergency orders which usually consist of only one or two order lines that often require additional attention from the

pharmacist but is a similar task from the order-picking personnel's point of view. On the other hand, the pharmacists' tasks do not require moving from one place to another between order lines, which is the likely reason behind the fact that order lists consisting of more than 5 lines are usually faster to inspect than to pick from the shelves.

The number of pre-implementation order-picking and dispensing errors was observed on 88 days between July and November for the pre-implementation pharmaceutical inspection process. The total number of order lines during these 88 days was 70 762. A total of 571 *order-picking* errors were made by the order-picking personnel and noticed by the hospital pharmacist, with additional 93 errors slipping past the hospital pharmacist unnoticed – producing a *dispensing* error – that were reported by the hospital ward staff.

Consequently, the number of order-picking errors that slipped past the order-picking personnel was 571 + 93 = 664, which translates to an order-picking error rate of 0.938% (664 errors / 70 762 rows). The observed dispensing error rate is 0.131% (93 errors / 70 762 rows). As mentioned before, only three error types were able to be recorded: wrong medication, wrong strength/dosage, and omission. Thus, during the inspection period there were 3 * 70 762 = 212 286 opportunities for error. Translating the number of order-picking errors to process sigma calculation measures, 3 128 defects per million opportunities (DPMO) are obtained, which produces a yield percentage of 99.69%. Using the Process Sigma Calculator[1], a Process Sigma of 4.23 can be obtained. As for the number of dispensing errors, 438 DPMO are obtained, which produces a yield percentage of 99.96% and a Process Sigma of 4.83.

After the implementation of the EDAs, a total of 9 579 order lines and the corresponding medication errors were recorded on 55 days. The low number of order lines per day is due to the fact that the EDA has only been taken into use for the orders of certain 8 wards during the testing phase. During the testing phase, a pharmaceutical inspection is still performed on the order lists, so as not to compromise medication safety before the reliability of the EDAs has been validated. However, in this study post-implementation order-picking errors are treated as dispensing errors, as they will be if the use of EDAs will be validated.

During the testing phase, 13 order-picking errors were detected out of 9 579 order lines, corresponding to an order-picking error rate of 0.136%. Using the same error categorization as before, this translates to 452 defects per million opportunities (DPMO), which produces a yield

[1] http://www.isixsigma.com/process-sigma-calculator/

percentage of 99.95%, translating to 4.82 Process Sigma quality. What can be noted is that neither the pre- or post-implementation dispensing error rates reached the Sigma level of 5.4 presented by Revere & Black (2003). However, it has to be kept in mind that, as pointed out previously, when measuring process quality with Sigma levels the categorization of error types has a considerable influence on the results.

Consequently, it would seem that the introduction of the EDAs would decrease the *order-picking error rate* by as much as 85% (0.938% pre-implementation vs. 0.136% post-implementation). A second research hypothesis is formulated:

H2: Using the EDAs decreases the order-picking error rate

In order to test the second research hypothesis for statistical significance, a Pearson's Chi-square goodness-of-fit test has to be performed by formulating the actual and expected observations' contingency tables. I denote ($\alpha = 0.05$):

H_0: *The use of EDAs has no effect on the order − picking error rate*

H_1: *Using the EDAs decreases the order − picking error rate*

Error rate:	0.938%	0.136%	
Actual observations	Without EDA	With EDA	Total
Order-picking error	664	13	677
No error	70098	9566	79664
Total	70762	9579	80431

Expected observations	Without EDA	With EDA	Total
Order-picking error	596,3	80,7	677
No error	70165,7	9498,3	79664
Total	70762	9579	80431

Table 5 - The results of the Chi-Squared Test (order-picking)

By using Microsoft Excel's CHISQ.TEST function, the probability that the differences between the sets are simply due to sampling error can be obtained: $p < 0.00001$, which is smaller than the alpha 0.05 defined previously. Thus, it can be concluded that the results are statistically significant and the second research hypothesis can be accepted; Using the EDAs decreases the *order-picking error* rate.

However, a look at the post-implementation process from the viewpoint of *dispensing errors* shows that while the order-picking error rate was reduced, the dispensing error rate would seem to increase. As stated, in the post-implementation setting all order-picking errors are assumed to produce a dispensing error due to the absence of the hospital pharmacist, who acts as a defense layer. Consequently, it would seem that the dispensing error rate is not decreased but would instead increase by 3.8% post-implementation (0.131% pre-implementation vs. 0.136% post-implementation). A third research hypothesis is formulated:

H3: Using the EDAs increases the dispensing error rate

Correspondingly, Pearson's Chi-square goodness-of-fit test has to be performed to test this hypothesis for statistical significance. I denote ($\alpha = 0.05$):

H_0: *The use of EDA has no effect on the number of dispensing errors*

H_1: *Using the EDA increases the dispensing error rate*

Error rate:	0.131%	0.136%	
Actual observations	Without EDA	With EDA	Total
Dispensing errors	93	13	106
No error	70669	9566	80235
Total	70762	9579	80341

Expected observations	Without EDA	With EDA	Total
Dispensing errors	93,4	12,6	106
No error	70886,6	9566,4	80235
Total	70762	9579	80341

Table 6 - Results of the Chi-Squared Test (dispensing)

This time, the CHISQ.TEST function provides a much higher probability of a sampling error: p = 0.09136, which is greater than the alpha 0.05. Thus, the above null hypothesis cannot be rejected and has to be accepted. Consequently, the change in the dispensing error rate is not statistically significant, and the third research hypothesis has to be rejected

However, it should be noted that while the occurrence of dispensing errors could not be reduced, it is also due to the fact that the pre-implementation dispensing error rate was rather low to begin with. Looking at the results from an alternative point of view, the findings prove that the same level of process quality could be achieved with less resources, i.e. the same dispensing error rate could be reached without the hospital pharmacist when the EDAs are in use.

