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Use cases and high-level requirements for safe interactions between automated delivery vehicles and human operators in a terminal

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Abstract

Small electric Autonomous Delivery Vehicles (ADV) can play an important role in future logistic chains under the last mile deliveries. In terminals where ADV are loaded with goods it is important that the interactions between the ADVS and the goods handling personnel is safe. Two workshops with developers of self-driving vehicles, researchers in the area of human-machine interaction and goods handling personnel form Postnord were conducted to identify challenges, needs and requirements regarding the design of ADV and the terminals för ADV. Due to COVID19, the workshops were carried out online and a video was shown to the participants demonstrating an ADV operating in a location representing a terminal. The two main objectives for this study were to gain understanding of the interactions between the ADV and human operators in the terminal and to identify high-level functional requirements for safe and efficient deployment of ADVs in terminals.

The identified use cases related to (i) the ADV's operations in the terminal, from entering to leaving the terminal and (ii) use cases where human operators interacted with the ADV, e.g. for loading/unloading goods. For each use case a high-level functional requirement was formulated. Human operators will most likely have important roles in delivery chains with ADV, such as loading and unloading of goods, as well as managing problems the ADV cannot solve. Consequently, how to design the human - ADV interactions will be critical from safety and efficiency points of view.

Key words: Automated delivery vehicles, Human – ADV interactions, Use cases, High-level functional requirements

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Innehåll

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Preface

This report is from the GLAD project (GLAD: *Goods deliveries under the last mile with automated delivery vehicles*). GLAD was a research and development project with the overall aim to gain knowledge about user needs as well as about the technical, societal, business and policy related challenges with automated delivery vehicles (ADV). The GLAD project was conducted during June 2020 and September 2022 and was coordinated by RISE Research Institutes of Sweden. The project was partly financed by the Swedish Transport Administration (ref. no. TRV 2020/26017). The partners in the GLAD project were RISE Research Institutes of Sweden, Aptiv AB, Combitech AB, Clean Motion AB and Halmstad university. The studies in the GLAD project are summarized in the following report:

- Söderman, M., (2022), *GLAD, Goods deliveries under the last mile with automated delivery vehicles - Summaries of the studies in the GLAD project*, ISBN 978-91-89757-24-0, RISE report 2022:135

The full reports from the studies in GLAD are:

- Andersson, K. (2022), *Autonoma leveransfordon – vad är de för sorts fordon och har det någon betydelse? (Eng. Automated delivery vehicles - what kind of vehicles are they and does it matter?),* ISBN 978-91-89711-44-0, RISE report 2022:100
- Söderman, M. (2022), *Typical and critical traffic situations with small electric delivery vehicles – indications for future automated delivery vehicles*, ISBN 978-91-89757-19-6, RISE report 2022:130
- Söderman, M., Andersson, J., Habibovic, A., (2022), *Use cases and high-level requirements for safe interactions between Automated Delivery Vehicles and human operators in a terminal,* ISBN 978-91-89757-20-2, RISE report 2022:131
- Andersson, J., Habibovic, A., *How to convey the intent of an automated vehicle with its longitudinal and lateral movements - evaluating four communication concepts in two traffic situations involving pedestrians* (Report under construction, 2022)
- Söderman, M., Clasen, R., Bergström, G., Collings, W., (2022) *Development of self-driving and control room functions and of external HMI for Automated Delivery Vehicles,* ISBN 978-91-89757-21-9, RISE report 2022:132
- Söderman, M., Clasen, R., Bergström, G., Collings, W., (2022) *People's understanding of external HMI and their experiences of interacting with an Automated Delivery Vehicle in a terminal context,* ISBN 978-91-89757-22-6, RISE report 2022:133
- Gonzales, S., Sveder, C., Oscarsson, E., Jönsson, S., (2022) *Challenges and potential business applications of Automated Delivery Vehicle initiatives - a brief overview,* ISBN 978-91-89757-23-3

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Sammanfattning (Swedish)

Små elektriska autonoma leveransfordon (ADV) kan spela en viktig roll i framtida leveranskedjor, i synnerhet under den s.k. sista milen. I terminaler där ADV omlastas är det viktigt interaktioner mellan ADV:erna och personalen på terminalerna är säkra. Två workshops genomfördes med utvecklare av självkörande fordon, forskare inom människa-maskininteraction, samt personal från en av Postnords godsterminaler för att identifiera utmaningar, behov och krav kring utformningen av ADV:er, men även på utformningen av terminaler där ADV kan köra. På grund av COVID19 genomfördes workshopparna online och en video visades för deltagarna som demonstrerade en ADV som kör in på en terminal för omlastning av gods. Målen för workshopparna var att (i) få förståelse för interaktionerna mellan ADV och personal i terminalen och (ii) att identifiera funktionskrav på både ADV och terminal för säker och effektiv interaktion mellan personal och ADV:er i terminaler.

