AMR: influencing factors and potentials of cloud-robotics

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DOI: http://dx.doi.org/10.25673/103490

Abstract
In recent decades, automated guided vehicles (AGV) have become the symbol of automated material flows in intralogistics. Technological progress helps AGVs to achieve an ever-higher degree of autonomy, enables free navigation and has led to AGVs nowadays increasingly being called autonomous mobile robots (AMR). This constant technological progress requires that the field and use of AMR be constantly reviewed and improvements sought. One potential approach, especially to make AMR fleets more efficient, flexible and scalable for future deployment, is cloud-robotics, whose main advantage is the on-demand provisioning of various IT-services. The aim of this paper is to determine the currently critical influencing factors regarding efficient AMR deployment and to highlight possible combinations of AMRs with a cloud. The influencing factors are determined by means of a systematic literature review (SLR) and completed and verified by means of an application-oriented reference process. The result is an overview of the currently critical influencing factors, prevailing deployment barriers and future potentials of AMRs.

1. Introduction
Since the decade of the 2010s at the latest, the terms automation, digitalization and networking, which are very often cited in connection with the generic term "Industry 4.0", have been the dominant trends of manufacturing companies. As a result, the field of logistics is also undergoing these developments [1]. In recent decades, AGVs have become a symbol of automated material flows in intralogistics. The exponentially increasing sales figures and the further predicted market growth of AGVs, show the still existing relevance of these technical solutions [2]. Technical developments such as laser-based free navigation or camera-based object detection have led to AGVs increasingly being referred to as AMR.
At the same time, the advancing automation of productions results in higher demands on the IT-system landscape [3]. Increasing process complexity (e.g. process time, container variance, etc.), increased transport volumes, and the desire for on-demand and rapidly adaptable material flow, require the exchange of a variety of data between network participants [4]. To cope with increased computational demands and the processing of larger data volumes, cloud-computing is finding more frequent application [5]. This involves powerful, flexible hardware and software infrastructures that a user can access on demand [6].
In sum, taking into account challenges such as process complexity, safety-related aspects and the influence of external environmental factors is a limiting, cost-relevant factor for AGV/AMR automation [7]. The networked exploitation of "Industry 4.0" potentials, which is given e.g. in the connection of an AGV with a cloud, represents an alternative course of action to counter these challenges and to secure the competitiveness of the manufacturing sector in a high-wage location as Germany [8,9].
There are already some SLR on the research area of AGV/AMR, which investigate higher-level aspects as well as detailed aspects such as navigation algorithms [10,11].
However, the described developments of industrial companies, the industry and the technology place the demand on a constantly updated view of the research area. In addition, the combination of the fields of AGV/AMR and cloud creates a new way of operating that needs to be investigated. In a first

step, current influencing factors of AGVs/AMRs are identified by using SLR. The determination of the influencing factors of AGVs/AMRs serves to identify current, central challenges and implementation barriers of these technical solutions. Finally, in a second step, potential fields and opportunities are uncovered that arise from the combined use of cloud-computing and AGV/AMR. In summary, the goal of this paper leads to the following question:

What are the factors that influence the use of AGV/AMR and how AGV/AMR be combined with cloud-technology?

2. Influence factor analysis with SLR

Oriented to the title of this paper and its objective, the following sections highlight the key features of the state-of-the-art in science and technology on AGVs/AMRs. The identification of influencing factors for AGV/AMR is derived here from the identified state-of-the-art, from an SLR and from an application-oriented reference process of AGV/AMR implementation and its operation. The potentials arising from the combination of AGVs/AMRs with a cloud are determined by mapping the opportunities and risks of cloud-technology in general and the AGV/AMR application.