5.3. Goods receipt phase data analysis

Next, the effects of the EDA implementation on the goods receipt part of the process are analyzed. Even though the goods receipt phase does not directly relate to the research questions or the theoretical framework, these findings are presented to give a better overall view of the effects of the EDAs on the whole medication dispensing process. For this part of the process, only throughput times were analyzed. Although it might provide opportunities for minor improvements in the process, analyzing errors in the order receiving phase would not likely reveal any considerable issues related to medication safety due to the number of safeguards between order receiving and patient medication consumption.

The same methodology is used as previously when measuring the efficiency of the order-picking process. To measure the efficiency of the goods receipt phase, the rows per hour efficiency rate is calculated:

$$\overline{x} = \frac{\sum Rows}{\sum Hours}$$

In the following table, the averages of process Length/Row and the corresponding Rows/hour (RPH) are calculated as weighted averages to form a better picture of the overall efficiency of the process in different HUS hospital pharmacy units. See Table 7 for the results of the pre-implementation, manual goods receipt phase data analysis:

	Averages, manual				
	Length of the goods received process	Number of rows	Length / row	Rows/hour	n (days)
Hyvinkää	0:34:47	23	0:01:32	39,1	19
Peijas	0:39:03	27	0:01:18	46,0	24
Jorvi	0:48:33	26	0:01:46	34,0	45
Meilahti	**1:55:31**	**53**	**0:02:11**	**27,4**	**21**

Table 7 - Pre-implementation throughput times of the goods receipt process (Oriola)

The pre-implementation data analysis results support the assumption that, most likely due to cramped premises, a larger variety of specialized medications etc., the goods receipt phase in Meilahti is seemingly more inefficient than in other HUS pharmacies even though there are two people working in the goods receipt area. Looking at Table 7, Meilahti seems to be the most inefficient of the units in terms of the goods reception phase, followed by Jorvi. The numbers in Jorvi are most likely explained by the fact that the goods receipt area is located on two separate floors, which slows down the process of receiving goods as medication containers have to be moved up and down in an elevator.

The EDA was first taken into use in the goods receipt phase in Meilahti in October 2014. The results of the post-implementation throughput times' data analysis are presented below:

	Averages, EDA				
	Length of the goods received process	Number of rows	Length / row	Rows/hour	n (days)
Meilahti	**1:42:00**	**55**	**0:01:52**	**32,1**	**16**

Table 8 - Post-implementation throughput times of the goods receipt process (Oriola)

According to the results shown in Table 8, it would seem that implementing the EDAs has improved the efficiency of the goods receipt process in Meilahti by approximately 17% (32.1 rows/hour pre-implementation vs. 27.4 post-implementation). Although not directly related to the order-picking process and thus slightly outside the scope of this study, the results are interesting and thus tested for statistical significance ($\alpha = 0.05$):

H_0: *The EDA does not improve the RPH of the process, i.e.* $\mu_0 = \overline{x}$

H_1: *The EDA improves the RPH of the process, i.e.* $\mu_0 < \overline{x}$

Where μ_0 is the baseline process efficiency rate, or the *hypothetical population mean*, and $\overline{x}$ is the sample mean of the post-implementation efficiency rate. In order to test this observation for significance, the sample standard deviation (s) needs to be calculated first using the formula:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

The sample standard deviation of the post-implementation process is 10.38. Next, the standard error of the sample mean ($\overline{x} = 32.1$) needs to be calculated using the formula:

$$SE_{\overline{x}} = \frac{s}{\sqrt{n}} = \frac{10.38}{\sqrt{16}} = 2.60$$

With the sample mean ($\overline{x}$), the process baseline mean (μ_0), and the standard error ($SE_{\overline{x}}$) we can calculate the Z statistic:

$$Z = \frac{\overline{x} - \mu_0}{SE_{\overline{x}}} = 1.83$$

With Z-score 1.83, a p-value of 0.033 is obtained. The result is significant at $p < 0.05$; thus, H_0 can be rejected and concluded that the EDA improves the efficiency of the order receiving process.

5.4. Packaging phase data analysis

The throughput times of the packaging phase were recorded by the author. The goal of this analysis was to find out how much of the packaging personnel's time is approximately spent packing the medications in the containers and how much on other related activities. The observation was performed on three days: July 11th and 16th as well as September 23rd. It needs to be acknowledged, thus, that solid quantitative results as such cannot be derived due to the small sample, but rather that the throughput times recorded on these dates provide support to the suggestions that can be made based on the on-site observation.

The packaging phase staff is two people per day. The results show that two hours and twenty minutes of the busiest work day (September 23rd) were spent directly on packaging the

medications in the containers. This comprises about 30% of the packaging personnel's working day. The longest packaging tasks took the personnel fifteen minutes and twenty-four seconds. Judging by these results and the on-site observations, it could be possible to streamline the process with the help of the EDAs so that the order-picking personnel could be able to perform packaging simultaneously when picking the orders. It has to be noted that if the second pharmaceutical inspection could be performed with the EDA while picking the medications, the order-picking personnel could place the medications directly to the containers where the medications are transferred to the hospital wards.

The rest of the packaging personnel's working day was spent on complementary activities, such as moving the roller cages from the loading area to the shipping area, fetching more containers, printing the address labels on the containers and waiting for the pharmacists to finish the pharmaceutical inspection that precedes the packaging phase. There was also one small medication delivery daily that the packaging personnel delivered on foot to a nearby hospital ward. Detailed work time records for all the activities proved too difficult to record for only one observer, however, the data that were attained are sufficient to get an overall picture of the process.

The key finding from observing and analyzing the packaging phase of the process is that a significant amount of the packaging personnel's time was spent on complementary activities. This is something that should be taken into consideration should the decision be made to streamline the process so that additional packaging personnel would no longer be used. If there would no longer be additional staff to handle the complementary activities related to the packaging phase, it should be taken into account that a part of the order-picking personnel's time would likely go to handling these activities.

