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Automated Guided Vehicles and Autonomous Mobile Robots in Hospitals

A Master's Thesis submitted for the degree of
"Master of Business Administration"

supervised by
Univ.Prof. Dipl.-Ing. Dr.techn. Wolfgang Kastner

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Vienna, 08.11.2021

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Affidavit

I, **SANDRA PERMANN**, hereby declare

1. that I am the sole author of the present Master's Thesis, "AUTOMATED GUIDED VEHICLES AND AUTONOMOUS MOBILE ROBOTS IN HOSPITALS", 64 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 08.11.2021

_____
Signature

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Last but not least, a big thank you to my children Maximilian, Frederick and Luisa: Thank you for your soggy kisses, your cuddles, your hugs and your words of encouragement. I love you guys to infinity and back.

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Abstract

The use of Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs) is steadily increasing. AGVs are vehicles for transporting loads and can move autonomously through buildings without the need for a driver. These vehicles are controlled by sensor-based guidance systems and software running on on-board computers and powered by rechargeable batteries. AMRs are able to understand and move around their environment without being directly supervised by an operator or moving along a fixed path. They are equipped with an array of advanced sensors that enable them to understand and consequently interpret their environment. This allows them to navigate around static obstacles such as furniture, and non-static obstacles such as people, so they are able to do their job efficiently in environments that are not suitable for AGVs. Their flexibility is the main difference from AGVs, which have to follow predefined and usually very inflexible routes. The areas of application for AGVs and AMRs are numerous. As in the past, they are mainly used in the field of internal logistics. However, there are many other areas of application that are continuously being expanded: Floor cleaning, for instance in train station halls or supermarkets, or their application for security in buildings, especially at night. Furthermore, AGVs are used in baggage handling in airports. AMRs can also provide services in hotels, such as guest reception, luggage service or room service. They also can be found in warehouses, farms, and container terminals, as well as in distribution centers, facade cleaning, and flexible manufacturing systems, as well as in aerospace and military equipment. However, AGVs and AMRs also play a major role in the logistics operations of hospitals, as well as various other healthcare facilities. A shortage of qualified staff and financial cutbacks are forcing hospitals to automate and optimize their organization. As a result, hospitals benefit greatly from the use of AGV and AMR systems through the introduction of lean management, well thought-out processes and clearly defined procedures, and standardized process management. This helps the hospital and its

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logistics department to work effectively and efficiently as well as cost effectively. In the course of the thesis, the reasons for the implementation of such systems will be investigated along with the areas of application of AGVs and AMRs including both the advantages and drawbacks as well as the benefits for the facility management. Among the most significant disadvantages are the relatively high acquisition costs for these systems. Consequently, the thesis also looks at what other potential areas of application exist for AGVs and AMRs which would provide a better justification for the substantial initial investment costs and whether these applications are worth the expense. The findings in this thesis are based on literature studies as well as interviews with an R&D department manager of an Austrian AGV and AMR manufacturer and the management of healthcare facilities.

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CHAPTER 1

Introduction

In this section, a brief background of the thesis will be presented, complemented by the definition of the research problem as well as an outline of the main research question, followed by the objectives as well as the structure of the thesis.

1.1 Background

The use of Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs) is constantly on the rise. The possible applications are diverse and go far beyond warehouse transport and the automotive industry (Ullrich and Albert [36], Fragapane et al. [22] and [21], Cramer et al. [18], Greaves [25]). AGVs are vehicles for transporting loads and are able to move through buildings on their own without the need for a driver. These vehicles are controlled by sensor-based guidance systems and software running on on-board computers, powered by rechargeable batteries.

AGVs have been used in hospitals since the 1980s and can perform a variety of transport tasks (Benzidia [15]) :

- Transporting laundry from the laundry to the wards and returning soiled laundry to the in-house laundry.
- Collecting of meals at the kitchen and delivery of these meals to the wards - refrigerated or heated, as required.

- Subsequent return of empty trays to the kitchen.
- Transport of sterile supplies between operating rooms and the Central Sterile Supply Department (CSSD)[1]
- Deployment in waste management for the transport of waste

Through continuous technical development in recent years, AMRs have been increasingly introduced in hospitals. These robots are more flexible than traditional AGVs and can also be deployed in public areas. Their primary use is for transporting small goods such as laboratory samples and for the delivery of medications, because, unlike AGVs, they can navigate around the hospital more independently, since they do not follow predefined paths but choose autonomously where to go. Service robots [2] are also being used more and more in the healthcare system, especially since Covid- 19, for example in the area of disinfection.

1.2 Problem description

Personnel and logistics expenses are the largest cost factors in hospitals [40]. The usage of AGVs and AMRs can help to significantly reduce the expenses incurred in these two cost areas. But the acquisition costs for such systems and robots are substantial, making it not a viable option for every hospital. This Master thesis examines the questions of when this investment is profitable for a hospital and what other potential use cases for AGV systems and mobile robots exist to further warrant the cost.

1.3 Research objective

AGVs and AMRs have a wide range of applications in hospitals (Pedan [32]). They take over tasks that relieve nursing staff both ergonomically and organizationally, so that they can devote their main attention to their core task - caring for their patients. The objective of this thesis is to provide an overview of the areas of application of AGVs and AMRs in hospitals. Furthermore, the advantages of their implementation for the hospital staff and in terms of costs will be investigated. It will also discuss the

[1] In german: Zentrale Sterilgutversorgungsabteilung (ZSVA)

[2] Service robot definition according to ISO 8373 is a robot "that performs useful tasks for humans or equipment excluding industrial automation applications".

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factors that justify the acquisition of such a system and the instances where it would be ill-advised to make the investment.

1.3.1 Research questions

This thesis is mainly focused on answering the following research questions:

1. Is the purchase of an AGV system for a hospital worthwhile? At which point does such an investment make economic sense?
2. Are AGVs and AMRs capable of carrying out other tasks in addition to their core tasks? Assuming so, which tasks? Will this pay off in the long run?

1.4 Thesis structure

The thesis is structured as shown below.

Chapter 1 - Introduction This chapter includes the background and problem statement for the thesis and furthermore the objective as well as the research questions and the research scope.

Chapter 2 - State of the art

In this chapter, an outline of the historical development of Automated Guided Vehicles (AGVs) leading up to Autonomous Mobile Robots (AMRs) and a representation of the areas of application of these vehicles is given, with a separate focus on the area of application in the healthcare system.

Chapter 3 - Problem statement

This chapter presents the challenges of the current healthcare system that may lead hospitals to invest in AGV and automation systems. Furthermore, it also includes a synopsis of the research questions that the thesis attempts to answer.

Chapter 4 - Research methodology

This chapter discusses the approach and methodology used to address the research questions.

Chapter 5 - Results

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This chapter contains the key findings obtained through answering the research questions. Possible measures, proposed solutions as well as obstacles are presented and discussed.

Chapter 6 - Conclusion

In the conclusion, there is a discussion regarding the answers to the research questions and a breakdown of the ensuing results.

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CHAPTER 2

State of the art

In this chapter, more information is provided about the historical development of AGVs and AMRs and in which areas they were used as well as their current areas of application. More detail is also provided on what tasks these vehicles can perform in the hospital and where their primary areas of use can be found.

2.1 Evolution of Automated Guided Vehicles

Automated Guided Vehicles, which are basically driverless forklifts and other materials handling vehicles, were invented by A.M. Barret Jr. in 1953 when he took a modified towing tractor that had been used to pull a trailer, as seen in Figure 2.1, and configured it to follow an overhead wire in a grocery warehouse, allowing the vehicle to be operated automatically. The technology soon proved to be appealing to factory and warehouse owners throughout the US during the late '50s and early '60s.

For the use in conventional factory or warehouse spaces, these areas were provided with floor markings, clear travel paths were created, with passive and active protective measures in place in order to reduce the risk for humans and to ensure that the transport of goods occurred as accident-free as possible. Safety of persons was ensured by using safety rails or "bumpers" as displayed in Figure 2.2 .

From the mid-1960s onwards, the area of application of the transport system was extended and it was now also used in individual transport, goods picking and in the food

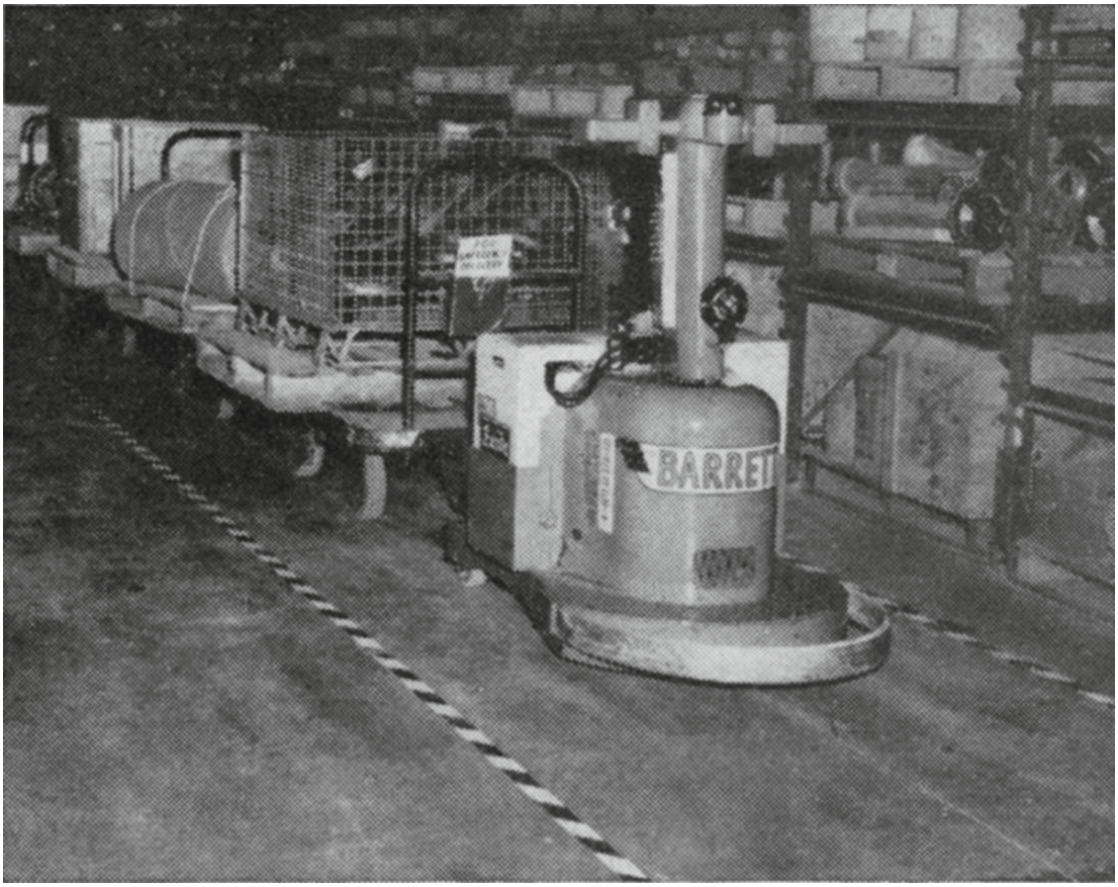

Figure 2.1: The first AGV produced by Barrett (Source: Ullrich (2019) [36], page 3)

industry. Tractors, pallet trucks and platform vehicles were automated and converted to AGVs. Magnetic sensors and simple electronics served as guidance system to specify the routes that vehicles followed. The vehicle would drive to stations in sequence, stopping at stop marks and restarting when prompted.