2.1. AGV / AMR - Components

In order to identify key influencing factors and possible barriers to the introduction of AGV/AMR in the field of intralogistics, it is necessary to briefly describe the basic structure of the technology. According to “VDI Guideline 2510”, an AGV consists of a vehicle, a guidance control, devices for location determination and position detection, devices for data transmission, as well as infrastructure elements and peripheral devices [12]. In an automated guided vehicle system (AGVS), one or more AGVs act as the actual means of transport. The master control system acts as a superordinate and determines the complete system required to process a transport order. The vehicle control of the AGV is subordinate to the master control. Other components of the AGV are the navigation technologies, which are responsible for localization and route planning. Navigation here ranges from rigid methods, such as optical or inductive guidance, to free navigation methods, of which laser navigation is the main representative. This type of navigation is characterized especially by a high flexibility of layout changes of the driving course and enables the fast programming (teach-in) of routes. Data transmission usually takes place via local, Ethernet-based networks. By means of data transmission, communication between AGVS, AGV and master control and ultimately also interaction between AGV and the environment (e.g. humans) is ensured. Finally, infrastructure elements and peripheral equipment such as charging stations, position markers for better localization and navigation, or even terminals with user interfaces that form a human-machine interface complete the components of the AGVS [13].

The constant further development of technology, especially in the field of navigation and object recognition, have led to AGVs being able to be used increasingly in unstructured environments. This (partial) autonomy of the systems finally led to the devices also being referred to as AMR [14]. Since AMRs and AGVs are primarily used for transport processes from the user's perspective, both terms are used as synonyms in this paper.

2.2. Application of a SLR for AGV/AMR

The objective of the SLR is to identify the key influencing factors involved in the use of AGV/AMR. The SLR was conducted using Elsevier's Scopus database, which claims to be the leading database for peer-reviewed scientific papers. The search here is divided into three steps:

1. Search title, abstract and keywords
2. Plausibility check result with existing SLRs
3. Screening and categorization into "relevant papers" and "non-relevant papers".

First, the database was searched in the Title, Abstract and Keywords section with various logical links of keywords derived from the research question. The keywords are "automated guided vehicle", "autonomous mobile robot", "intralogistics", "influencing factors" and "barriers". In the first search, representing the intersection of "automated guided vehicle" OR "autonomous mobile robot" in combination with an AND-operation with the relevant application area, "intralogistics", 344 documents have been found. In a further selection step, namely the addition of the keywords "influencing factors" and "barriers", the number of relevant documents was finally reduced to 53.

The second step of the SLR is characterized by a plausibility check consisting of a mapping of already existing SLRs on the topic of AGV/AMR and the result of the Scopus search. If existing SLRs contain relevant papers that were not found by the described database search, this literature is added in this step.

Finally, in the third and last step, all papers are screened and classified into the categories "relevant" and "not relevant". The focus of this screening is on checking the abstract and the content of the paper. For the classification of the literature into "relevant" and "not relevant", the level of consideration of this paper is the decisive criteria. This research paper is a preliminary study that examines the use of AGVs/AMRs at an aggregate, holistic level. Scientific papers that contain the keywords or are already listed in other SLRs but consider certain elements and functions of AGVs/AMRs (e.g. navigation algorithms) at too fine a level of detail are classified as "not relevant." Figure 1 illustrates the selection process of this SLR.

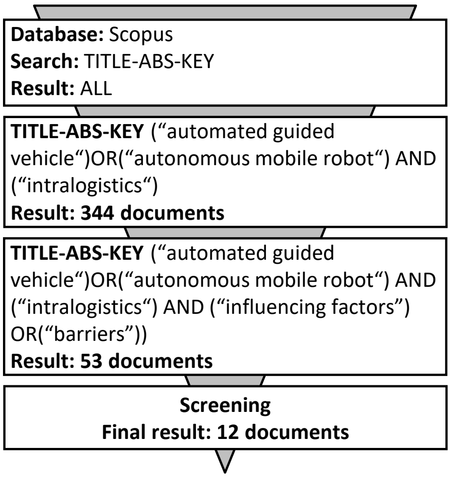

Figure 1: Selection process

2.3. Delimitation of a reference process

From the perspective of application-oriented research, it makes sense to define a reference process that serves to consider factors from practical projects in addition to literature-based factors influencing AGVs/AMRs. The reference process consists of the basic phases of the life cycle of an AGV/AMR or an AGV/AMR-project and ranges from the planning phase, through the implementation and commissioning phase, to the operation of an AGV/AMR.