5.5. Interview findings

To obtain answers to the second research question regarding employee perceptions, the employees who had already participated in the test phase of the EDA implementation were interviewed. The interviews included open-ended questions as well as questions that the interviewees were asked to answer on a likert-scale of 1-5. The questionnaire can be found in Appendix 3. The answers were divided as follows:

Question	Average (n = 8)	Std. dev. (n = 8)
Q1: How much do you think the EDA will benefit the order-picking operations in the long run? (5 = will benefit greatly, 1 = will impede greatly)	4.25	0.89
Q3: Do you think there will be problems in implementing the EDAs? (5 = the implementation will not face problems, 1 = the implementation will face severe problems)	1.88	0.35
Q5: Do you think that the employees have been taken into consideration sufficiently during the implementation project? (5 = employee perceptions have been heard and they have been taken into account, 1 = employee perceptions have not been considered at all)	3.75	1.58
Q7: According to your initial experiences, how would you perceive the ease-of-use of the EDAs? (5 = very easy to use, 1 = very difficult to use)	3.25	1.04
Q10: How do you perceive the commitment of other employees to the implementation project? (5 = the employees are very committed, 1 = the employees resist the project)	3.88	1.25
Q12: How likely do you consider that the project will succeed in the long run? (5 = very likely, 1 = highly unlikely)	4.63	0.52

Table 9 - The averages to the interview answers

The key takeaway from the answers is that although the employees had all faced either considerable or at least some difficulties (Q3), all of them considered that the project was either likely or very likely to succeed eventually (Q12). Indeed, many interviewees perceived that the EDAs will in all likeliness help the employees prevent dispensing errors, but only after the developers can get the devices to work without problems.

During the interviews it became apparent that the employees considered that in general the EDAs could benefit their work notably in the long run (Q1). However, the interviewees presented a number of concerns regarding the issues that the implementation project has faced. The most common concerns were related to technical and scheduling issues. One employee expressed their disbelief regarding the schedule of the project: "The first time they started talking about it [the implementation of the EDAs] was already a few years ago. Back then they promised us that when our operations would be merged [Töölö and Meilahti hospital pharmacies were merged in 2013] we would have the EDAs in use … to help deal with the merger -- it's already been long past that and I've said it will probably take a few more years" (member of the order-picking staff, February 5th 2015). The project has been postponed on several occasions, most recently during the time this thesis was being written.

All of the interviewees mentioned that there have been either some or significant technical difficulties during the testing phase of the EDAs (Q3). The most notable difficulties have been related to the fact that the devices occasionally disconnect from the network due to a probable software bug. This causes considerable delays in the work as the devices have to be rebooted over and over again. For some reason, the employees stated, this problem occurs most often on Monday mornings; on Mondays it takes a lot longer to start the devices and when they finally do start, they disconnect from the network after a while. The employees reported that on some occasions the malfunction was so severe that the EDAs had to be turned off and the order-picking process had to be completed manually with printed order lists. However, as far as the interviewees understood the problem was something that hopefully can be fixed by the software provider as soon as possible before the full-scale deployment of the devices.

One of the employees, who had the most experience in using the device and had also provided training for the other employees during the project – and who therefore could be described as the "project champion" – reported that on one occasion they had noticed that the wrong drug had been dispensed and sent to a hospital ward. This was due to the fact that when picking large quantities (e.g. 100 packages) of the same drug the employees don't have to scan all of the items but can instead scan one item and then insert the number of items that were picked. However, on this occasion the employee had picked a number of packages of the same drug but in different strength. This proves a good example of how the EDAs do not completely prevent opportunities of error when picking LASA medications. As the champion emphasized during the interview, even though the EDAs do mitigate the risk of picking the wrong (LASA) medication, it does not replace the need for individual precaution. This statement is also supported by previous

literature: overreliance on the EDAs, as on any technology, may weaken employee vigilance by "relocating" human factor problems rather than completely obviating them (e.g. McDonald 2006; Emmerton & Rizk 2012).

Regarding the ease-of-use, all of the employees agreed that using the barcode scanner would be considerably faster and more accurate in the long run than checking the Vnr codes from a sheet of paper. However, some of the employees hoped that the user interface would be more intuitive and that currently it had too much unnecessary information. As one employee put it: "To access the most important piece of information – how many units of the product have to be picked – an employee has to scroll down to see [the correct amount] whereas it would be more convenient if the amount were shown straight away on the screen like with the product name" (member of the order-picking staff, February 12th 2015). Another employee argued that "when you start using [the EDA] it's difficult at first because there's all this information that you don't always need, for example how many units of the item we have in stock … you only need that information if there's nothing on the shelf to check if we really have run out … it takes time to get used to the amount of information and looking for the information you need … maybe after a while you might get used to it but it might be frustrating for people at first" (member of the order-picking staff, February 5th 2015). Thus, in order to achieve improved user acceptance through better ease-of-use, it could be beneficial to improve the intuitiveness of the user interface.

When asked about employee involvement during the project, interviewee perceptions varied more than with the other questions (Q5; standard deviation 1.58). The open-ended answers shed light on this variation: some of the interviewees mentioned that they felt that their input was initially not requested in the planning phase, and that rather than asking them to try out different EDA options they were simply "-- presented with the model that the management had chosen for us" (member of the order-picking staff, February 5th 2015). When asked what the interviewees would have changed had they been given the chance to influence the decision-making, the answers included e.g. the following: "It would be better if the EDA had a strap in the back like the previous model [a thick elastic band that can be used to strap the device to the back of one's hand so that both hands can be used without laying down the EDA] because otherwise there's a risk of dropping the EDA or losing it or, in the worst case, accidentally sealing it inside a box and sending it somewhere else along with the medications!" (Member of the order-picking staff, February 5th 2015 and "It would be more convenient if there was a holder [for the EDA] … that could be attached to one of the order-picking carts" (member of

the order-picking staff, February 12th 2015). However, at least one employee agreed that they had been involved in the testing phase and that their requests for more stylus-pens and additional configurations to the devices have been taken into account.