Track guidance was provided by current-carrying conductors in the floor or optical guides on the ground. The vehicles themselves were controlled by built-in tube technology, which was then controlled by relays and step-by-step motion, and in the late 1960s by semiconductor technology.

The classic automated guided vehicle system then emerged in the 1970s. The electronics consisted of simple on-board computers. Large control cabinets were used for block section control of the system, and wire was laid in the floor for active inductive track guidance and for data transmission. In some cases, data was transmitted via this wire

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Figure 2.2: AGV with safety bumper (Source: Moshayedi et al. (2019) [31], page 6)

and in rare cases [36] via infra-red or by radio. The system capabilities and system controls were improved and the vehicles could thus be used more flexibly. Whereas in the 1960s it was only possible to move the vehicles forwards in one direction, they were now finally also capable of moving backwards and moving "two-dimensionally". Demands for AGV systems grew steadily, especially in the automotive industry. The systems were integrated into production processes by using the vehicles as mobile workbenches in series assembly as can be seen in Figure 2.3 [36].

At the end of the 1980s, demands dropped sharply and the large AGV plants in Europe were discontinued. The main reason for this was that Japanese car manufacturers were now able to supply higher-quality products at lower prices. As a result, from the mid-1990s until 2010, new technical standards were created by equipping vehicles

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Figure 2.3: AGVs as mobile workbenches in series assembly (Source: Ullrich and Albrecht (2019) [36], page 9)

with electronic controls and non-contact sensors. The control system was now simply operated via a commercially available PC. In the driver-less vehicle itself, a programmable logic controller (PLC) or a microcomputer was used. The string-line guidance was replaced by magnetic and laser navigation, and data transmission was carried out via WLAN from this point on.

In addition, AGVs now became increasingly used in intra-logistics. The unilateral mode of transport that had been the norm until then was replaced by a complex transport network in which several vehicles were used, with the result that the transport of goods became much more flexible. On production lines, existing staging racks were converted into automated logistics units, and AGV systems were used more frequently in hospital logistics. Progress in computer and sensor technologies made it possible to further develop vehicle and control technology. This enabled the vehicles to operate faster and more agile. The manufacturing and acquisition costs decreased, while new navigation methods such as magnetic point, laser, transponder and building navigation increased the range of applications. Transponder and building navigation were expanded. System control was carried out via PCs, and data was transmitted for the most part via WLAN.

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Interest in AGVs also increased among universities and other research institutions. A number of innovative solutions were developed. The Fraunhofer Institute IPA, for example, developed the "Care-O-Bot", one of the first service robots. The University of Duisburg, on the other hand, launched the "MobiRob", an industrial robot on a mobile platform. The first AGV swarms also were developed.

2.2 Current state of the art and fields of application

AGVs and AMRs continue to be used predominantly in the field of internal logistics. However, there are now many additional fields of application that are being continuously expanded. According to Ullrich and Albrecht [36], AGVs can be used for floor cleaning, for instance in train station halls or supermarkets, or for security in buildings, especially at night. Furthermore, AGVs are used for baggage handling in airports, as for example at Miami Airport, where an automated baggage handling system was installed in 2019. AGVs and AMRs also provide services in hotels, such as welcoming guests, luggage service or room service. But they also are found in warehouses, on farms, at container terminals, in distribution centers, for facade cleaning, and in flexible manufacturing systems, as well as in aerospace and as military equipment [37]. Figure 2.4 [21] shows an oversight of areas for the application of AMRs.
AGVs and AMRs however, are also playing a significant role in the logistics sector of hospitals, as well as in various other healthcare facilities.

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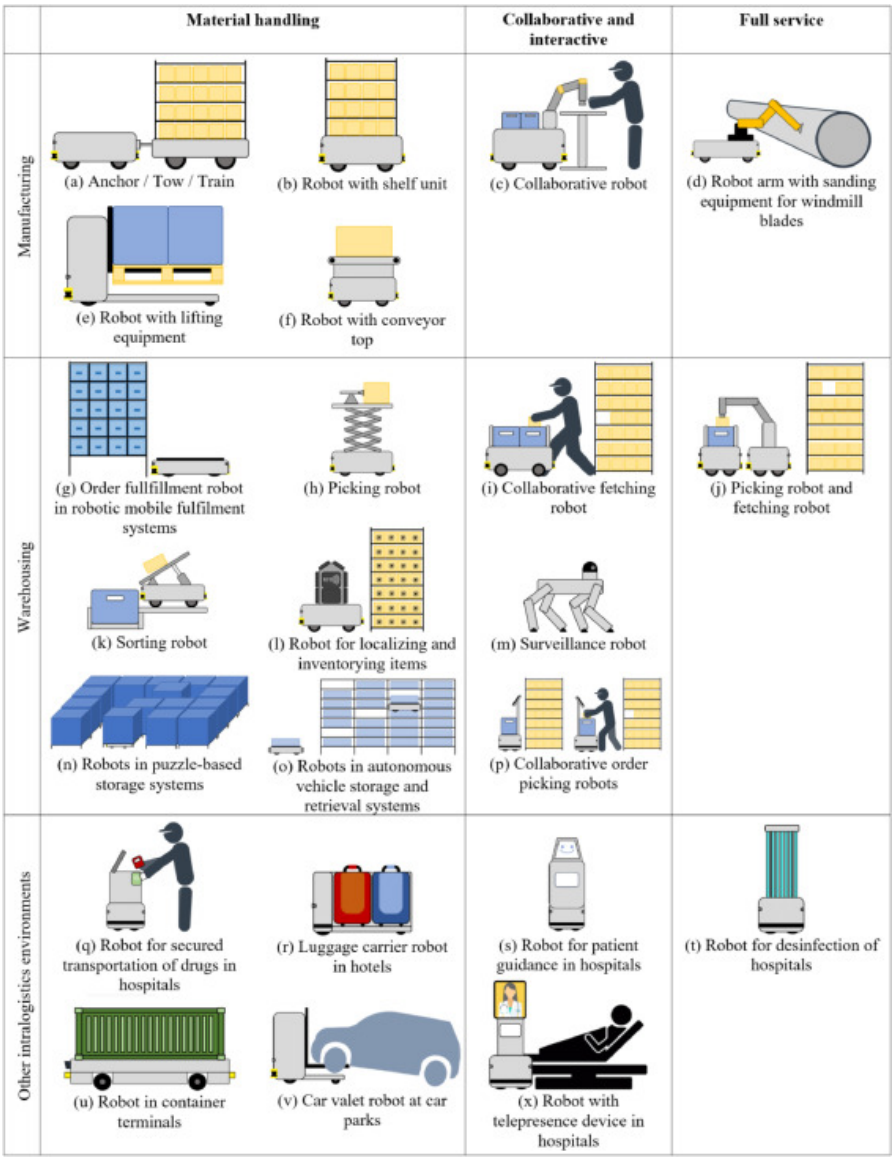

Figure 2.4: Areas of application of Autonomous Mobile Robot (AMR) (Source: Fragapane et al. (2021) [21], page 3)

2.2.1 Automated Guided Vehicles vs. Autonomous Mobile Robots

AGVs are driverless vehicles and mobile robots used for transport loads that are operated by on-board computers. These self-driving vehicles are capable of navigating without human intervention and are operated with rechargeable batteries. Figure 2.5 shows such a vehicle.

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Figure 2.5: SSI Compact Load AGV (Source: [8])

Main elements of an AGV system: An AGV system basically consists of vehicles, control system, the pick-up and delivery stations and the transport network as shown in a video produced by Kollmorgen in 2019, which and can be accessed via the link in Figure 2.6.

AMRs have the ability to understand and move through their environment without being directly supervised by an operator or moving along a fixed path. AMRs, as seen in Figure 2.7, are equipped with a range of advanced sensors that enable them to both understand and consequently interpret their environment. As a result, they have the ability to navigate around static obstacles such as shelves as well as non-static obstacles such as people, resulting in them being able to perform their work in environments not suited for AGVs with efficiency. Their flexibility is the main difference to AGVs, which are required to follow pre-set and usually very inflexible routes. In contrast, AMRs have the ability to select the most efficient route.

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Figure 2.6: Components of an AGV system (Source: [2])

Figure 2.7: Autonomous Mobile Robot MiR100 (Source: [4])

2.2.2 Types of Navigation

AGVs and AMRs can be broadly divided into three groups, with the distinction closely linked to the vehicles' navigation types which can be seen in Figure 2.8 and Figure 2.9 .

The name "Automated guided vehicle" already implies that these vehicles are guided. For this purpose, several methods are available.

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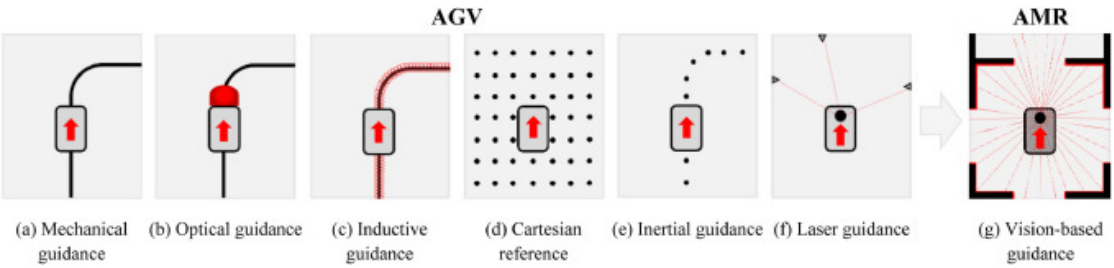

Figure 2.8: Guiding systems of AGVs and AMRs (Source: Fragapane (2021) [21], page 2)

- The classical AGV, which is track-bound, with magnetic sensors in the ground - magnetic point navigation as seen in Figure 2.10.
- The system with predefined tracks without magnet hole in the ground, but with self-localization.
- Free driving system with self-localization, which does not follow predefined tracks, but has a defined free area on the floor.