Studien fokuserade dels på ADV från att den anländer till terminalen, omlastas och lämnar terminalen, dels på situationer där personal interagerar med ADV vid lastning/lossning av gods. Utifrån varje situation formulerades ett eller flera funktionskrav på ADV och/eller terminalen. Personal på terminaler kommer att fylla viktiga uppgifter i leveranskedjor med ADV, såsom lastning och lossning av gods och att hantera problem som ADV inte kan lösa själv. Därför blir interaktionen mellan godspersonal och ADV viktig både ur säkerhets- och effektivitetsperspektiv.

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1 Background

The acceleration of e-commerce has increased the demand for integrated omnichannel retailing and requires fast, affordable and sustainable last-mile delivery solutions [1]. However, deliveries of packages have been viewed as a future bottleneck of growth. The costs of global parcel delivery, excluding pickup, line-haul, and sorting, have been estimated to amount to over 50% of the total logistic cost [2].

Small electric Autonomous Delivery Vehicles (ADV) are anticipated to play an important role in last-mile deliveries. ADVs can deliver meals, groceries, packages, mail, and retail products. Since ADVs are small, electric, quiet and produce no exhaust fumes they can operate in indoor environments, such as terminals, warehouses or other premises for goods handling. On a global scale the ADV market is estimated to grow annually of 19 % between 2018–2024, in monetary terms from about €12 billion in 2018 to about €34 billion by 2024 [3].

A main argument för ADVs' efficiency is that they are driverless, but also means great technical challenges to accomplish. Moreover, terminals need to be adapted to driverless ADVs and organized to secure safe and efficient operations, especially in situations where human operators and ADVs are going to interact.

2 Objectives

This study explored several interactions points in a scenario where an ADV enters a terminal for smaller goods (packages, letters etc.), drives to a loading/unloading area and exits the terminal. A use case can be defined as *a specific description of how actors and technical systems (inter)act to achieve specific goals* [4]. A use case includes the conditions, prerequisites and end-state of a sequence of interactions in a multi-agent system and can provide a common framework for cross-functional teams and thereby facilitate successful design work.

The objectives for this study were:

- To gain understanding of the interactions between the ADV and human operators in the terminal.
- To identify high-level functional requirements for safe and efficient deployment of ADVs in terminals.

3 Method

3.1 The setting

The study was originally planned to be carried out as joint workshops with a team of experts from the partners in the project and with workers from a freight terminal. However, due to the outbreak of COVID19 the workshops had to be re-scheduled and carried out online. Therefore, a video was produced which showed the ADV operating in a terminal-scenario. The terminal was represented by a garage with the

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basic features for the purpose of this study (Figure 1). The ADV was represented by an electric three-wheeler (Zbee [1]) which was controlled remotely (Figure 2).

