User Experience of Automated Guided Vehicles

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Abstract: The use of Automated Guided Vehicles (AGVs) in industrial contexts and warehouses has strongly increased in recent years. This raises the question how employees experience their encounters with AGVs on the work floor. To answer this question, we conducted contextual interviews in four different companies with employees that encounter AGVs in their daily work. The employees reported many problems concerning the perceivability (e.g. visibility of warning lights) and understandability of the AGVs auditory and visual signals. The AGVs were also criticized for being too abrupt in their startup and stopping behavior. They were found to be unpredictable, showing even uncooperative, egoistic or "rude" behavior, ignoring other traffic participants and even causing accidents, because of unexpected behavior. AGVs were expected by the interviewed employees to "see" and consider more of their surroundings. Furthermore, problems of trust and acceptance were reported. A range of design implications are drawn from the above findings, for example the use of common standards for the design of signals and implementing an intuitively understandable movement behavior of AGVs.

Keywords: User Experience, Automated Guided Vehicles (AGVs)

1. Introduction

The use of Automated Guided Vehicles (AGVs) in industrial contexts and warehouses has strongly increased in recent years. In these contexts, AGVs usually are in operation in mixed traffic with pedestrians and manually driven trucks. To ensure a safe and efficient interaction between the various traffic participants, AGVs must give visual and/or auditory signals in specified situations, for example in case of automatic movements and changing direction (ISO 3691-4, 2020). Many AGVs use orange blinking lights on both sides of the vehicle and a beeper to communicate. Lights blink simultaneously prior to starting automatic movement and alternating on the left and right side during automatic movement. Prior to turning left or right the light on the respective side blinks about twice as fast as before, while the other side is turned off. All AGVs in this study used these signals. Some were equipped with additional signaling devices. Recently, AGVs started to use multicolor LEDs. This led to a wide range of signaling designs. This and the fact that mixed fleets with AGVs from different suppliers have become more common, makes it necessary to take a closer look at how these signals are perceived and understood by the employees on the work floor and how they must be designed from this human-centered perspective.

Since AGVs are getting more and more autonomous, their behavior becomes less predictable. This makes it even more important to evaluate their effect on the humans encountering them and draw design implications from the interaction between AGVs and people on the work floor.

In this contribution we report on the User Experience (UX) of employees encountering AGVs on the work floor. UX covers "*all aspects of how people use an interactive product: how well they understand how it works, how they feel about it while they're using it, how well it serves their purposes, and how well it fits into the entire context in which they are using it*" (Alben, 1996, quoted in Robert & Lesage, 2011). People encountering AGVs can be seen as indirect users, who do not directly interact with, but use the output of the system (UXQB, 2020).

2. Problem statement and central question

The study was part of an evaluation effort by the world's second largest supplier of material handling solutions such as material handling trucks and automated warehouse execution systems. The company's product management observed various problems in AGV applications, such as a lack of acceptance by the employees and accidents between AGVs and other traffic participants on the work floor. The central question for our explorative study was: **How do employees experience the encounter with AGVs?** This concerns the perception and understandability of the AGVs behavior and signals, the behavior of the humans themselves in interaction with the AGVs, as well as emotional (people's feelings towards the AGVs) and social or "relational" aspects.

3. Methods

Field data were gathered through contextual interviews and processed through joint interpretation sessions (Holtzblatt, 2012). Further data structuring was done by affinity diagramming. A total of sixteen contextual interviews were conducted with employees that regularly encounter AGVs at their workplace at four different industrial sites. The employees were interviewed while doing their work, so that questions could be asked based on observations of the employees' interactions with the AGVs. The specific questions revolved around the employees' perception and understanding of the AGVs auditory and visual signals and the AGVs movement behavior (e.g. startup and stopping behavior). Furthermore, the employees' own behavior in interaction with the AGVs, how they feel about the AGVs and how they see their relationship with them were addressed in the questions.