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Figure 2.9: Navigation technologies (Source: Kollmorgen [6], page 4)

2.3 Mobile robot application in hospitals

Automated Guided Vehicles were introduced in the field of material transport in hospitals as early as the 1980s. How they can be used in the hospital today is shown in Figure 2.11.

Primarily, they are used for the transport of large and heavy goods:

- Transportation of meals from the main kitchen to the wards in special food containers, which are either heated or cooled. Once the meals are over, the empty

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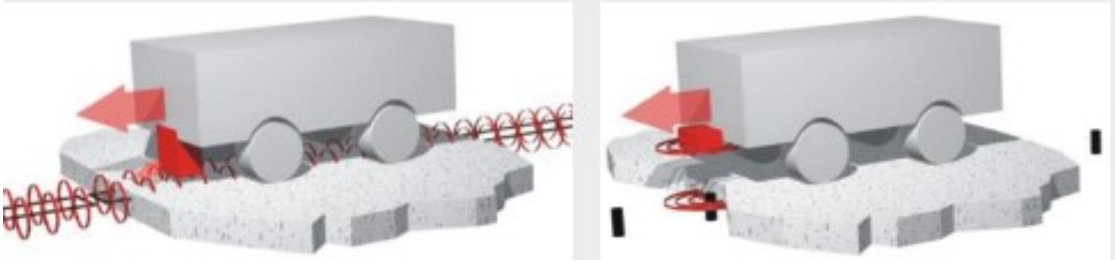

Figure 2.10: Navigation with two types of magnetic sensors (Source: Ullrich and Albrecht (2019) [36], page 36)

trays then travel back to the kitchen.

- Laundry delivery from the laundry to the wards and return delivery of dirty items.
- Waste collection throughout the hospital and delivery to the garbage collection area.
- Transportation of sterile supplies between CSSD and the operating rooms.
- Delivery of medications from the in-house pharmacy to the wards.
- Delivery of specimens to laboratories.
- Mail delivery to the respective departments.
- Patient transport.

Many hospitals still use pneumatic tube systems to dispatch laboratory samples and pharmaceuticals from the wards to the laboratories or from the in-house pharmacies to the wards and departments. In the future, however, these systems will increasingly be replaced by far more sophisticated systems such as AMRs, as seen in Figure 2.12 and Figure 2.13. One of the main reasons for this is that any modifications to pneumatic tube systems are structural in nature and require changes to the building structure, for example to walls or wiring. AMRs, on the other hand, can be used more flexibly, are easily reprogrammed, and are ready for operation without significant structural changes. In addition, AMRs are better in terms of data protection, as it is possible to restrict the access to authorized persons only.

According to Volland [40], logistic- related activities make up one of the largest cost items after personnel costs in the hospital. The manual delivery of transport goods

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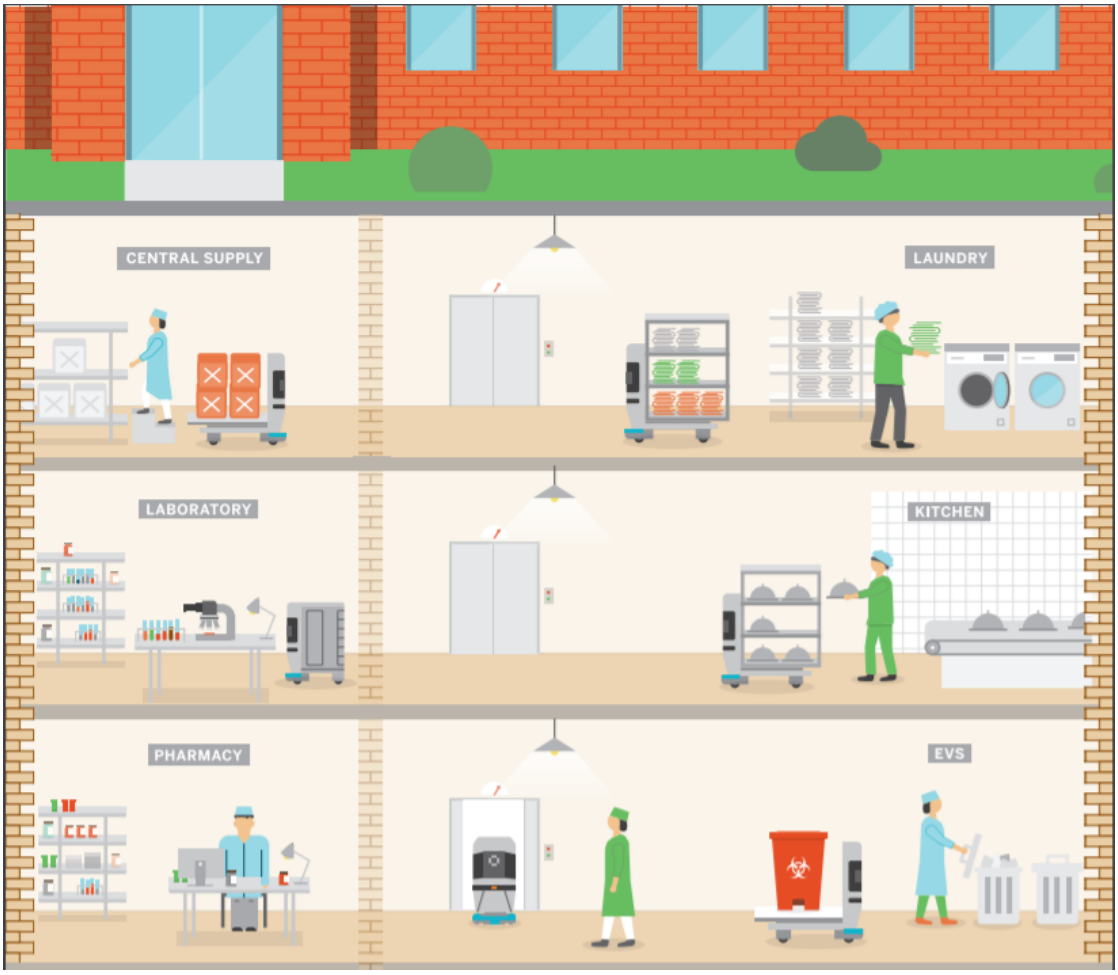

Figure 2.11: Mobile Robots in hospitals (Source: Aethon [5], page 2)

generates higher costs and the healthcare staff is bound to dedicate a significant amount of time to carrying out this type of work. By using automated systems and mobile robots, transport of goods can be carried out more efficiently resulting in an improved quality of service, or as Granlund [24] states in her paper "*[...] automation of hospital internal logistics can be a tool in improving the efficiency.*" Additionally, automated systems and mobile robots are more flexible than pneumatic tube systems, and there is also no need for significant structural changes required by their installation.

AGVs can cover large distances. These factors among others are the reasons behind the impact of AGV systems on hospital logistics as a whole. The fact that AGVs sometimes use the same elevators and facilities - unless they are restricted to freight

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Figure 2.12: Sally Courier DS Automotion (Source: DS Automotion [7])

Figure 2.13: Sunway Heroes Hospital logistics robot (Source: Sunway Heroes [9])

elevators - as healthcare staff, patients and visitors does also have a major impact on hospital operations. Therefore, it is essential that internal logistics are adapted to achieve positive long-term results and that a holistic approach involving the hospital's entire information system is needed to deploy automated systems.

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CHAPTER 3

Problem statement

This chapter describes the problems addressed in this thesis: the challenges of the current healthcare system leading to the investment in AGV and automation systems by hospitals.

"*A well functioning internal logistic system is critical for the overall function of healthcare operations, but often is the value adding processes of patient care diminished by numerous logistic activities required by the hospital staff. The vision is an efficient supportive logistic system, enabling the staff to focus on activities value adding for the patient.*" [24].

Hospitals are very complex systems that involve an extensive network of organizations (see Figure 3.1) that must work together for the various processes.

A multitude of changes, as well as financial cutbacks, result in the need for numerous healthcare organizations to both rationalize their resources and to optimize their flows [15]. Inpatient care is currently under great pressure to change, especially in industrialized nations. The long-term goal is to make nursing-related and patient-centered care more professional and to relieve nursing staff by reducing the number of non-professional tasks they have to perform. Logistics is involved in many of the indirect care activities that medical staff tend to spend time on. Due to decreasing financial and human resources in healthcare, the use of AGVs, AMRs and Service Robots in hospitals along with organizational and interdisciplinary focus is gaining increasing importance [27].

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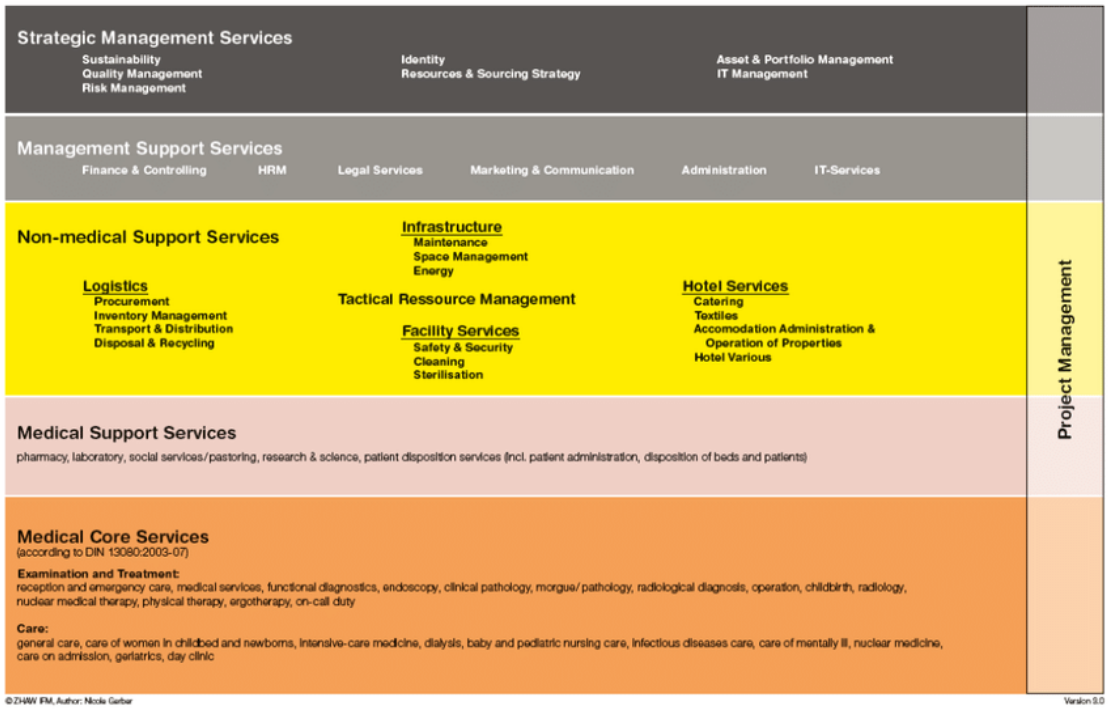

Figure 3.1: Service Levels in hospitals (Gerber (2016) [23], page 12)

Figures 3.3 and 3.2 and numerous surveys and reports show that healthcare staff in hospitals are required to devote a considerable amount of time to activities that fall into the category of low-value routine tasks, but which require time that is not spent on direct patient care. These tasks, which also include traveling long distances and very often ergonomically strenuous work, result in nursing staff being less available to care for patients, and often only with delays. The use of AGVs and AMRs can massively reduce this time.