Perceptions on employee commitment, likewise, varied between the interviewees. One interviewee who thought that employee commitment has not yet been fully attained stated: "Of course, everyone has to commit in the end. However, especially the older workers have been reluctant to pick up new technology … it really comes down to how well they can make it work, because at first it couldn't decipher all the barcodes but now it's working a lot better … if they can make it work and everyone sees how the EDA helps to make less errors then I think everyone will become committed" (member of the order-picking staff, February 12th 2015). Another person concluded that "I don't think people have objected the project as such but more so all the problems that we've faced during the implementation. After all it's very annoying when you have to reboot the EDA so often" (member of the order-picking staff, February 12th 2015).

The employees also wished for additional functionalities to the EDAs: "-- currently there's no notification when there's a new order-list that needs to be picked. With manual picking we would always see when the pharmacist put out new lists that have to be picked. With the EDA it doesn't update automatically but instead the pharmacist has to shout out when there's a new order list" (member of the order-picking staff, February 5th 2015). Another interviewee added that "-- especially with cold-stored products that are on separate order-picking lists it would be important to have a notification from the device when they have to be picked" (member of the order-picking staff, February 5th 2015).

The key findings from the interviews are that even though the employees had faced considerable problems during the implementation, they perceived that the EDA will benefit their work in the long run, that the devices were relatively easy to use, and that the implementation project is very likely to succeed. Due to the small sample size, no statistical analysis can be performed and thus no research hypothesis can be formed. However, as the findings are relevant to the second research question, a research proposition is presented:

P1: Employee perceptions on the usefulness and the ease-of-use of the EDA implementation dictate the perceived likelihood of success of the implementation project

6. Conclusions

This chapter presents the key findings of the study and relates them to the research questions, previous literature regarding the subject, and the theoretical framework. Theoretical and managerial implications are made based on the results. Lastly, limitations on the interpretability of the results and avenues for future studies are presented.

6.1. Key findings

Statistical analyses in line with the methodology used in studies by De Koster et al. (2007), James et al. (2009) and James et al. (2013) were performed to calculate the change in the efficiency of the order-picking process as well as in the order-picking and dispensing error rates. The findings from these analyses provide answers to the first research question: "How will the introduction of enterprise digital assistants affect the efficiency and medication safety of the order-picking operations at a hospital pharmacy warehouse?" In other words, the success of the EDA implementation was measured in the way that was chosen in the theoretical framework. The second research question is answered with the findings from the questionnaire and the interviews in accordance with the methodology presented in the theoretical framework.

The key findings of this study are that introducing automation in a hospital pharmacy environment can improve work efficiency without increasing the dispensing error rate. After examining prior research related to the subject, a clear research gap could be identified related to the effect of EDAs on work efficiency. A theoretical framework was formulated based on the previous literature, with three main measures to assess the success of the EDA implementation. Research hypotheses *H1-H3* answer the first research question, and research proposition *P1* provides an answer to the second research question. The following findings and research proposition can be made based on the measures:

Measures presented in the theoretical framework	Methodology used to attain results and findings	Hypothesis / Research proposition based on the results	Hypothesis testing
Measure 1: Effects of the EDA on work efficiency	Calculating rows per minute picked pre-and post-implementation (Similar to one used by De Koster et. al 2007; James et al. 2013)	*H1: Using the EDAs improves the efficiency of the order-picking process*	*H1: The results are statistically significant*
Measure 2: Effects of the EDA on medication safety	Calculating the order-picking and dispensing error rates pre- and post-implementation (Similar to one used by James et al. 2009)	*H2: Using the EDAs decreases the order-picking error rate* *H3: Using the EDAs increases the dispensing error rate*	*H2: The results are statistically significant* *H3: The results are not statistically significant*
Measure 3: Employee perceptions on the usefulness of the implementation and its likelihood of success	Questionnaire and interviews (question themes based on Burchell 2011)	*P1: Employee perceptions on the usefulness and the ease-of-use of the EDA implementation dictate the perceived likelihood of success of the implementation project*	*P1: Due to small sample size, the findings cannot be tested statistically*

Table 10 - Summary of the findings

The introduction of the EDAs resulted in a 34% improvement ($p < 0.05$) in the rows/minute efficiency rate in the order-picking phase. Moreover, the order-picking error rate that marks the accuracy of the process was reduced by 85% from 0.938% to 0.136% (chi-squared test, $p < 0.05$). However, there was no statistically significant difference in the dispensing error rate, which dictates how many medication errors are delivered to the hospital wards, and thus works as the best indicator for overall medication safety of the process. Although the aforementioned numbers may sound overly optimistic, it should be noted that similar improvements have been achieved in comparable studies before, as can be seen from Table 1. For example, in the study by Poon et al. (2005), the rate of target dispensing errors decreased likewise with 85%.

Moreover, the introduction of the EDAs resulted in a 17% improvement ($p < 0.05$) in the rows/hour productivity rate in the order receipt phase. The effects of this improvement are even more beneficial when taken into consideration that this way the products can be delivered faster to the warehouse. It is not uncommon that a product that is received in the morning is already waiting for a delivery further to the hospital wards.

The improvement in work efficiency can be contributed to a number of things, such as less time spent looking for the correct row in a list of orders, and less time double-checking that the dosage/strength is correct. The employees also needn't use as much time double-checking that they picked the correct medication among LASA (look-alike/sound-alike) medications. When taking into consideration that during the interviews the employees reported that the device occasionally disconnects from the network, discontinuing their work, it would seem that there is potential for even further improvement in productivity.

The reduction in the number of order-picking errors further contributes to the improved work efficiency: when employees make less order-picking errors, they have to re-pick items less often after the pharmaceutical inspection. In addition to facilitating the picking of LASA medications, the reduction in the number of order-picking errors can likely be contributed to the fact that checking the medications is a repetitive and tedious task for a human being, which can result in a completely understandable deterioration in focus during the working day, especially if experiencing stress or fatigue or if the picking process is continuously interrupted by additional tasks (Keers et al. 2013).