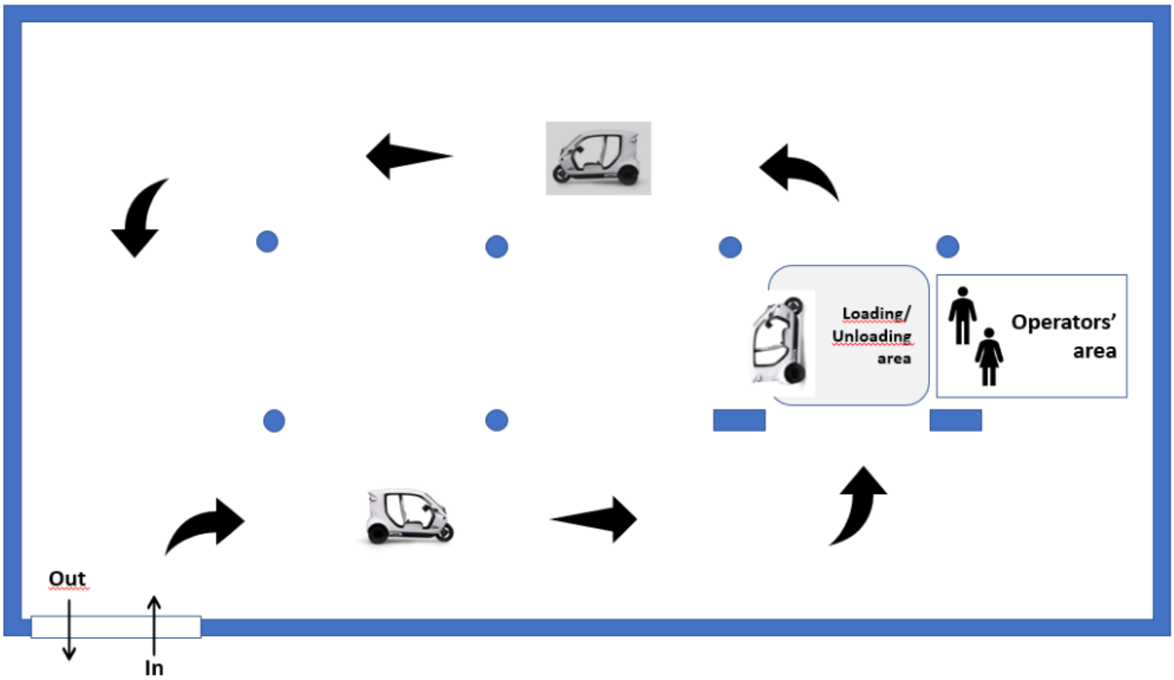

Figure 1. *Plan of the garage representing a terminal in this study. The arrows indicate the driving path through the terminal.*

Figure 2. *The vehicle used in the study. In its current version it is designed for manual driving and not designed to carry goods.*

3.2 Procedure and participants

Two workshops were carried out online. Prior to the workshops information about the tasks and routines at a terminal was collected through interviews with staff at one of Postnord's terminals in Gothenburg, Sweden, in which small manually driven electric delivery vehicles operate, Figure 3. Observational studies were also carried at the terminal to gain insights in the daily routines, which gave important information about the goods handling personnel's tasks and roles, the logistics in the terminal and about usability and interactions matters with the goods and the delivery vehicles. The observations also provided important information about the use cases that were explored in the workshops.

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In the first workshop two developers of ADVs and four researchers in the field of Human factors participated. In the second workshop the same researcher as in the first workshop and two workers from one of Postnord's terminals in Gothenburg, Sweden, participated.

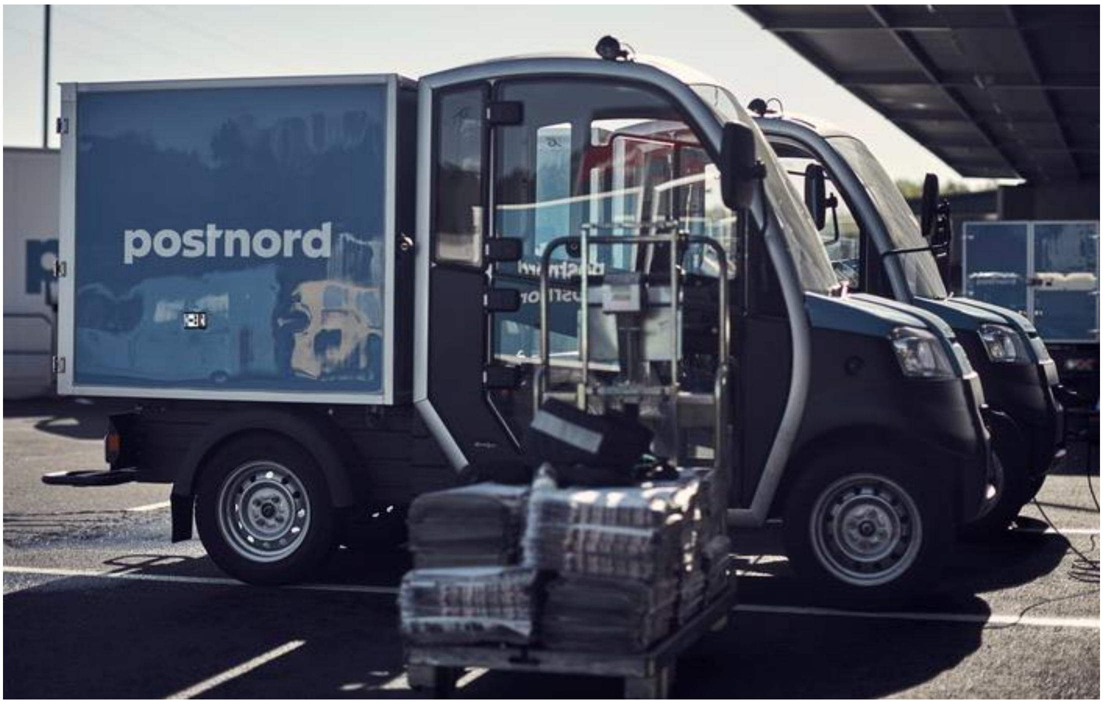

Figure 3. *The type of electric delivery vehicles that are used at Postnord for last mile deliveries, for example in Göteborg, Sweden (photo: Johan Stjerneus, Postnord mediabank).*