A holistic approach to healthcare is generally required, encompassing management and organizational issues. Resources must be rationalized and processes optimized. As a result, many processes must be automated, including logistical processes. After all, logistics costs account for 30% of hospital spending, according to [15] in reference to [33] and [28] .

The high initial capital costs of AGV systems also pose a significant problem. The acquisition of an AGV system is very expensive in the short term and as a result many hospitals shy away from the investment costs, as it takes some time for the

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investment to amortize. Consequently, hospitals prefer to continue to invest in the hiring of additional staff or in the purchase of alternative equipment, such as tractors or forklifts.

The objective of the thesis is to study if the acquisition of an AGV system and AMRs is worthwhile. Not only will the costs themselves be examined, but also further benefits for the hospital will be scrutinized. Moreover, it is investigated whether there could be further areas of application for AGVs and AMRs that better justify the high acquisition costs and whether those applications are feasible.

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Activity	Time (%)
Direct care	
Patient hygiene	12,5
Nutrition	3,9
Treatment	3,9
Observation/examination	3,5
Transportation/physical training	3,2
Support and information/teaching	2,8
Category sum	29,8
Indirect care	
Report/information	8,7
Food handling	7,7
Own transportation	6,6
Handling of medication	5,6
Care documentation	5,4
On-call/Preparedness	3,7
Paper/computer work	3,2
Cleaning/bed-making	2,7
Phone calls (incoming/outgoing)	2,2
Rounds	2,2
Transport outside the unit/ward	1,7
Medicine preparation	1,3
Supply room handling	1,3
Washing/dishing	1,1
Care planning	0,2
Monitoring	0,1
Category sum	53,6
Administrative time	
Conference/education/information	3,0
Administrative paper/computer work	2,2
Staff planning/recruitment	1,8
Teaching/supervision of staff and students	1,0
Staff/support dialogue	0,7
General assignments	0,6
Quality/research/improvement work	0,3
Category sum	9,6
Personal time	7,1
Total sum	100

Figure 3.2: Time allocation per activity (Granlund (2013)[24], page 9)

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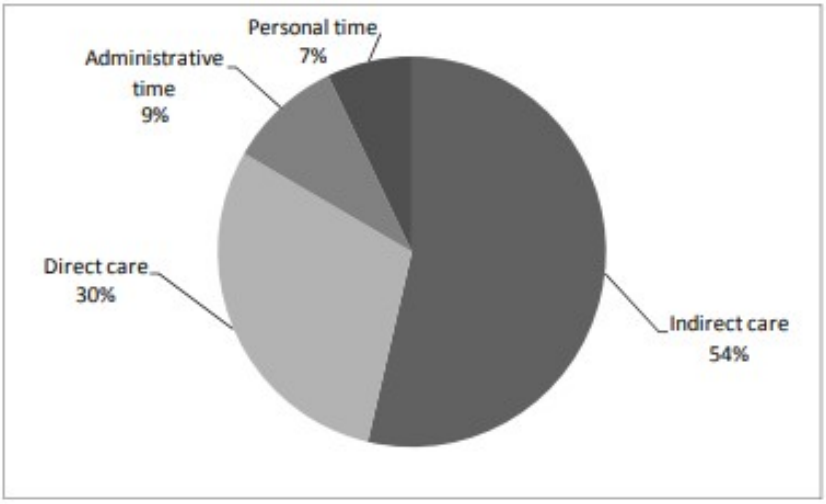

Figure 3.3: Time spent on activities by health care professionals. (Granlund (2013)[24], page 9)

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CHAPTER 4

Research methodology

This section provides a discussion and a description of the approach and methodology used to address the research questions.

4.1 Approach

For this thesis, a combination of two research methodologies was used: first, an extensive literature review and, based on this research, semi-structured interviews with an employee of DS Automotion and an employee of an Austrian hospital where at the time of the interview an automated system is currently not in use.

Interviews with an employee of the company DS Automation were conducted semi-structured. The starting point was a questionnaire that was prepared in advance. This however only served as a guideline, as the interview itself was very informal, even though a large part of the topics in the questionnaire were being covered. The interview was conducted via Zoom. Informal and semi-structured approach, mixture of pre-determined questions, which then resulted in a free-flowing conversation about various aspects related to areas of use of an AGV. Notes were taken during the interviews, however the conversations have not been recorded.

4.2 Literature study

Literature review was used to conduct research and gain knowledge of the current state of art of AGVs and AMRs, the historical evolvement and the general areas of use as well as areas of specific application involving AGVs and AMRs in hospitals. As a general introduction into the topic, the book "Driverless Transportation Systems" [36] served as a comprehensive overview of the historical development of AGVs up to the fields of application in the 21st century. On the basis of the knowledge gained, keywords as defined in Figure 4.1 could be formulated to narrow down the search in the desired research field. The literature search was started in the "Catalog Plus" of the library of the TU Wien. Cross references and references in the literature retrieved there led to an increased use of Google Scholar, which had a large and comprehensive database on the topic. Very often the searches on Google Scholar linked to the database of ScienceDirect (https://www.sciencedirect.com/) and to the IEEE Xplore library (https://ieeexplore.ieee.org/), both of which provide a significant amount of literature on the subject of this thesis. The main source of research information was found in published papers or reviews. An additional resource, especially for the chapter on the state-of-the-art, were the homepages of well-known manufacturing companies of Automated Guided Vehicles (AGVs), which provided very comprehensible information on the applications of AGVs.

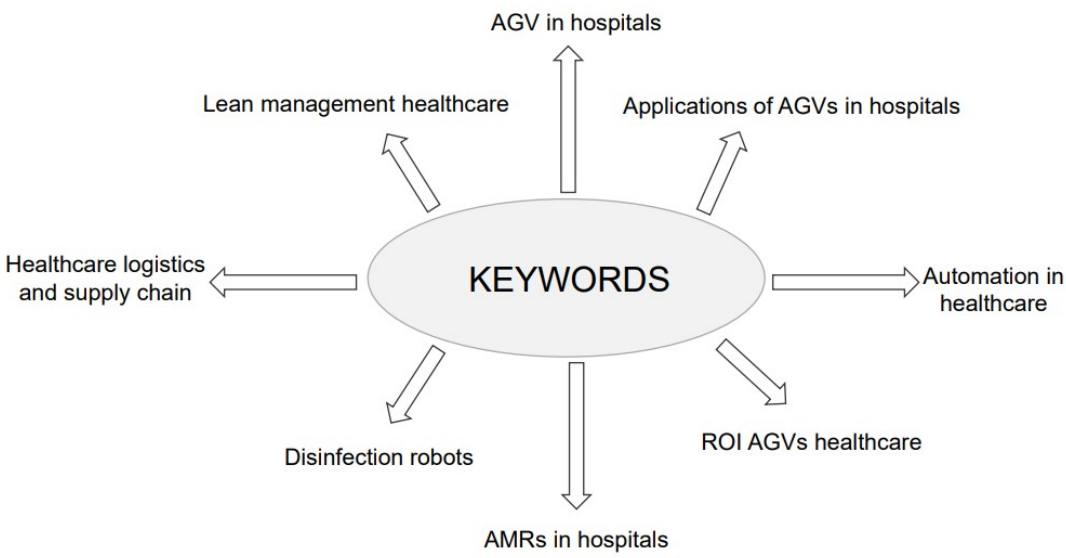

Figure 4.1: Keywords for literature research

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As part of the literature search, articles and journals listed as below in Table 4.2 were studied, however not all publications viewed are referenced in this thesis. This was due to the fact that some publications were very informative in terms of content, but the material was then not applicable to the master thesis. However, some key- words and bibliographic references led to further literature.

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Author	Title	Year
Ageron et al.	Healthcare logistics and supply chain – issues and future challenges [12]	2018
Antony et al.	Design and Implementation of Automatic Guided Vehicle for Hospital Application [13]	2020
Bechtsis et al.	Sustainable supply chain management in the digitalisation era: The impact of Automated Guided Vehicles [14]	2017
Benzidia et al.	Investigating automation and AGV in healthcare logistics: a case study based approach [15]	2019
Bhosekar et al.	Simulation optimization of automated guided vehicle system in a health care facility [16]	2018
Cardarelli et al.	Cooperative cloud robotics architecture for the coordination of multi-AGV systems in industrial warehouses [17]	2017
Cramer et al.	Benchmarking low-cost inertial measurement units for indoor localisation and navigation of AGVs [18]	2019
Dobrzanska et al.	Modern logistics in health service [20]	2013
Diab-El Schahawi et al.	Ultraviolet disinfection robots to improve hospital cleaning: Real promise or just a gimmick [19]	2021
Fragapane et al.	Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda [21]	2021
Fragapane et al.	Material Distribution and Transportation in a Norwegian Hospital: A Case Study [22]	2018
Gerber et al.	How FM can enable the increasing need for process orientation in hospitals [23]	2016
Granlund and Wiktorsson	Automation In Healthcare Internal Logistics: A Case Study On Practice And Potential [24]	2013
Greaves et al.	Key questions about the future of laboratory medicine in the next decade of the 21st century: A report from the IFCC-Emerging Technologies Division [25]	2019
Ho et al.	A multiple-attribute method for concurrently solving the pickup-dispatching problem and the load-selection problem of multiple-load AGVs [26]	2012
Kriegel et al.	The requirements and applications of autonomous mobile robotics (AMR) in hospitals from the perspective of nursing officers [27]	2021
Kritchanchai et al.	Develop a strategy for improving healthcare logistics performance [28]	2017
Kumar and Rahman	RFID-enabled process reengineering of closed-loop supply chains in the healthcare industry of Singapore [29]	2014
Mittal et al.	CASE STUDY Technology in healthcare: A case study of healthcare supply chain management models in a general hospital in Singapore [30]	2017
Moshayedi et al.	AGV (automated guided vehicle) robot: Mission and obstacles in design and performance [31]	2019
Pedan et al.	Implementation of Automated Guided Vehicle System in Healthcare Facility [32]	2017
Poulin	Benchmarking the hospital logistics process [33]	2003
Prabhakar et al.	Design and Simulation of an Automated Guided Vehicle through Webots for Isolated COVID-19 Patients in Hospitals [34]	2020
Turing	On computable numbers, with an application to the Entscheidungsproblem [35]	1936
Ullrich and Albrecht	Fahrerlose Transportsysteme [36]	2019
Vaule	Measures for Timely Delivery of Materials Transported by Automated Guided Vehicles (AGVs) in Hospitals [37]	2018
Vis	Survey of research in the design and control of automated guided vehicle systems [38]	2006
Vishwakarma	Components of Automated Guided Vehicle: A Review [39]	2019
Volland et al.	Material logistics in hospitals: A literature review [40]	2017
Wang and Chang	Facility Layout for an Automated Guided Vehicle System [41]	2015
Yousefli et al.	Maintenance work flow management in hospitals: An automated multi-agent facility management system [42]	2020
Zheng et al.	Laser-Based People Detection and Obstacle Avoidance for a Hospital Transport Robot [43]	2021