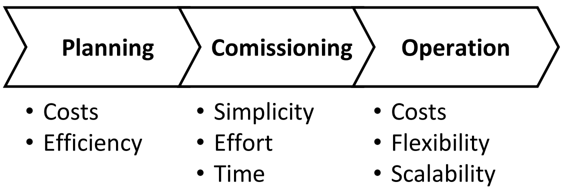

Figure 2: Illustration of reference process

From the different planning and lifecycle phases of AGV/AMR, practice-relevant influencing factors such as costs in the respective lifecycle phases, implementation effort or adaptability to new environmental conditions can be collected.

2.4. Influencing factors cloud

In recent years, there has been a noticeable trend towards shifting corporate activities to a digital space. At the same time, this development places higher demands on the performance of information technology and systems and requires high computing power as well as large storage capacities. One idea for resolving this conflict is flexible and scalable hardware and software infrastructures. Cloud-computing, to which this advantage in particular is attributed in comparison to other infrastructures (e.g. client-server model), appears to be a promising concept in the context of “Industry 4.0”, which focuses on flexible and demand-oriented resource utilization [15].
To describe the concept, the definition of the U.S. Institute of Standards and Technology (NIST) is increasingly being used, which sees cloud-computing as a model that enables one or more users to access a pool of resources via a network. Characteristic features are the demand-oriented use of resources and the user's expectation of constant availability. The word "cloud" and the associated metaphor indicate that the services provided are available via the internet or intranet [15,16].The term "cloud-robotics" was first used in 2010 and now refers to robotic or automation systems that use cloud-infrastructure to compute or provide data [17,18].
In general, cloud-approaches and the underlying IT-infrastructure are assigned the following strengths [15]:

2.4.1. Costs

- Low investment in IT-infrastructure
- Low maintenance costs

2.4.2. Operational

- Flexibility
- Scalability
- Fast realization of projects
- Availability regardless of location

2.4.3. Strategic

- Development of new business areas ("X-as-a-Service")
- Access to technologies also for SMEs
- On the other hand, there are risks that arise from the implementation of projects with a cloud:
- Central accumulation of data provides attack surface
- Single point of failure
- Lack of standards
- Data protection and data security

In the second part of the objectives and questions of this paper, the focus is on the possible combinations of the sub-areas “AGV/AMR” and “Cloud”. For this purpose, it is fundamentally necessary to make the strengths and weaknesses of both sub-areas transparent in order to derive suitable combination options in a next step.

Table 4: Overview about AGV/AMR influencing factors and potentials of cloud-robotics