The key findings regarding medication safety presented in this study are that the EDAs notably reduce the number of order-picking errors, however, the dispensing error rate remained the same. The reason for this is that even though order-picking errors occurred more often without the EDA, the hospital pharmacists were able to prevent the dispensing of the wrongly-picked medications to the hospital wards. Consequently, in light of the results presented in this thesis, the same level of medication safety could be achieved with fewer employees. However, it has to be kept in mind that if the use of EDAs will be validated and the pharmaceutical inspection needn't longer be performed in the hospital pharmacy, this will reduce the number of safeguards from two (the order-picker and the pharmacist) to one (the order-picker using the EDA).

The interviews also provided a number of interesting findings. Firstly, even though the employees voiced their concerns regarding the issues that the project had faced, all of them considered that the project was either likely or very likely to succeed in the long run. Similar

findings are presented by Nanji et al. (2009), who observed that negative perceptions were mitigated by the functionality of the used technology. These findings are to a certain extent in conflict with the status quo bias theory (Samuelson & Zeckhauser 1988), which states that even small losses related to changing may be perceived higher than they are and thus lead to a status quo bias. However, it would seem that the employees at HHP perceive the benefits of the change higher than the costs. Also, the fact that the employees seem relatively committed to the cause could imply that they are not too committed to their old ways of working and that they do not have negative presumptions about the future of their workplace, as presented by Burchell (2011).

6.2. Theoretical implications

The key theoretical implication of this study is the inclusion of effects on work efficiency when introducing automation in the form of EDA devices. This study uses the measure of order-picking productivity presented by De Koster et al. (2007) and James et al. (2013) to measure the increase in order-picking productivity when implementing EDA devices. The results of this study show that considerable improvement in work efficiency can be achieved by automating repetitive and labor-intensive work tasks such as double-checking medications.

The literature review presented in this study also provides implications to the interpretation of error rates presented in the academic literature. As the categorization of different types of medication errors, as well where and how the number of errors are observed and recorded, is subjective to each study and their resource constraints, it can be concluded that caution should be carried out when comparing results between different studies. The medication delivery process, unlike many industrial and even some service processes, is not standardized and thus the research environment bears a great impact on the interpretability of the results, making the comparison of Six Sigma –related DPMO measures incoherent.

6.3. Managerial implications

The results of the study imply that the efficiency of the order-picking process can be improved with the help of the EDAs. This means that should the implementation be successful in a larger scale as well, more of the hospital pharmacy personnel's time could be focused on additional work tasks that call for specialized knowledge. This would leave more time for e.g. ward pharmacy and to process reverse logistics. This way, patient care and warehouse inventory management could be improved without increasing staff resources. Breen & Crawford (2005) state that "Employees whose working conditions are improved by whichever means (e.g. the introduction of automation to replace a tedious office task) can increase productivity and lead to an enriched working environment. Such improvements may also be realized by the introduction of technology to replace repetitive and labor-intensive tasks -- and ensure that experienced staff are used in a more productive manner." This shows that managers in hospital pharmacies and other similar warehouses should consider EDAs as a less-costly alternative for full-scale automation systems such as carousels and other types of warehouse robots. The full price of an EDA implementation moves in the tens of thousands depending on the size of the warehouse, the number of devices and the required software installations – a price estimate from the case organization was calculated at 60 000€ - whereas the prices for automation robots usually move in the hundreds of thousands.

Tyynismaa et al. (2013) studied the occurrence of adverse drug events (ADEs) in HUS. Their results show that 1 177 ADEs were reported in HUS in 2012. According to the authors' estimates, this corresponds to over two thousand unplanned treatment days. The cost of one treatment day in HUS is 750 euros, which accumulates to over €1.8 million in additional costs yearly. Speaking in strictly financial terms, the 'break-even point' of the EDA implementation would thus be 60 000€ / 750€ = 80 prevented unplanned treatment days, or approximately 47 prevented ADEs. It has to be noted that this calculation does not yet take into account the possible cost-savings that could be achieved by streamlining the process.

6.4. Limitations

The Hawthorne effect, first observed in the 1920s work productivity studies in the Hawthorne Works factories, may present a limitation to the interpretability of the results. The effect implies that once employees know that their work is being observed they might be enticed to work more productively, even though nothing else in the work setting was changed (McCarney et al. 2007.) As the productivity of the order-picking personnel has not been previously measured, simply the fact that they know their work is being observed during this study might motivate them to work more efficiently than normally. On the other hand, in this study their work was observed both pre- and post-implementation.

Moreover, as the pre-implementation throughput times were recorded manually whereas the post-implementation data were collected from the ERP systems, some assumptions had to be made to make the results comparable. For instance, it was assumed that extra work tasks that preceded order-picking – such as finding an available trolley, selecting the order list and locating the first medication – took on average 1 minute to complete. This assumption was based on on-site observations made by the hospital pharmacy managers. Consequently, one minute of order-picking time was added to the throughput time of each of the order-lines collected from the ERP system.

Also, the fact that some of the data were recorded by the pharmacy staff means that their truthfulness cannot be validated. However, a more reliable way of recording the results would have required the full-time contribution of at least two observers: one handling the end of the wards and the other making observations in the hospital pharmacy.

Additionally, the employees could have been more careful as they were using a new technology, causing them to pay more attention to what they are doing than usual. As employees become more and more accustomed to relying on the EDA to using the EDAs, the risk of overreliance of technology grows more significant (e.g. McDonald 2006; Emmerton & Rizk 2012).

6.5. Implications for future studies

One limitation related to the generalizability of the results is that they were obtained during a test phase when the EDAs were first taken into use with only a few customers, i.e. hospital wards. In order to conclude whether the results are applicable in a larger scale, a follow-up study should be performed once the use of EDAs has been established pharmacy-wide. In order to give the employees enough time to adjust to the new devices and the software developers to resolve all the related problems, the follow-up study should be performed 6 months to a year after the full-scale implementation has been completed.