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4.3 Interviews

For the collection of secondary data, the form of qualitative interviews was chosen. To this end, both an unstructured and a semi-structured interview were conducted. For the unstructured interview, an employee of a regional hospital in Western Austria was chosen to conduct the interview anonymously and without being recorded. Therefore, the interview yielded little usable data, but provided some impetus for further literature research. The second interview was semi-structured and was done with an employee of the company DS Automotion, one of the European market leaders in the field of automated guided vehicles for hospitals in Europe. During this interview, a series of questions and topics were addressed, which the author of the thesis had previously compiled in the form of a questionnaire (see appendix). This allowed a more detailed look into a particular topic if required, as well as a more flexible approach when needed.

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CHAPTER 5

Results

Within this chapter, a discussion of the main findings acquired from the research is presented and it attempts to answer the research questions in a conclusive and comprehensive way. Possible measurements, proposed solutions and obstacles are introduced and then discussed.

5.1 Automation in hospitals

A growing and aging population, not to mention Covid-19, is placing a tremendous strain on existing health care resources that is steadily increasing. This means that the cost of health care is increasing proportionately, while funding is not increasing at the same rate. In addition, the workforce is aging and the shortage of skilled workers in the marketplace is increasing. Therefore, it is inevitable to change the accustomed and traditional ways of working. As a result, automation in the medical field is advancing. The introduction of AGV systems and RFID are making a significant contribution to relieving healthcare staff of numerous manual tasks, many of which are not only very time-consuming but also physically demanding. Kriegel et al. [27] also suggests that non-nursing work such as administrative tasks, messenger services, etc. should be delegated to less qualified staff to make up for the shortage of skilled workers.

Each hospital requires a customized system because each hospital has different requirements for the number of vehicles used, the number of pick-up and drop-off points, and

the utilization of the vehicles. These considerations must be made at three different levels:

- The Tactical Level, where management of AGV systems, vehicle scheduling, work order for vehicles, battery management, determination of the number of vehicles required must be determined,
- The Operational Level, where routing, localization of obstacles and ways to avoid them, design and control of the routing system are determined, and
- The Strategical Level, where the planning of the routing is done in relation to the different connections within the network (the network being the hospital), i.e. the positioning of the pick-up and delivery stations.

There are also different system models, depending on the needs of the customer: Leasing and operator models, where the operator can be both the company supplying the system or the hospital itself. In Austria and Germany, the common practice is for the hospital itself to be the operator.

In new hospitals, the level of automation is higher because there is better infrastructure and the number of available technologies is higher. Thus, automation is incorporated into the planning process from the beginning, whereas in an existing hospital, the technology and operating systems must first be upgraded. Those responsible at DS Automotion have found that integrating AGV systems in existing hospitals is much easier in most cases, as there are already working procedures and processes in place. In new buildings, such as the Floridsdorf Clinic, there were no tried and tested processes and procedures - and above all no clearly defined logistics procedures. In this case, new processes and procedures have to be created from scratch and it takes a relatively long time to optimize the system, processes and procedures.

Using Kriegel's [27] roadmap in Figure 5.1 [27] as an example, we can see what the modular adaptation of hybrid AMR services to existing structures and processes might look like.

Transport Flow

Fragapane et al. [22] describe in their case study of a Norwegian hospital how such transport flow may occur and also illustrate it in their control model in Figure 5.2 [22] as follows:

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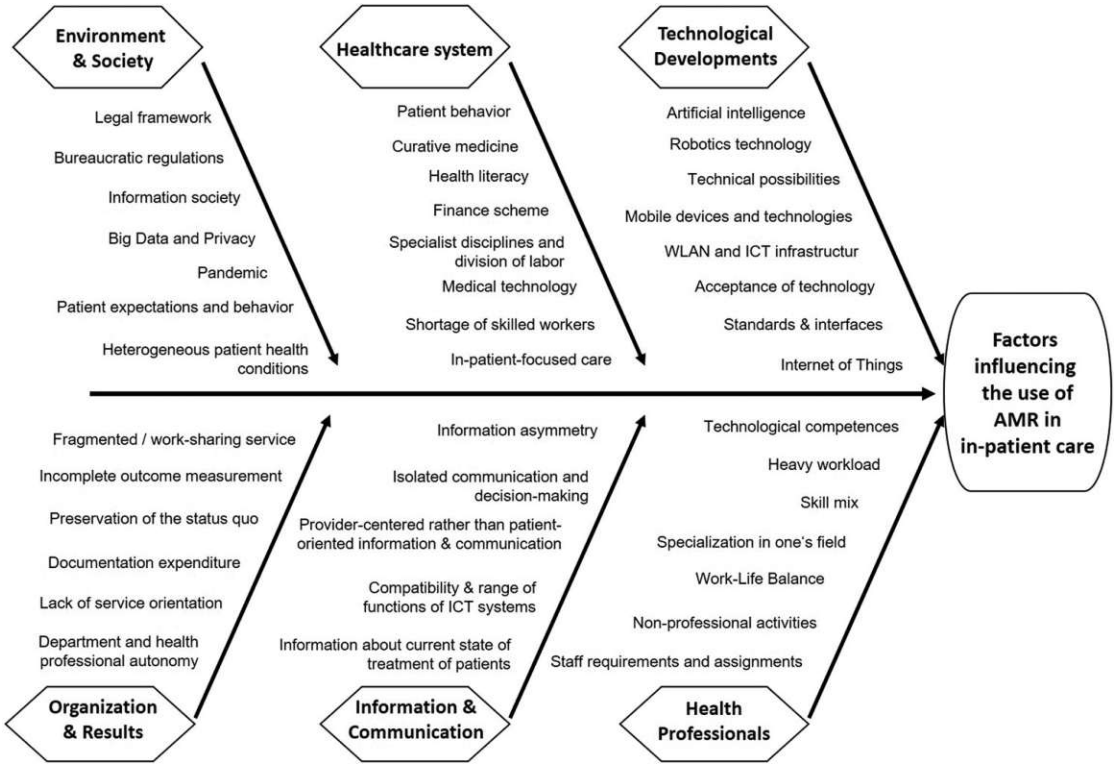

Figure 5.1: Factors for the use of AMRs in hospitals(Kriegel et al. (2021) [27], page 5)

"There are six main groups of goods supporting the daily operations of the hospital. The six groups consist of consumer goods, laundry, food, sterile goods, pharmaceutics, and waste. Many suppliers are connected to the hospital supply chain, shipping goods directly to the hospital or to its warehouse. At the warehouse, the products are stored and sent to the departments when needed. The hospital's warehouse packs the wagons according to the orders from the departments and places an RFID-tag[1] on the wagon that includes information about its final destination. Trucks transport the packed wagons several times during a day to the goods arrival at the hospital, based on a schedule. When the truck returns, it takes the empty wagons back to the warehouse. On a daily basis, clean fabrics at the laundry are packed into wagons and shipped by trucks to the goods arrival at the hospital. At goods arrival, the wagons are moved to the AGV pick-up station. The RFID-tag will be read by a RFID-reader on the AGV,

[1]Radio Frequency Identification (RFID) is a technology that uses wireless and contactless radio waves to transmit data. This allows items equipped with RFID- tags to be identified both automatically and uniquely. At hospitals, for instance, these are affixed to linen and medical equipment [29]. As a result, they are automatically inventoried.

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which sends information to the AGV system. The RFID-tag contains information about the order and delivery destination. On the return, the truck takes the dirty fabrics and wagons back to the laundry. In general, the goods on the wagons are transported to specified delivery places at the departments. When the wagon arrives at its destination, the AGV system sends a message to the department and its person in charge. The person in charge collects the goods, and then the wagon is placed at a pick-up station or is filled with a new order of goods before being placed at a pick-up station. To initiate return transportation of a wagon by an AGV, the wagon has to be placed at a pick-up station with a RFID-tag informing the wagons final destination. The wagon is then picked up by the AGV and transported to the final destination."