Part	Category	Subcategory	Nr	Factor	Source	Literature
A	**Reason for AGV/AMR introduction**		1	Cost savings	SLR	[7,11]
			2	Skills shortage	SLR	[7]
			3	Quality	SLR	[7]
			4	Industrial safety	SLR	[7,13]
			5	Process stability	SLR	[7]
			6	Efficiency (productivity)	SLR	[19]
	AGV/AMR operations	**Project / overall system**	7	Simplicity of implementation	Reference process	[11,20]
			8	Scalability	SLR	[19]
			9	Robustness	SLR	[11,19]
			10	Flexibility	SLR	[11,19,21]
			11	(Project-)Planning	Reference process	[20]
			12	(Project-)Commissioning / Realization	Reference process	[20]
		Function / process	13	Navigation	SLR	[13,22–24]
			14	Route planning	SLR	[22,25]
			15	Localization	SLR	[19,22,24]
			16	Object detection	SLR	[22]
			17	Route optimization	SLR	[24]
			18	Order management	SLR	[13]
			19	Fleet management	SLR	[19]
			20	Traffic control / deadlock prevention	SLR	[10]
			21	Guidance control system	SLR	[13]
			22	Vehicle control	SLR	[13]
		Hardware	23	Battery - runtime	SLR	[10]
			24	Computing power (onboard)	SLR	[11]
			25	Sensors	SLR	[13,24]
			26	Mechanics	SLR	[13,24]
		Software	27	Artificial intelligence (e.g. machine learning)	SLR	[11,26,27]
			28	SLAM	SLR	[11]
			29	Sensor fusion	SLR	[22]
		Autonomy	30	Dynamic modeling of environment	SLR, reference process	[28]
			31	Driving on released areas	SLR, reference process	[28]
			32	Driving around obstacles	SLR, reference process	[28]
			33	Acting on object recognition and classification	SLR, reference process	[28]
			34	Dynamic route planning in mixed operation	SLR, reference process	[28]
			35	Detect and respond to vehicle condition data	SLR, reference process	[28]
			36	Guidance control functions in the vehicles	SLR, reference process	[28]
		Radio technology	37	Latency	SLR	[10,29]
			38	Reliability	SLR	[10,29]
			39	WLAN	SLR	[13]
			40	LTE, 4G, 5G	SLR	[10,13,29]
		Costs	41	Purchase price	Reference process	[30]
			42	Planning / commissioning costs	Reference process	[30]
			43	Operating costs - energy costs	Reference process	[20]
			44	Operating costs - Maintenance costs	Reference process	[20]
			45	Operating costs - repair costs (spare parts)	Reference process	[20]
			46	Costs computer hardware	Reference process	[29]
	AGV/AMR barriers		47	Flexibility	SLR	[11,21,31]
			48	Cycle time	SLR	[11,21]
			49	Speed due to safety	SLR	[20]
			50	Mixed operation	SLR	[13]
			51	Load pickup / load transfer	SLR	[13]
			52	Availability	SLR	[32]
			53	Variant variety container	SLR	[30]
			54	Costs	SLR	[31]
			55	Application area outdoor	SLR	[7,31]
			56	Manufacturer-independent control system	SLR	[33]
			57	lack of know-how, knowledge, competence	SLR	[31]
			58	Lack of guidelines, regulation, standardization	SLR	[31]
Part	**Category**		**Nr**	**Factor**	**Source**	**Literature**
B	**Cloud**		59	Efficiency increase	SLR	[29]
			60	Main application	SLR	[29]
			61	Outsourcing options	SLR	[10]
			62	Target architecture	SLR	[11]
			63	Single Point of Failure	SLR	[10]
			64	Incentives / Advantages	SLR	[29]
			65	Obstacles / Disadvantages	SLR	[29]

3. Framework of influencing factors

Derived from the question "*What are the factors that influence the use of AGV/AMR and how AGV/AMR be combined with cloud-technology?",* the results of identifying the factors influencing AGVs/AMRs and combining them with a cloud-technology are divided into two Parts. Part A summarizes the results of the SLR, and the investigation of the reference process for AGV/AMR. Part B focuses on possible combinations of AGVs/AMRs and cloud. Table 1 represents an overview about all identified influencing factors.

3.1. Influencing factors – AGV/AMR

Answering the sub-question "What factors influence the use of AGV/AMR?" is the focus of Part A. The influencing factors were mainly determined by an SLR and supplemented by taking the view of an application-oriented reference process. To provide a better overview of the influencing factors, the factors are further divided into main categories and subcategories. The main categories here are reasons for AGV/AMR introduction, AGV/AMR operations and AGV/AMR barriers. Since the sub-question primarily focuses on the use of AGV/AMR, the main category AGV/AMR operations is so extensive that sub-categories are necessary.

3.1.1. Influencing factors - reasons for AGV/AMR introduction

The influencing factors in the main category of reasons for AGV/AMR introduction summarize the main motives of users to introduce AGVs/AMRs. The corresponding motives are essential and form the starting point for advantageous and requirement-oriented combination options of AMRs with a cloud.

3.1.2. Influencing factors – AGV/AMR operations

The multitude of influencing factors related to the operation of AGVs/AMRs makes it necessary to specify the main category in a second level with subcategories. The subcategories are:

- Project / overall system
- Function / Process
- Hardware
- Software
- Autonomy
- Radio technology
- Costs

The subcategory Project / overall System comprises influencing factors that can either be transferred for a complete AGV/AMR project, e.g. (project-)planning, or describe characteristics of the overall system, such as robustness. The category Function/process, on the other hand, includes influencing factors that relate to AGV/AMR-internal running functions, such as navigation or localization. The Hardware and Software categories contain components and trends from the respective fields. The influencing factors and requirements that are discussed in the course of an intensifying autonomization of AMR/AGV are listed in the main category Autonomy. The main category Costs details the general block of costs incurred into different cost types. In order to connect the AGV/AMR area to a cloud, a radio link must be formed. Finally, these influencing factors form the subcategory radio technology.