Moreover, in order to more specifically define the effect of reducing the dispensing error rate on medication safety, a more detailed study on how many of the dispensing errors reach the patient in HHP (producing an ADE) should be carried out. This way, the probability of a dispensing error ending up all the way to the patient could be estimated. Consequently, the cost of lengthened patient stays due to dispensing errors could be calculated, in a similar way as in the study by Maviglia et al. (2007). The HUS hospital district has 22 hospitals with some 2 831 beds in total, of which 950 are located in HUCH and 118 in Haartman hospital both in close proximity to the HHP. Consequently, judging by its size HHP should be able to achieve similar results as Brigham and Women's Hospital in Boston which was subject to Maviglia et al.'s (2007) study. However, there might be additional factors that influence the implementation, for example in regards to the organization, infrastructure or information systems.

In addition, to find out the actual effects of dispensing errors on patient safety, a more comprehensive study should be carried out where dispensing errors could be tracked all the way from the hospital pharmacy to the hospital wards. This way, the average cost of one dispensing error could be calculated. Consequently, cost-and-benefit calculations could be made to test whether the investment in EDAs is financially justifiable. A similar study was performed by Sakowski & Ketchel (2013).

7. Discussion

In this part, the key findings of the study are discussed. Additional findings and observations that arose during the research process but did not fit in the scope of the research are also reviewed.

The key findings of the study show that even though the manual, pre-implementation medication dispensing process didn't produce a considerable number of medication errors, some improvement can be attained by taking into use EDA devices. The most notable benefits from the implementation are that a larger amount of orders could be processed with the same number of employees, and that the same level of medication safety could be reached with fewer hospital pharmacists placed at the end of the order-picking supply chain. This would free staff resources from the rather tedious and repetitive task of checking medications to perform work closer to the patients. Moreover, if the order-picking personnel could place the picked medications directly to the transport cases, less trained staff would be required. Additional efficiency improvements could be attained at the order receipt phase each day when new medications are delivered. The results show that the order receipt phase could be performed faster with the EDAs, which means that certain orders that are waiting for a delivery to the wards could be distributed more quickly.

However, the occurrence of emergency orders is something that should be taken into consideration when planning the EDA implementation. Although at least one pharmacist would remain as part of the process even after the EDA implementation, how the smaller number of pharmacists can handle emergency orders during rush hours is something that requires the hospital pharmacy managers' attention. This is something that should be supervised after the implementation.

Furthermore, as with any IT-related implementation, this study shows that problems and issues related to new devices are to be expected and should be budgeted enough time and resources to solve. If a full-on implementation of the EDA devices would have been rolled out with a tighter schedule, it would seem very likely that the dispensing work would have been compromised gravely. Luckily, enough time was scheduled for the implementation so that the employees had time to get used to the devices and that problems could be debugged while most of the work was still carried out manually. As it was pointed out during the interviews, the issues had

generated some dissatisfaction, however, most of the employees agreed with the long-term benefits of the devices and still perceived the change as positive. Still, employee usage of the devices should be followed to ensure that any possible error-provoking conditions are handled appropriately so that they don't develop into manual overrides or affect work quality in any other way, as discussed by Keers et al. (2013). Moreover, it is possible that as the employees get more used to the devices, the results may be further improved.

The results from previous studies (Table 1) also suggest that there could be room for further improvement. The results from the study by Oswald and Caldwell (2007) show a dispensing error rate as low as 0.03% after implementing an automated pharmacy carousel system (APCS). However, it has to be kept in mind that APCSs are notably more comprehensive automation solutions. Considering the relatively low investment costs of the EDAs, a dispensing error rate of 0.136% can be considered a fair achievement.

During the on-site observation and discussions, the inadequacy of the premises were reported on a few occasions. Work tasks requiring focus such as office work are performed right next to the loading area where container boxes are placed on the roll cages. The decibel limits of 45dB set by TTK (Työturvallisuuskeskus, The Centre for Occupational Safety) for office work are occasionally exceeded. Employee dissatisfaction might stem from insufficient working conditions, which is why these issues are also visited in the discussion section of this thesis. Thus, it could be beneficial to redesign the working environment so that the order-picking activities could be performed without obstacles. A good opportunity for this would be in the near future when HHP is moving to new premises.

While this study focuses only on barcode technology applications, other alternatives exist for automating the identification and collection of medications. Radio-frequency identification (RFID) provides a more advanced alternative for barcode technology. For example, RFID allows scanning products from a distance, without visual contact. Moreover, RFID tags are re-writable and can include individualized information, such as an expiry date. In addition, certain types of RFID tags can be used to monitor the storage temperature of the medications, a feature that would be useful with cold-stored items. RFID tags are widely in use in other logistics applications. Their downside compared to barcodes is their price, which is higher than that of barcodes. Thus, it might not be feasible to tag cheap, generic medications with RFID tags. However, with rare medications that are expensive and susceptible to expiry, RFID tags could provide a viable option. Another useful application could be narcotic medications that could be

tracked better with RFID technology. For a more detailed comparison between barcode and RFID technologies, see Appendix 5.

Tyynismaa et al. (2013) studied the results of HaiPro reports in HUS from the year 2012. A total of 10 031 HaiPro reports were submitted in 2012, of which 51% (n = 5 159) were related to medication errors. According to the HaiPro reports, the most common reasons behind the reported incidents were either unknown (26%) or related to communication or flow of information (20%). The most common corrective action was reported to be "informing the staff and communicating about the incident" (76%) and "no corrective action deemed necessary" (16%). Only a bit more than two per cent of the incidents led to planning or developing active procedures to avoid similar events in the future (Tyynismaa et al. 2013.) While this study takes a rather quantitative approach to dealing with medication errors, human factors should not be ignored. The results show that there is room for a more systematic approach to dealing with the causes behind medication errors. A root-cause analysis of the causes behind the errors would likely reveal interesting results and whether active planning or developing of additional pre-emptive measures would be appropriate.

In this study I have used both quantitative and qualitative methods to examine both technological and human-centered ways to tackle issues related to medication safety. I hope the findings contribute to discussion on medication safety and offer solutions to people working in hospital pharmacies to ensure the highest level of safety of care.