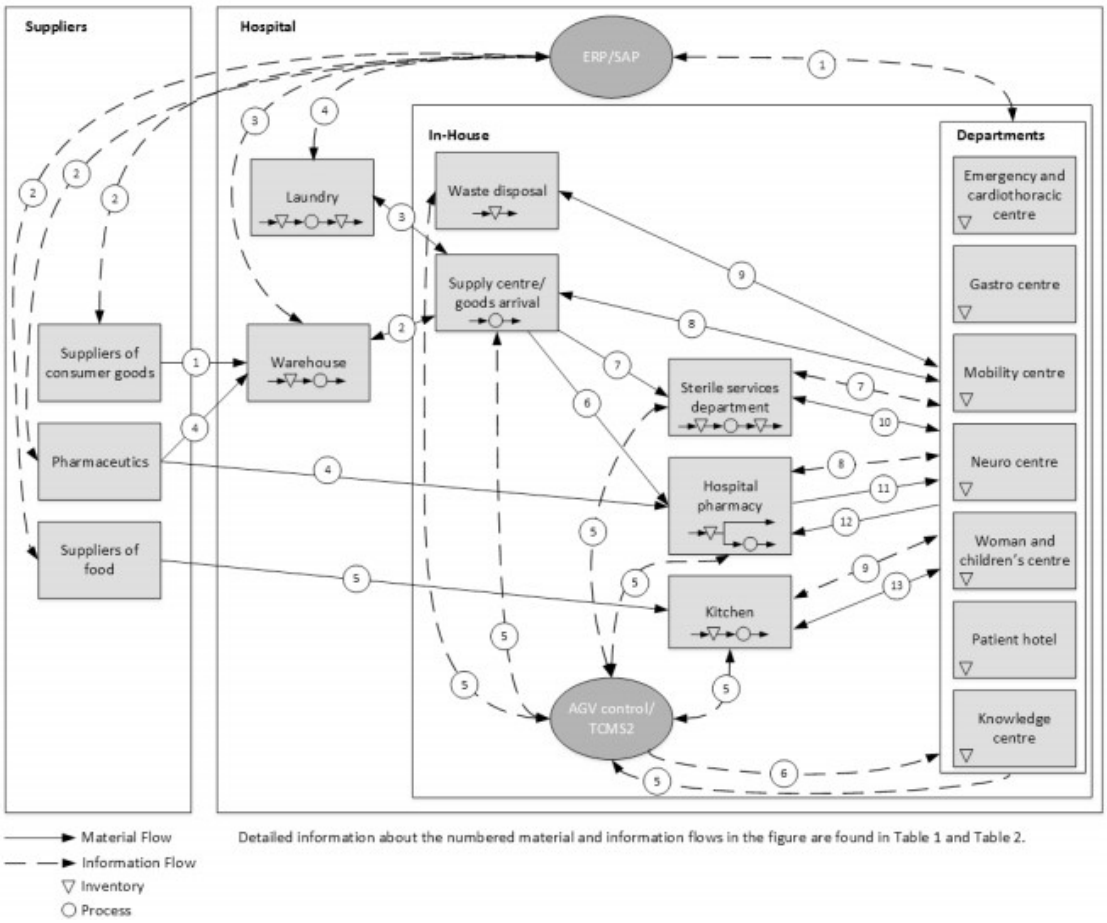

Figure 5.2: Control Model of goods handling in a Norwegian Hospital (Fragapane (2018) [22], page 354)

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The hospital's supply chain[2] must be coordinated with the AGV system. This is a very demanding process, as it involves developing advantageous solutions and distributing responsibilities appropriately. It is also important to integrate an interface between AGV and manual operations into the viable process. AGVs are capable of transporting goods vertically and horizontally because they can access elevators compared to other conveyor systems. Of course, solutions can also be designed where material handling is manual, semi-manual and automated. There are simply not enough common practices or standards in this area because each hospital has different structures and tools [40], so a customized solution is required.

5.2 Area planning

An important aspect of acquiring and integrating an AGV system is also space planning. The following important points must be clarified in advance:

- Where are the departments located and how are they arranged?
- Where are the various delivery centers located?
- How can the AGVs be integrated with manual and external processes[3]?

The capacity of the delivery routes must be designed to allow the vehicles to move without difficulty: Elevators and aisles must be wide enough, vehicles must fit well through the (elevator) doors, and they must be able to fit in the elevators. Predefined environmental conditions such as floor conditions, ambient light and surroundings must be right for AGV systems to function optimally. If this is not the case and these conditions must be created or maintained at significant expense, this can result in additional costs that may not have been budgeted for. Establishing a fixed schedule for vehicle deployment is also important. Although the system can operate on demand, it is more profitable in the long run if there is a clearly defined logistical schedule within specific time windows.

[2]The supply chain includes: Supply, procurement, inventory management, distribution and planning.

[3]External systems include elevators, doors, fire alarm systems and access control systems, among others, with which the AGVs must cooperate.

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5.3 Holistic approach

Hospitals are very complex structures consisting of a large number of departments. This produces a large number of data and in order to manage this data, a customized information system for each hospital is essential. The requirements of such a system can be seen in Figure 5.3. This illustration also shows that a holistic approach is required for the implementation of such a system. All the workflows and processes of each department must be taken into account in order to be able to guarantee efficient processes. It is therefore essential that automated systems such as AGVs and AMRs must also be integrated into the information system in such a way that their workflows and processes interact and work together with the existing procedures and processes. Only by doing so will it be possible to provide better healthcare for patients in the long run.

Introduction of lean management

"From the moment we automate we are constrained to reconsider and re-examine our logistics flow system. Since dedicated software needs to be programmed to manage the AGV, we need to question the relevance of what exists" [15].

As a result of the introduction of automated processes, there are naturally changes in the logistical processes. But there is also now a need for an effective and efficient management system to manage the automated logistics operations of AGVs.

When implementing Lean Management - Lean working[4] in hospitals, automation via AGVs and AMRs is feasible because it improves workflows and increases productivity in healthcare. Numerous strategies for technology management already exist regarding organization, function, applications and processes, since technology is essential for productivity to leap, as Granlund and Wiktorsson [24] pointed out.

It is expensive to customize logistical processes for each ward. A standardized way of working with efficient flows is therefore necessary. For this reason, lean principles are a very sensible approach to adopt here..

[4]Lean management is a method in which processes are to be continuously optimized, waste (things that do not add value to the final product) is to be minimized("creating value without waste") and the entire value chain is to be made more efficient. Processes and responsibilities must be clear in order to increase productivity.

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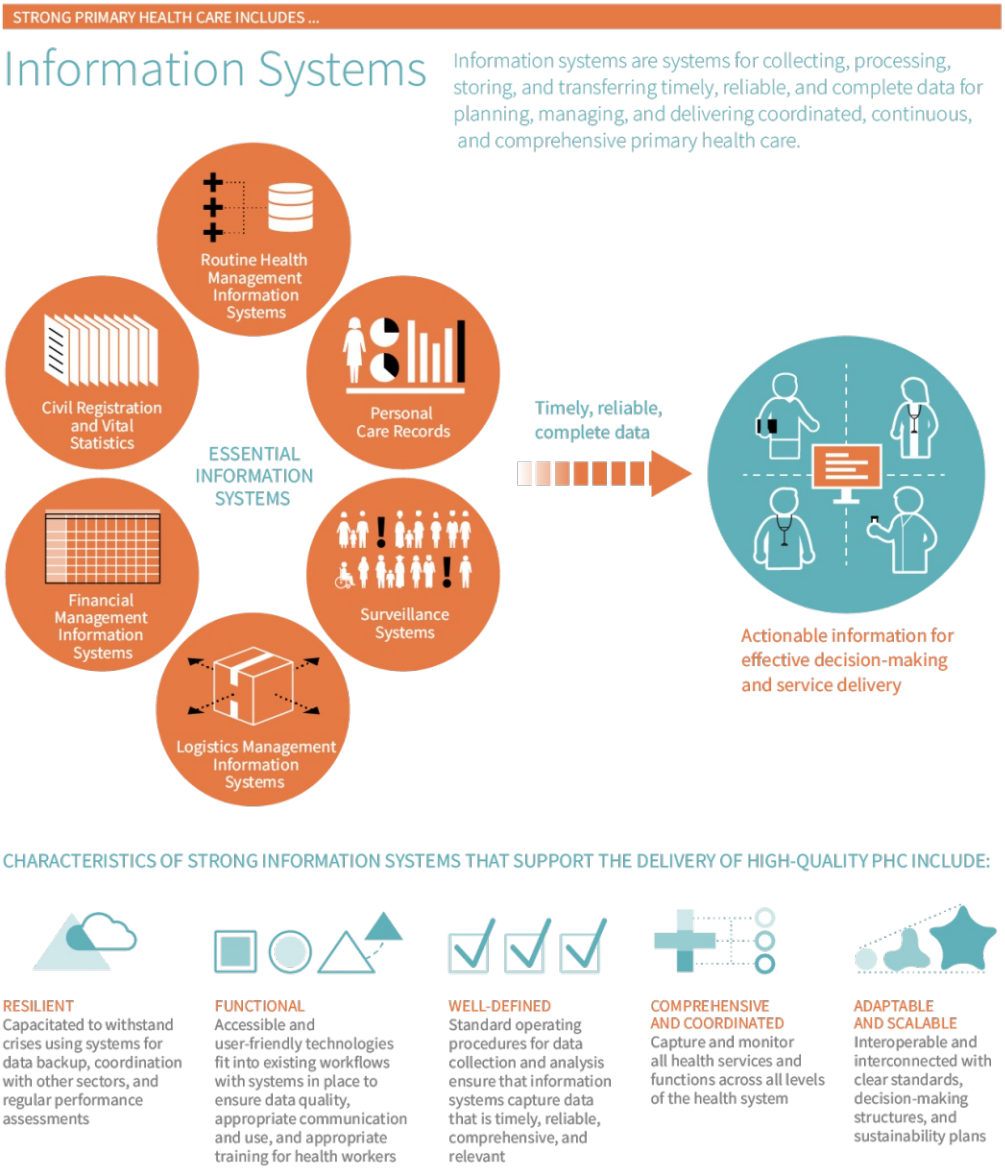

Figure 5.3: Information systems in hospitals [3])

5.4 Advantages and disadvantages of AGV systems

There exist some valid reasons for the acquisition of an AGV system, but sometimes there are also viable considerations for not making the investment. These advantages and disadvantages are discussed here.

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5.4.1 Advantages

Advantages for AGV systems that are repeatedly mentioned [14]:

- Cost efficiency
- Savings in personnel costs
- Improved adaptability
- Increased safety
- Increased eco-efficiency by replacing diesel-electric drive systems with lithium-ion and lead-acid batteries, which produce fewer emissions and thus have a lower impact on the environment.
- Less energy consumption
- and higher productivity

As a result, through the process of automating many of the hospital's operations in the areas of catering, laundry, sterilization, waste and pharmaceuticals substantial cost savings can be achieved.

Granlund and Wiktorsson [24] demonstrate how many employees are needed to transport small items such as blood, samples and pharmaceuticals. In the case presented, there were 55 employees who performed these activities. The Landeskrankenhaus Innsbruck, an Austrian example, has more than 30 employees in the logistics department alone who are responsible for the logistics of transporting goods. The hospital in Innsbruck, however, does not have an automated system. Due to the high personnel costs, this is a significant cost factor in the total expenses of this department. In their study, Dobrzanskas et al. [20] show that the number of employees in the logistics department can be significantly reduced through automation.