The workshop started with introducing the participants to a scenario in which an ADV enters the terminal, drives to its dedicated area for loading/unloading and exits the terminal. In the video the following use cases were demonstrated:

1. ADV enters the terminal (Figure 4)
2. ADV drives to load/unloading area (Figure 5)
3. ADV stops at load/unload area
4. Personnel load/unload goods (Figure 6)
5. Personnel perform vehicle diagnosis
6. Personnel sends ADV to next mission
7. ADV exits the Terminal (Figure 7)

Figures 4 and 5, *The ADV enters the terminal and drives to the load/unload area.*

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Figures 6 and 7, *The ADV at the load/unload area and the ADV exits the Terminal.*

The workshop was divided into three parts. In the first part the participants were asked to discover (potential) problems and critical situations in the demonstrated use cases. In the second part they were asked to identify needs and requirements regarding the goods handling personnel, the ADV and the terminal. In the third part they were asked to suggest solutions to the identified problems, needs and requirements. A digital whiteboard (MIRO[2]) was used on which all the participants could put their notes about the problem, needs & requirements and the suggested solutions (Figure 8). The participants could read the notes from the other participants simultaneously. The video and the digital whiteboard remained accessible to the participants after the workshop allowing them to view the data and to add further input.

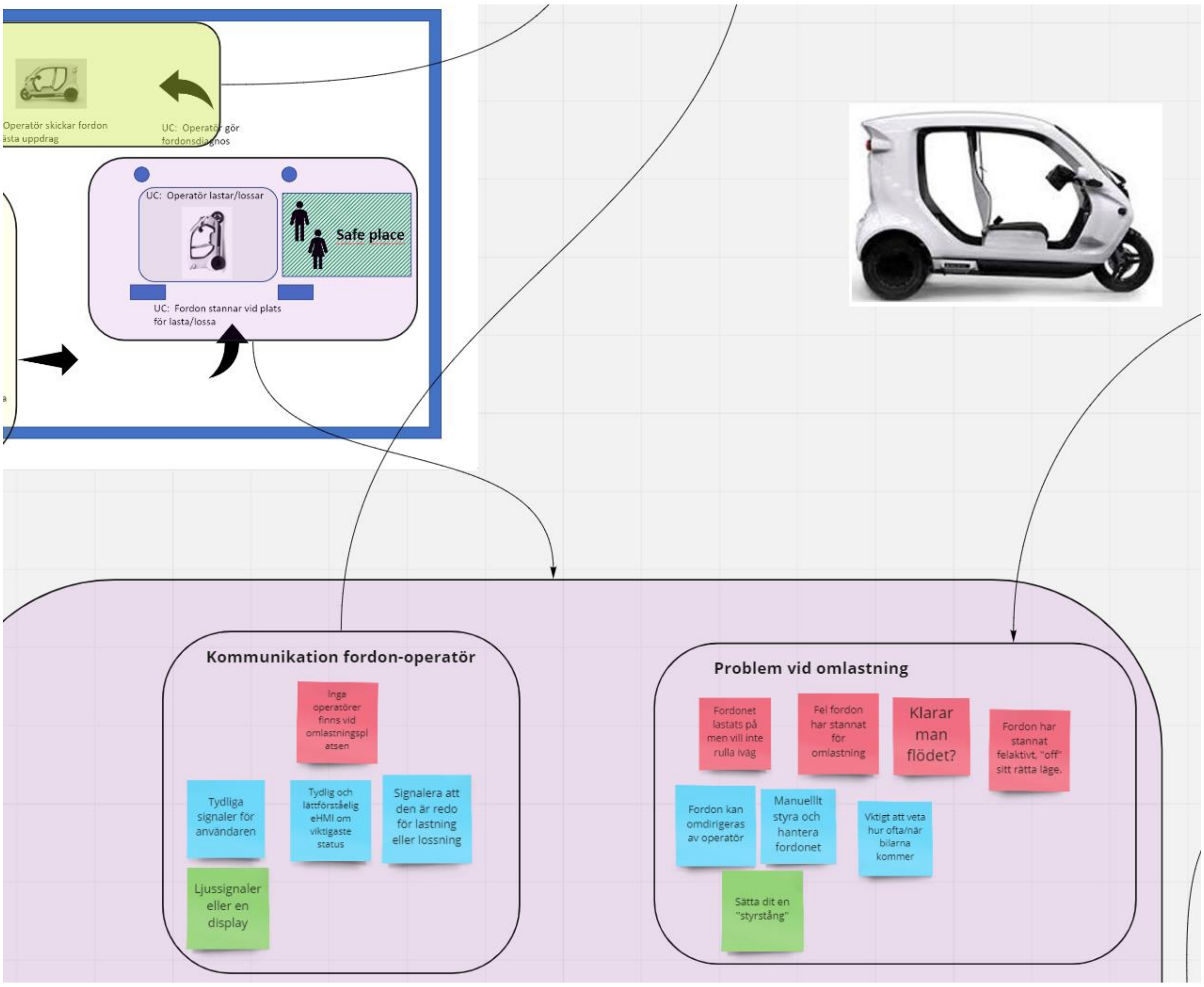

Figure 8, *Detail from the digital whiteboard with illustrations, topics and notes. The whiteboard was also used in the affinity diagram analysis (clusters, relationships and categories of identified problems, needs and requirements, in Swedish).*

3.3 Data analysis

The data on the MIRO-board was analyzed by using affinity diagrams, which is a method to structure data by sorting the collected data into groups and subgroups and to find relationships between the groups [5, 6]. The collected data is qualitative and in the first step of the analysis the data was processed from specific data (the individual notes) towards more general patterns of categories of data, e.g. clusters of data related to specific use cases, stakeholders or functions. The relationships between the clusters were also drawn to indicate associated areas of problems, needs and requirements between the use cases [7,8]. In the second step of the data analysis high-level functional requirements were formulated with focus on the interaction points between the ADV, the terminal and the goods handling personnel. A functional requirement (FR) specifies what function(s) a product or a system shall fulfil in order to perform its task(s). FRs do not specify *how* to do it (that is part of the solution creation, which is based on the FRs). FRs can also be ranked in terms of their mutual importance by phrasing the FRs as "shall" or "should".