3.1.3. Influencing factors - barriers

The category of barriers is aimed at influencing factors which are cited in the literature as preventing the use of AGVs/AMRs. The knowledge of currently existing barriers and automation hurdles is a necessary condition for a successful combination of AGVs/AMRs with a cloud, since in the best case the combined approach invalidates precisely these disadvantages.

4. Influencing factors - Cloud

Part B of the identified influencing factors deals with the second part of the question, namely *how AGV/AMR be combined with cloud-technology?"*. In addition to advantages and disadvantages of the combination, the points of increased efficiency, outsourcing options, main application, target architecture and the single point of failure are explicitly mentioned.

In the area of outsourcing options, the focus is on processes, services and workflows that are currently performed locally on an AGV/AMR. For example, it is imaginable to outsource computing operations to the cloud. The outsourcing of computing power can have two effects. Firstly, it can extend the battery runtime by outsourcing computationally intensive steps [29]. Although most AGV/AMR are electric anyway, this aspect can be an opportunity to further improve the sustainable operation of AGV/AMR. Secondly, it is possible to install less powerful computing units in the AGVs/AMRs, on the one hand to achieve cost effects via an AGV/AMR-fleet and on the other hand to possibly achieve faster computing time and thus ultimately process time in a very powerful and high-performance cloud environment. Finally, complete services can be realized via a cloud ("Function-as-a-Service").

A cloud also offers the possibility of setting up an AGV/AMR manufacturer-independent, higher-level control system. In this way, services such as a global map or order management, which are classically located in the manufacturer's own control system, can be provided for a heterogeneous AGV/AMR-fleet. Setting up a cloud as the global coordinator of an AGV/AMR fleet also makes it possible to equip the infrastructure with sensor technology and to connect it as a source of information. For example, process-critical areas such as crossings can be monitored with sensor technology and bring about better traffic control of AGVs/AMRs. In sum, all peripherals such as traffic lights and gates can be integrated in a comprehensive and meaningful way via a cloud platform.

On the other hand, the provision of services and the enrichment of a cloud platform with functions involves the risk of a single point of failure (cloud failure leads to AGV/AMR-system failure) and protection against external attack. The task here is to develop an overall concept that takes all influencing factors into account and ensures productive use.

Another issue raised by the establishment of combined operation of AGVs/AMRs with a cloud is the question of the control and target architecture. It must be evaluated in which way and at which point of the concept a centralized, decentralized or hybrid architecture is advantageous.

In sum, however, the combination of AGVs/AMRs and a cloud provides an opportunity to make AGV/AMR deployment more efficient.

5. Results

Table 4 represents the overall result of the SLR, serves as orientation and shows a complete enumeration of all relevant influencing factors as well as their origin. The influencing factors are well suited for a subsequent expert survey, e.g. in the form of a Delphi-survey, which can then provide an evaluation and a statement on the significance and importance of individual influencing factors.

Due to the good further differentiation possibility of the influencing factors into different characteristics, Part A shows a high suitability for closed questions of possible linking surveys, while Part B forms the basis for open questions.

6. Conclusion

This paper includes the identification of key influencing factors of AGVs/AMRs and their application in the form of a cloud-robotics approach based on the question "*What are the factors that influence the use of AGV/AMR and how AGV/AMR be combined with cloud-technology?".*

The determination of the influencing factors is carried out by means of SLR and taking the perspective of a reference process, which is to ensure in particular the aspect of an application-oriented research. The complete result of the research is summarized in Table 4.

The mere listing and compilation of the central influencing factors gives users an overview of the potential pain points in the operation of AGVs/AMRs and how they can combine these with the advantages of a cloud. In addition, the identification of the influencing factors lays a foundation for further research. Based on the table, a questionnaire can be developed that can be answered, for example, in the form of a Delphi-survey. By conducting a Delphi-survey, the user then receives, in addition to the transparency and listing of the factors, an exact evaluation and ranking of the factors for an efficient and successful AGV/AMR-deployment. In order to obtain creative and realistic possible combinations of AGVs/AMRs with a cloud-technology, the factors from Part B should be addressed in questions that are as open as possible. From the Delphi-survey, research will get more precise clues about how AGVs/AMRs can be operated more efficiently with the help of a cloud.

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