AGVs offer many advantages over manual transport systems in hospitals:

- They are more flexible,
- are more cost-effective in the long run,

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- can be loaded and unloaded automatically,
- and utilization is better because there is no dependence on existing human labor [15].

AGV systems are system flexible and can be expanded systematically as needed: A good example is the University Hospital in Cologne. DS Automotion installed an automation system with AGVs there as early as 2003, which has since been expanded and adapted several times.

As shown in Figure 5.4, the time saved by the healthcare staff through the utilization of AGVs is also a major advantage for the hospital.

Staff	Activity	Current state (min.)	After AGV integration (min.)	Time reduction (min.)
MA	Morning toilet	150	150	0
	Blood test subscription	300	300	0
	Clean laundry delivery	75	0	75
	Breakfast delivery	60	0	60
	Lunch delivery	90	0	90
	Afternoon toilet	300	300	0
	Dinner preparation	30	30	0
	Dinner delivery	60	0	60
	Evening toilet	300	300	0
	Dirty laundry transport	60	0	60
	Total	**1440**	**1080**	**345**

Figure 5.4: Time reduction of healthcare staff in different scenarios(Pedan (2017) [32])

The AGV system has higher fixed costs than a manual transport system [14]. However, it also has the higher economic potential, as the variable costs and labor costs are lower. But the benefits of AGV systems are not only monetary:

- Fewer workplace accidents because the likelihood of human error is reduced.
- Less property damage when loading goods.
- Up to 99% utilization because vehicles are in operation almost around the clock. The only exceptions are battery charging times and maintenance and repair times.

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5.4.2 Disadvantages

One of the counter-arguments to the purchase of an automated system, which keeps coming up, in addition to the high initial costs, is the uncertainty about the maintenance and operation of the system. In the interview with the DS Automotion representative, this issue was also addressed, and their approach to solving it is as follows: AGV systems are designed to last a long time. Depending on the Service Level Agreements (SLA), maintenance is performed by DS Automotion every six months according to the maintenance contract. The SLAs for service personnel vary widely and are adapted to the customer's needs - because every hospital is different.

Another challenge with automation and the use of an AGV system is that a higher technical level is required. Therefore, the demands on service and technical personnel naturally increase. Higher competencies and more diverse skills [15] are required in the area of technology and IT, which translates into higher demands on staff skills.

Moreover, in Austria and Germany, hospitals are the operators of the AGV systems and staff are trained to maintain and repair the systems themselves. The training costs for the staff can be one more point considered as a disadvantage.

5.5 Advantages and disadvantages of AMRs

Just as with AGV systems, there are both arguments for and against the purchase of AMRs.

5.5.1 Advantages

- AMRs can act autonomously: Obstacles can be detected without assistance . The robot can react swiftly to changes in the environment and can therefore also be used among a human crowd.

- AMRs are flexible: They, contrary to AGVs, do not need a predefined path. In most cases, a starting point and a destination point are all that is required. In between these points, the robot creates its own path by detecting obstacles via scanning them and then navigating around them. Because of this, AMRs are much more flexible than AGVs, a fact that makes it much easier to use them for new tasks, as they are not bound to predefined routes. Any changes made

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to AGVs in terms of routes and environments involve substantial structural and financial effort. AMRs, on the other hand, only need to be reprogrammed and can be quickly deployed for new routes.

- AMRs can be installed quickly: AMRs can be installed quickly because the necessary software is already part of the product. Interfaces to the existing software, for example of production lines, are now an industrial standard. This enables an uncomplicated transfer of work orders for AMRs into the existing system. AMRs can thus be integrated into the existing logistics setup within a matter of weeks, depending on the complexity of the task at hand.

- AMRs are compatible with a wide variety of add-on modules: AMRs can be equipped with various add-on modules: Containers, hooks, conveyors, platforms and racks as shown in Figure 5.5, as well as grippers. Consequently, their fields of application are quite flexible.

- AMRs are a reliable workforce: They can operate on a 24-hour basis, depending on their battery runtime. Furthermore, they are much more accurate, compared to their human counterparts.

- The use of AMRs puts employees at less risk and they are subject to less physical strain: With AMRs, employees are exposed to fewer potential risks and occupational accidents can be reduced as a result. In addition, the robots can also be used in work environments that can be dangerous for humans, for example in nuclear power plants.

- AMR systems are easy to expand and to upgrade: Their easy implementation in a facility makes it possible to expand an AMR fleet without difficulty. Starting with just a few units, it is possible to upgrade and purchase new robots on an ongoing basis as and when required. This can help to avoid high investment costs at the beginning.

- Locations and area of operation of AMRs can be changed easily: AMRs can be taken to other locations in a very uncomplicated way. Thus, they can be used in several departments in hospitals since the simple implementation makes it very easy to exchange the vehicles between different departments.

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- Utilizing AMRs makes it possible to reduce labour costs: They can take over many tasks that were previously performed by human workers. In addition, damage to equipment is less likely to occur. This results in the reduction of operating costs.

Figure 5.5: AMRs with add-on modules (df Automotions & Robotics [1])

5.5.2 Disadvantages

- AMRs can only be loaded to a limited extent: The load capacity of AMRs varies by model and manufacturer but is generally limited. Compared to AGVs, the vehicles can only carry a maximum of one ton. They are therefore better suited for lightweight tasks, which of course limits their application possibilities considerably.

- Low speed: The driving speed of AMRs must be limited to 7 km/h for safety reasons, to protect the people around them so they can react to their actions.

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- High initial costs: The initial cost of an AMR can seem very high. But as described in Chapter, in the long-term a positive Return Of Investment (ROI) can be achieved.

- Requirements for the area of use are high: The area surrounding the AMR should not be too damp or too dusty, otherwise the AMR's sensors will be disturbed, making navigation problematic. Floors and interfaces between rooms must also be as even as possible. Adequate space for navigating must also be available.

- Long charging time: The battery life of AMRs can vary, as can the charging time. Charging can take up to three hours. During this time, the vehicles are not operational, and this time is regarded as downtime, and if required, must be compensated for by using additional AMRs.

- Safety risks and safety specifications: Precisely defined safety specifications are necessary for the commissioning of AMRs so that the risk of injury to people in the immediate vicinity of the vehicle, for example due to overloading of the device, can be avoided as much as possible.

5.6 Return on Investment (ROI) and costs

Rising healthcare spending but a lack of matching funds means many hospitals are reluctant to invest in an automated system. For an AGV system to be profitable for the hospital, its profitability must be calculated before it is purchased. For this purpose, a comparison between the costs of conventional transport methods (manual, semi-automatic with tractor), if necessary an RFID system, as was done in the case of Mittal et al. [30]), as seen in Figure 5.6, and the desired AGV system is essential. Only in this way can the return on investment be determined and the profitability compared.

5.6.1 ROI

Return on investment (ROI) is difficult to calculate because each AGV system must be tailored to each hospital. This customization of the system derives from the fact that each hospital differs both structurally and in terms of the building structure, such as the size of the hospital, the number of rooms, the number of different departments, and the medical focus. These factors then result in the different processes and procedures in hospital logistics and departments. In turn, the AGV system has to cover the

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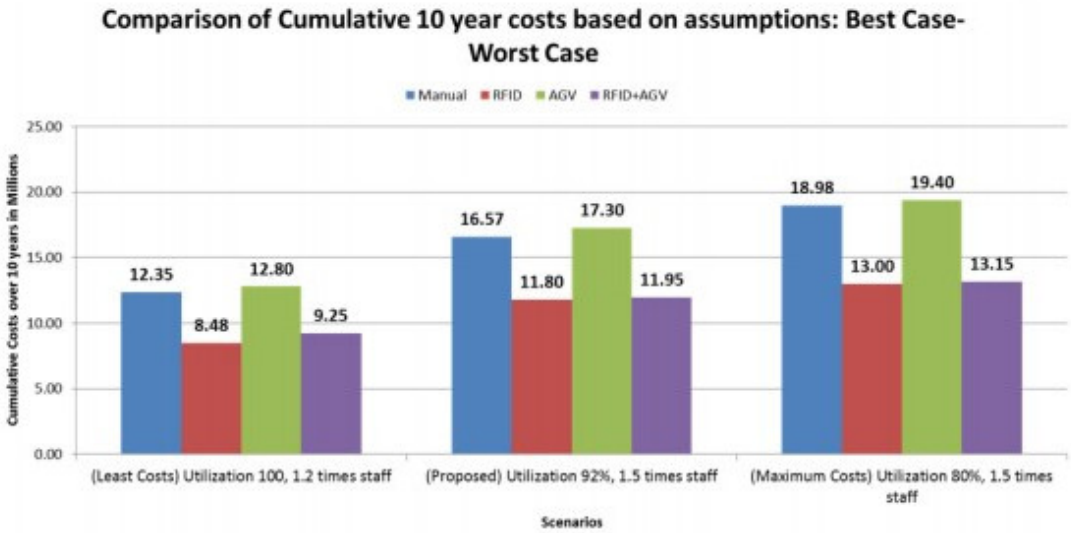

Model	Total Amount (10 years)	Range* in Million USD	Manpower Requirement (Range)
Manual	$16.5 M	12.3M- 18.9M	55 (41-63)
RFID (automated inventory check)	$11.8M (-4.7M)	8.5M- 13.0M	38 (27- 42)
AGV (Automated Transport/Delivery)	$17.3M (+0.8M)	12.8M- 19.4M	53 (38- 60)
RFID+AGV	$11.9M (-4.6M)	9.2M- 13.1M	34 (25- 38)

*Range: Based on Best Case- Worst Case Scenario; all prices in USD

Figure 5.6: Cost comparison between different systems (Mittal et al. (2017) [30], page 68)

requirements and needs of these departments. As a result, every calculation of ROI is unique. In addition, the break-even point, shown in Figure 5.7, is only part of the calculation. AGVs are depreciable assets that last for years. After the high initial investment in an AGV system, the capital expenditures are low. The long-term impact and cost savings over a 10-15 year vehicle life cycle have to be taken into account when calculating ROI.