Before selecting the interview partners, suitable sites, representing a variety of AGV applications, had to be chosen. The following variations played a role in the selection of the different sites:

- warehouses versus industrial production sites
- size: small versus big AGVs
- AGVs with simple versus advanced signaling equipment

- much versus little other traffic
- AGVs working on their own versus performing tasks in collaboration with humans.

The four sites selected had the following characteristics:

- a warehouse with a medium size AGV with simple signaling devices, driving in intensely mixed traffic, performing a collaborative task
- an industrial site with very large AGVs and very little mixed traffic
- an industrial site with a very well equipped AGV and intensively mixed traffic
- an industrial site with AGVs with simple signaling devices used as assembly trolleys in very close contact with pedestrians.

Figure 1: *Two of the sites visited, with AGVs varying in size and signaling equipment*

For the experience of the encounter with an AGV it makes a difference if persons are pedestrians or if they drive a vehicle themselves (e.g. a forklift truck). Because of the significance of these two roles, for each site two interviewees for each of these roles were selected by the company's contact person.

4. Results

4.1 Perceivability and understandability of the AGVs signals and driving behavior

Employees reported many problems concerning the perceivability (e.g. visibility of warning lights) and understandability (meaning) of the AGVs auditory and visual signals. For example, the blinking signal for an upcoming turn was not understood as such by various employees, because it was displayed by the same lamps that blink to signal automatic movement and because the blinking frequency was very different from that common for cars. Concerning the driving direction, a clear signal was only shown by one AGV through a projection of blue light on the floor in the direction of driving. This was perceived as very helpful. However, interviewees demanded further signals, for example white light in the direction of driving and red light on the opposite side.

The start of automatic movement of the AGVs was signaled by blinking orange lights and beeping. Although auditory warnings were criticized in general for being annoying, in this case it was seen positively and preferred to optical signals with lamps on the body. Additionally mentioned as helpful was the blinking of the projected lights on the floor in front of the AGVs and a small initial lift of the forks (similar as mentioned in Philips (2018), where movements, such as folding out the mirrors and rising up, signal the upcoming start of an autonomous car).

Some AGVs were giving an auditory signal when they detected something in their safety field (e.g. a person). This was stated to be clear and helpful. One AGV visualized the size of the safety field with a red line projected on the floor and would start to blink this light in the case of a safety field violation. This was also rated positive, because it was easily understood by the employees interviewed.

Besides explicit visual and auditory signals the movement behavior (trajectory, acceleration and deceleration behavior) of the AGVs was stated to be a very important source of implicit information for the employees to predict the future behavior of the AGVs. Some interviewees stated that they mainly rely on the current movement behavior to anticipate the future path and do not consider the visual and auditory signals at all. It was also stated that it fosters predictability if the AGVs drive on fixed routes.

4.2 Perception and interpretation of the AGV's behavior and emotional reaction

Artificial beeping sounds were interpreted by many interviewees as annoying and inappropriate. However, one interviewee stated that the sound generated by the electric motors is very helpful for noticing an AGV approaching from behind.

The AGVs were criticized for being too abrupt in their startup and stopping behavior. The time between starting signal and setting off to move was perceived as too short (about 1s). AGVs were found to be unpredictable. Their behavior was even perceived to be uncooperative, egoistic or “rude”, ignoring other traffic participants, e.g. blocking the way of other vehicles or even causing accidents because of unexpected movement. AGVs were expected by the employees to “see” and consider more of their surroundings.

Because of the lack of understandability of the AGVs signals, the unpredictability of its behavior and the perceived lack of its cooperative behavior, many interviewees were annoyed and stressed by the AGVs. Some felt unsafe in their presence and did not trust them. Others had so much trust in them that they lacked adequate caution in encounters.

4.3 People's behavior during encounters with AGVs

As could be observed on-site, the employees’ own behavior in encounters with AGVs, e.g. in terms of giving or taking right of way, differed, some being cautious and “avoiding” encounters with AGVs, others claiming their right, “as humans”, to take priority, despite the regulation at all sites that AGVs have right of way. At the site where the AGV was marking the safety area with red lines projected on the floor some people avoided this area very strictly, others did not mind at all and relied on the vehicle to stop. At one site employees blocked AGVs the way, because they had to handle loads next to the path of the AGV.