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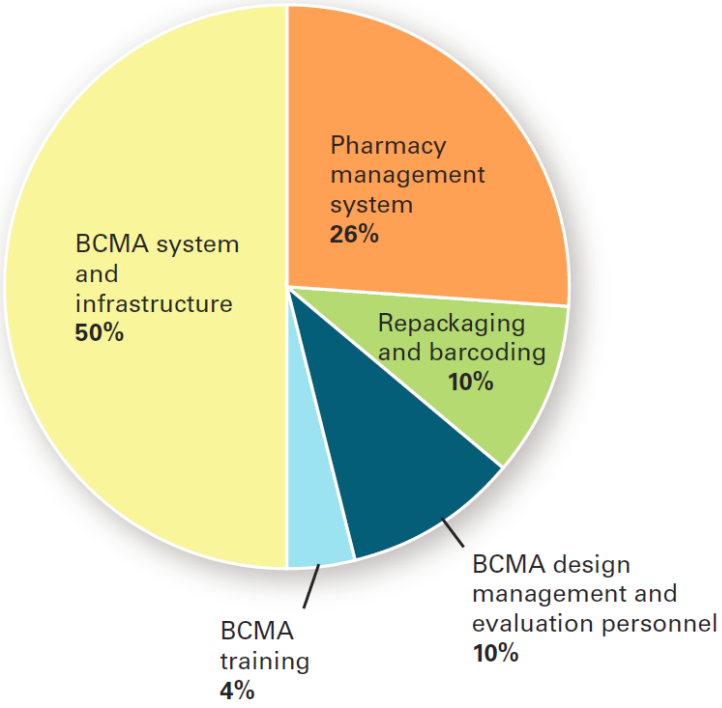
Appendices



Appendix 1 - Cost breakdown of a 5-year BCMA implementation project. Source: Sakowski & Ketchel 2013

Table 5.
Use of Machine-Readable Coding in the Inpatient Pharmacy To Verify Doses[a]

Characteristic	During Restocking of ADCs		Before Dispensing (With or Without Robot)	
	n	% Hospitals	*n*	% Hospitals
No. staffed beds				
<50	80	33.8	104	23.1
50–99	75	41.3	86	25.6
100–199	68	42.6	72	33.3
200–299	77	49.4	79	45.6
300–399	64	51.6	64	54.7
400–599	90	60.0	92	54.3
≥600	63	68.3	64	65.6
All hospitals—2011	517	43.3[b]	561	33.9[c]
All hospitals—2008[3]	. . .[d]	. . .	526	24.0
All hospitals—2007[4]	. . .	. . .	531	18.4
All hospitals—2005[6]	. . .	. . .	510	11.5
All hospitals—2004[7]	. . .	. . .	492	9.2
All hospitals—2002[9]	. . .	. . .	511	5.7

[a]ADC = automated dispensing cabinet.
[b]Uncorrected $\chi^2 = 16.4632$, $df = 6$, design-based $F(4.17, 2125.21) = 3.2964$, $p = 0.0095$.
[c]Uncorrected $\chi^2 = 38.6852$, $df = 6$, design-based $F(4.19, 2318.78) = 8.1725$, $p < 0.0001$.
[d]Not surveyed.

Appendix 2 - Use of Machine-Readable Coding in the Inpatient Pharmacy to Verify Doses. Source: Pedersen et al 2012

Questionnaire for the employees of HUS Hospital Pharmacy related to the implementation of the Electronic Digital Assistants (EDAs)

The purpose of this questionnaire is to collect employee perceptions related to the implementation of the new EDA devices, especially in regards to the order picking process, where it has not yet been fully implemented.

In your answers, please take into account that the devices and the embedded software are provided by different service providers. When answering to the questions related to the use of the EDAs, please elaborate in your answers to what extent your views are in regard to the device and in what extent to the software.

1. How useful do you think the EDAs are in regards to the order picking process?

	1 – The EDAs complicate work significantly	2 – The EDAs complicate work slightly	3 – The EDAs don't complicate or benefit work	4 – The EDAs benefit work slightly	5 – The EDAs benefit work greatly	
Complicates work	○	○	○	○	○	Benefits working

2. What kind of complications/benefits do the EDAs have in regards to your work?

_____

_____

_____

3. Do you think there will be complications in implementing the EDAs?

1 – Implementation will face considerable difficulties that will adhere with work	2 – Implementation will face slight difficulties that will affect work	3 – Cannot say	4 – There might be minor difficulties that don't adhere	5 – I don't think the implementation will face any difficulties

				with work		
The implementation will face complications	○	○	○	○	○	The implementation will succeed without complications

4. If you believe the implementation will face difficulties, please elaborate what kind of difficulties (e.g. related to the devices or the software):

_____

_____

_____

5. How well do you think that employee perceptions have been taken into consideration during the project?

	1 – Employee perceptions have not been taken into consideration at all	2 – Employee perceptions have been heard but not taken into account sufficiently	3 – Cannot say	4 – Employee perceptions have been heard and taken into account to a certain extent	5 – Employee perceptions have been heard and they have been taken into account sufficiently	
Employee opinions have not been heard	○	○	○	○	○	Employee opinions have been heard

6. In what ways do you think that employee perceptions should have been taken into account better?

_____

_____

_____

7. According to your initial expression, how do you perceive the ease-of-use of the EDAs?

	1 – I have faced considerable difficulties in using the device	2 – I have faced slight difficulties in using the device	3 – Cannot say	4 – The device has been relatively easy to use	5 – The device has been very easy to use	
Difficult to use	○	○	○	○	○	Easy to use

8. What factors have made the use easy/difficult? Have there been differnces between different functionalities (inventory, order picking, order receiving)?

_____

_____

_____

9. Do you feel that you need additional training in using the EDA? If yes, do you think you would require training in using the device or the software? What kind of training?