These are factors that should also be considered in a cost calculation. It is also important to keep in mind that the final return on investment for installing an AGV system includes not only direct costs such as hourly wages, equipment, maintenance, etc., but also indirect costs. Indirect costs are all those factors whose value is difficult to determine: improved efficiency, increased safety, redistribution of labor, to name a few. The adaptation of the hospital environment must also be calculated. This is what happened in the calculation in Figure 5.8

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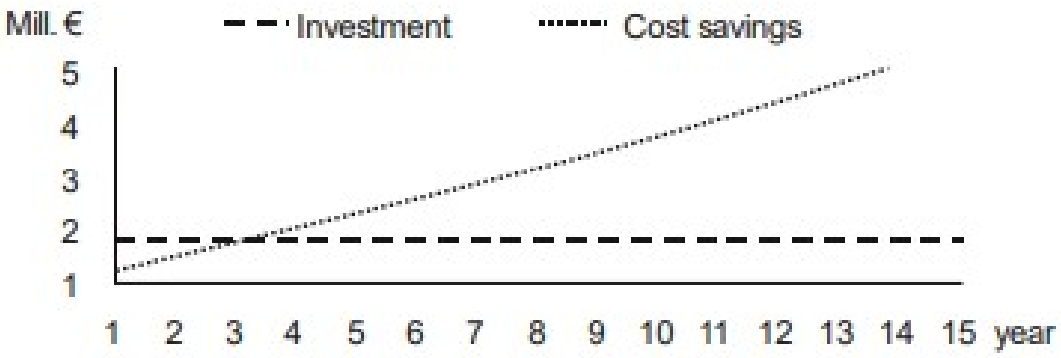

Figure 5.7: Break-even point and cost savings (Dobrzanska et al. (2013) [20], page 62)

Costs	Price (€)	Comments
Purchasing and setting AGV cart	50, 000	
Installing and marking AGV navigation	700	Floor marking
Customization of hospital environment	65,000	Door, elevator and AGV interface
Total	**115,700**	

Figure 5.8: The investment intensity of integrating AGVs (Pedan et al. (2021) [32], page 669)

5.6.2 Costs

At DS Automotion, the AGV "Sally", seen in Figure 2.12, costs €30,000 as a basic element without a container. The system is then adapted and expanded according to customer requirements. This then results, in part, in the total cost of the system. "Sally Kurier", the AMRs sold by DS Automotion, in contrast, costs €50,000 without complete system and €80,000 including complete system[5]. Even if the initial investment seems expensive, the fact remains that automation through AGVs and AMRs, especially in the logistics process, is an essential tool for improving productivity, which in turn reduces costs.

It is important to mention that the purchase of an AGV system is worthwhile only above a two or three shift system regarding the logistics personnel. Prior to this, the investment in an automated system is not economically viable.

[5]Complete system is a closed system, with operation directly on the vehicle through an integrated control panel, and no external system.

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5.7 Secondary applications for AGVs and AMRs

5.7.1 Room mapping via laser scanner

CAD plans are an important tool in Facility Management (FM), as they form the basis for space management. But they can also serve as basic data for mapping the AGV systems. At DS Automotion, these are referred to as "contours," according to our interviewee. This data can be captured by the vehicles themselves offered by DS Automotion. Using laser scanners, it is possible to measure and to map a room or an entire building. However, the sensors have a limited accuracy and the data is thus only sufficient for a rough inventory, but not for an accurate one. The safety laser scanners used are usually too inaccurate for a map or floor plan. DS Automotion has equipped an AGV with a Faro 2D scanner[6] to capture this data. With the help of 3D scanners, it is also possible to create a digital 3D model for Building Information Modeling (BIM). In the course of possible renovation work, this 3D model can then be of great advantage, especially in project planning. However, this also requires the right program to process the collected data. Furthermore, the initial cost of such equipment is quite high and amounts to approximately € 50,000 [7]. In addition to the laser scanner and the program for recording and processing the data, one or more people are also needed to process the data so that it can be used by the end user. Such an investment is obviously not profitable for a hospital, since the necessity of a building area evaluation is rarely required. If needed, external companies specialized in this area can be hired to perform the survey.

5.7.2 The use of AGVs and AMRs in times of Covid-19

During times of Covid-19 as well as other pandemics, the use of AGVs and AMRs shows to be particularly useful, as the reduced number of contact points can reduce the risk of infection. For instance, robots can be used to supply food to patients as well as deliver other necessities such as medication and to remove waste from patient rooms without requiring hospital staff to come into direct contact with patients. Robot also do not spread diseases and are able to move through quarantine stations without the risk of infection. In addition, their use can greatly reduce human interactions in the

[6] Faro: `https://www.faro.com`

[7] Pricing based on DS Automotion interviewee and the pricing on the website http://www.3dcad-gmbh.de/3d-laserscan/laserscanner-kauf-miete/3d-laserscan-system-kaufen.html

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event of a pandemic.

5.7.3 Disinfection robots

Figure 5.9: UV- Desinfection Robot Yezhik(www.aitheon.com [11])

Following the outbreak of Covid-19, the use of disinfection robots has been steadily increasing. Their use contributes significantly to the reduction of the risk of infectious diseases and other dangerous pathogens. Especially the demand for UV-robots has been increasing considerably. By using Ultraviolet (UV) light, viruses and bacteria can be killed and a room can be disinfected. Despite the fact that there are now several suppliers and models on the market, as seen in Figure 5.9 and Figure 5.10, the acquisition, maintenance and repair costs associated with these robots can be very

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high and it is questionable in many places whether these investment costs are justified. A significant advantage of using a disinfection robot is definitely the creation of an automatic disinfection log, which allows to check at any time if and when a room has been disinfected.

Figure 5.10: UV-Desinfection Robot (www.mobile-industrial-robots.com [10])

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5.7.4 Others

Other potential applications for AGV systems could include:

- Sensor control: Room monitoring through sensors mounted on the vehicle, such as room temperature, humidity, light intensity, etc.
- Security: AGVs and AMRs could take over security rounds.
- Collection of lost items.

Problems:

- Sensor control: Are the sensors of sufficient quality to record the data? Does the vehicle need to be upgraded at great cost to achieve the desired result?
- For security checks by vehicles at night: Is the environment well enough illuminated? If there are not enough lumen in the lighting, the built-in lasers may not be usable, for instance.

In addition to insufficient lumen in lighting, dirt can also affect the use of a laser. In general, the use of AGVs and AMRs in hospitals is complex depending on many factors and regulations- hygiene, hospital, radiation, volume. Strict hygiene regulations must be met, hospitals must be structurally suitable for such use, radiation matters, as does the noise level of the vehicles themselves. These points must be taken into account when installing an AGV system and using AMRs, and they also play a significant factor in determining whether an additional task area is possible for a vehicle.

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CHAPTER 6

Conclusion

In the conclusion, a discussion of how the research questions have been answered occurs. The results are analyzed and a final summary is presented.

This thesis has aimed to find answers to the following research questions:

1. Is the purchase of an AGV system for a hospital worthwhile? At which point does such an investment make economic sense?
2. Are AGVs and AMRs capable of carrying out other tasks in addition to their core tasks? Assuming so, which tasks? Will this pay off in the long run?

The first part of research question (1) is straightforward to answer, because there is considerable literature on how the introduction of automated systems such as AGVs and AMRs can relieve health care personnel [24], [27]. On (2): Secondary tasks which can be physically demanding and time-consuming can be taken over by the assigned vehicles, so that the medical staff of a hospital can concentrate more on their main task: caring for the patients. As to the the second part of research question (1), a literature research was conducted, which also includes studies on Return on Investment and costs ([20], [32], [30]), as well as the conducted interviews. As a result, it has become clear that the acquisition and installation of these systems is paid off after few years, depending on the scenario ([20] [18]).

To get answers to the question (2) in detail, a deeper research study was necessary next to two qualitative interviews with an R&D department manager of an Austrian AGV and AMR manufacturer and the management of healthcare facilities. The interviews conducted were revealing in answering the research questions, as they provided a deeper insight into the field and also realistic prices for the purchase of each system. AGVs and AMRs can very well be equipped with additional devices and sensors to perform secondary tasks in addition to their originally planned tasks. A cited example of this is the mapping of a room. In the course of the research, however, it became apparent that the acquisition of additional equipment rarely pays off. Instead, it is often more cost-effective to commission external companies with these additional tasks, as they already have the necessary equipment, the expertise and, above all, the specialized personnel required to handle the resulting information.

In the beginning, the assumption was made that upgrading AGVs and AMRs with additional equipment would result in a greater benefit for the end user, in this case, the hospital, because not only would the healthcare staff be relieved through the automated systems, but the accumulation of additional data such as room mapping as well as room monitoring through sensors attached to the vehicle, e.g. room temperature, humidity, light intensity, etc., could also result in a further benefit for facility management. The research unexpectedly led to the realization that, at this point in time, it is not worthwhile for a hospital to add additional equipment to AMRs and AGVs. For one thing, it is difficult to create the appropriate baseline conditions for the data to be recorded at all, as the environment must be suitable - light conditions, cleanliness, floor conditions - for satisfactory results to be obtained. Secondly, the complexity of using AMRs and AGVs for additional tasks bears no relation to the additional costs involved: Acquisition costs for additional equipment, the creation of a suitable environment, the processing of the collected data, for which skilled staff is required, which then again means higher personnel costs.

As a result, at this point in time, such an investment in add-on equipment and additional duties for AMRs and AGVs is not recommended. However, since there is continuous technological development and constant research into the improvement of AMRs, AGVs and sensors, it cannot be ruled out that the situation could improve soon.

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Acronyms

2D Tow-dimensional.

3D Three-dimensional.

AGV Automated Guided Vehicle.

AMR Autonomous Mobile Robot.

CAD computer-aided design.

CSSD Central Sterile Supply Department.

FM Facility Management.

PC Personal Computer.

PLC Programmable logic controller.

R&D Research and development.

RFID Radio Frequency Identification.

ROI Return Of Investment.

SLA Service Level Agreement.

UV Ultraviolet.

WLAN Wireless local-area network.

ZSVA Zentrale Sterilgutversorgungsabteilung.

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Appendix

Questionnaire for the interview with DS Automotion, conducted on February 17, 2021

Question 1: Which systems/ vehicles is DS Automotion selling for hospitals?

Question 2: What do they offer that differentiates them from their competitors on the market?

Question 3: What about value creation? Why should a hospital - from a financial point of view - purchase such a system?

Question 4: At what point does such an investment pay off (ROI= Return of Investment) What is the minimum size of a hospital that an acquisition makes sense?

Question 5: How does the acquisition process work? Leasing? Rent? Purchase?

Question 6: How does the process work? Who installs the system and software? Who operates the system? Who trains the people? How is the system/software integrated into the overall hospital system? What happens in the event of a system failure?

Question 7: Looking ahead, what will be the latest developments in this area in the near future?

Question 8: What additional data, also related to building automation, can these vehicles record? Example: map for self-location is necessary - can this data be passed on to the customer so that they can update their floor plans? Or does DS Automotion get this data from the customer - new buildings / BIM?

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