4.4 The relationship between employees and the AGVs

Regarding the relationship between the employees and the AGVs, AGVs were personified strongly through name-giving by the employees or interactions similar to interactions with persons (e.g. yelling at them). AGVs that worked fine were seen as team members, the ones that were not working properly were seen like children that need to be taken care of.

An important aspect is also the task division between humans and AGVs. For example, one interviewee stated that the AGV is doing his previous work now, which was fine for him, because it was a part of work that he did not like much.

5. Design implications

A range of design implications can be drawn from the above findings. The main information channel is and should be the visual one. With LED displays, information about the state and the intention of the AGV can be provided efficiently. However, common standards should be considered. For example, the signal for turning was not understood by various employees, because its frequency was about double the common frequency of cars. Well known signals from the automotive sector seem to be very appropriate. Beiker (2020) states that Autonomous Vehicles in public traffic should continue to use the signals used for human-driven vehicles and should use them in the same way.

Supplementary to LED displays on the body of the AGV, information projected on the floor seems to be useful. Especially projected light in front of the AGV in the direction of driving and projected lines marking the safety field were rated positively.

Auditory information seems to be a very good supplement to visual information but must be used carefully because it easily gets annoying. Use of sound and its level should be dependent on the criticality of the information and the surrounding sound level (Beiker, 2020). Permanent sound can be useful (e.g. sound of electric drives), but should not be too loud or intrusive, especially when generated artificially. Situational auditory warnings (e.g. starting movement or stopping because of an obstacle) were rated very positive. It was observed that if there are too many similar sounds at the same time, e.g. from multiple AGVs, people get used to the presence of the audio signals and urgent warnings can be overheard. This is supported by Beiker (2020). "*The problem of prevalent auditory communication in traffic would be noise pollution and an overload of this communication channel*".

Besides these two explicit information channels, the implicit information given by the movement behavior is very important. Thus, it is very important to design a consistent and readable movement behavior (readability meaning the possibility for people to derive the upcoming behavior of the AGV from the current behavior). Also here, known concepts from other contexts like road traffic could be used to improve this readability. Incomprehensible or sudden changes in speed or direction should be avoided. AGVs should behave in a forward-looking way and drive defensively.

In order to successfully use AGVs in the field, it is important that they are accepted by the people around them and that they can work efficiently also in cooperation with humans. Feldhaus (2022) states that it is very important for the acceptance of robots, that their use also has a benefit for the employees, for example by overtaking dangerous, boring or strenuous tasks.

If people feel that they are informed about the state and intention of the AGVs and they also understand the information given, they start to develop trust in the AGVs. When trust is rising people start to feel safe. Then, and even more when they have the impression that their own work isn't hindered and efficient collaboration with the AGVs is possible, the acceptance will rise.

6. Outlook

The study has shown that there is potential for improvement in the user experience of employees encountering industrial AGVs. Concerning explicit communication by AGVs, e.g. through visual and auditory signals, some suggestions have already been made above that match with standards and designs in other sectors like the automotive industry. The standardization of signals of AGVs has already been started by the working group "Harmonization of warning signals for AGVs" within the VDMA (German mechanical engineering industry association). Part of this process is the construction of prototypes and their evaluation with users in the field.

To enhance the implicit communication via movement behavior, more research is needed on how AGVs must behave in mixed traffic. Much research has already been done in the context of autonomous vehicles in road traffic. A good overview can be found in Beiker (2020). Mankowsky (2019) states that moving through a complex flow of traffic requires mind reading capabilities based on the perceived movement behavior of other traffic participants and that the introduction of robots in traffic might disturb this process. Thus, the movement behavior of robots must be designed in a way that it provides good hints for humans, enabling them to "feel" robots the way they can feel other traffic participants. In the field of AGVs in warehouse and industrial contexts, we have already started such work within the research project iMOCO4.E (2022). In this project, the driving behavior of AGVs will be evaluated and improved using virtual reality experiments.

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