_____

_____

_____

10. How do you perceive the commitment of the employees to the project?

1 – The staff is resistant towards the project	2 – The staff resists the project ot	3 – Cannot say	4 – The staff is committed to a certain extent	5 – The staff is very committed

		a certain extent				
The staff is not committed	○	○	○	○	○	The staff is very committed

11. Which factors do you think affect the commitment of the staff positively/negatively?

_____

_____

_____

12. The goal of the project is to improve the accuracy of the order-picking operations and enable the performance of the pharmaceutical inspection with the device so that the pharmaceutical staff resource could be better used in other areas of their expertise. How likely do you think the project is to succeed?

	1 – I consider it highly unlikely that the project would succeed	2 – I consider it relatively unlikely that the project would succeed	3 – Cannot say	4 – I consider it relatively likely that the project will succeed	5 – I consider it highly likely that the project will succeed	
The project will likely fail	○	○	○	○	○	The project will likely succeed

13. Which factors do you think will mostly affect the success/failure of the project?

_____

_____

_____

Appendix 3 - The questionnaire

Apprendix 4: The Dolphin 70E Black & Dolphin 7800 Enterprise Digital Assistants (EDAs)

The Dolphin 70E Black EDA is the enterprise digital assistant that the HHP is planning to take into use. An older model, Honeywell Dolphin 7800 has also been in use. The device is equipped with a capacitive touch screen and WebMarela software provided by Affecto Ltd. Although the devices were originally to be implemented in October 2014, the software proved difficult to program by the software provider, due to which the implementation (and the timetable of this thesis) were unfortunately postponed. During primary testing, staff members voiced their concerns regarding the font size which they found too small and difficult to read. In the informal discussions that were had with the staff members at the hospital pharmacy premises during the testing period, some staff members complained about the battery and the fact that settings such as screen brightness were difficult to access. However, they thanked the lightness of the new EDA and the fact that they preferred the larger touch-screen to the setup of a smaller touch screen and physical buttons.

The goal of implementing the EDA's is to reduce dispensing errors and streamline the order-picking operations. Firstly, the management at the hospital pharmacy expect the introduction of barcode readers to mitigate the occurrence of human error. Human error can occur if the members of the pharmacy staff misread the name or quantity of the medicine they are picking from the shelves. Currently, the order is double-checked by a pharmacist after the order has been picked by the pharmacy staff. However, sometimes these errors go undetected by the pharmacist. This can be caused by a number of things, e.g. stress, hurry at the hospital pharmacy or difficulties to concentrate due to a noisy working environment.

Secondly, the management expect that the introduction of the devices could streamline the operations. If the practice is accepted by FIMEA (Finnish Medicines Agency), the second pharmaceutical inspection needn't longer be performed by a hospital pharmacist. This could also eliminate the last step of the supply chain where the warehouse staff pack the medicines in containers and prepare them for sending. Instead, the order-picking staff could place the medicine packages in the boxes right after picking them from the shelves and subsequently take the containers to the delivery zone where the logistics personnel could pick them up.

Figure 12 - Left: The Dolphin 70e Black Enterprise Digital Assistant used in HUS, Right: Dolphin 6100 used in Eksote

Similar devices have already been taken into use in a few other hospital districts in Finland. Eksote (Southern Carelia hospital district) took the devices into use between 2013 and early 2014. The product training consisted of one 90-minute lecture where the staff were familiarized with the functions of the device and the embedded software. The testing period started in September 2013 and lasted until January 2014. During the test period, a pharmacist inspected all of the order lists that were picked with the EDA. The software was modified along the test period anytime problems came up with its usability. For example, the browsing function was improved and a function was added for leaving a product for a second delivery.

After all the necessary modifications had been made to the software during the testing period, a validation period was started in January 2014. The validation period was initially planned to last one month, however, after a software bug was noticed the validation period was prolonged until the end of March. During the validation period, a pharmacist inspected all of the order lists that were picked with the EDA and order-picking errors were recorded.

Appendix 5: Barcode and RFID technology

The current method of identifying medications at the hospital pharmacy is using the Nordic article number, Vnr. The Vnr number is a six-digit code given to all medicine packages in the member countries. The member countries are Finland, Sweden, Denmark, Norway and Iceland.

The code can be used to identify an individual medicine package at any part of the medicine distribution chain. The Vnr code is often included in the item's barcode, however, it itself is merely a line of digits (000001 – 199999 and 370000 – 599999) and therefore alone undecipherable to a barcode reader.

Barcodes are an inexpensive and simple way of recording information. Its uses are multiple, which has made it very popular in a number of applications, such as labeling groceries and other goods. Barcode technology is already widely utilized in hospital pharmacies both in Finland and abroad. In Finland, at least the North Savo (PSSHP) and Southern Carelia (Eksote) hospital districts have already used handheld barcode readers in hospital pharmacy operations. During the validation period in Eksote hospital pharmacy, 13 errors were recorded out of 5 715 order lines, corresponding to a dispensing error rate of 0.23% (Eksote, 2014). However, not all medicine packages have barcodes on them when they are received in the hospital pharmacy. Thus, to be able to implement barcode-reading technology, the pharmacy will have to manually post barcode-stickers on some of the medications.

Although inexpensive and thus more common, barcodes do have their downsides when compared to the more expensive Radio Frequency Identification (RFID) tags. Firstly, a barcode includes only a product number, it doesn't include information such as expiry date or batch number. Secondly, barcodes are not re-writable, i.e. once a product is labeled with a barcode, it cannot be altered and information cannot be added. Barcodes can only be scanned one at a time and require a direct visual connection to be read. RFID allows scanning from a further distance, without visual contact, and multiple products can be scanned at the same time, allowing for faster scanning of multiple products at the same time.

However, the price of RFID technology is higher than that of barcode technology. The price of the tags ranges between 0.06€ - 5€, depending on the standard. The RFID readers cost between a few hundred and a few thousand euros (RFIDLab Finland, 2014.) Barcodes, which do not require a separate tag but only the ink and the material the ink is injected on, cost virtually nothing and are often included in the medications when they arrive from the medicine suppliers and manufacturers.