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4 Results

4.1 Needs and challenges for ADVs operating in goods terminals

The analysis from the affinity diagram resulted in four main groups of data. One group convened matters associated with the ADV entering and driving in the terminal, for example permission for entering the terminal, navigation in the terminal, logistics to avoid queues (when several ADVs are operating in the terminal), and arbitration matters, i.e. interaction and decision strategies between the ADV, the terminal and the goods handling personnel.

Another group convened goods handling matters, such as loading/unloading of the ADV's, ergonomics (lifting, stretching, shoving heavy goods), securing correct delivery destinations. A third group convened needs & requirements about the ADV, for example the design of the goods box, the ADV's turning radius, status (damages on the ADV, system failures) as well as the ADV's communication to the surrounding, e.g. type of modality (haptic, acoustic, visual), messages (safe/unsafe mode, safe/unsafe to approach, emergency stop etc.), priority schemes and how the ADV can adapt the communication to the current situation in the terminal [cf. 7]. The fourth group was about deviations from the "normal" operations in the use cases, such as loss of signals, damages on the ADS, theft, hacking or manipulation of software, undefined failures etc.

4.2 High-level functional requirements

Table 1 shows the identified use cases and the high-level functional requirements, related to the ADV and the Terminal, respectively. Figures 9 and 10 illustrate the high-level functional requirements for the ADV and the terminal, respectively. These high-level functional requirements were generated at an early stage in the project and can be subject to changes as the project progresses.

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Table 1. The identified use cases and high-level functional requirements.

Use Case	High level Functional requirement
ADV enters the terminal	Only ADV with permission can enter the terminal
ADV drives to the load/unloading area	The ADV shall be able to navigate in terminal.
ADV drives to the load/unloading area	The terminal should have dedicated lanes for the ADVs and for the human operators respectively.
ADV drives to the load/unloading area	The terminal shall allow multiple ADVs to operate in the terminal without interfering with each other.
ADV drives to the load/unloading area	The terminal should be designed according to the turning radius of the ADV.
ADV drives to the load/unloading area	The ADV shall have a turning radius that allows it to operate in the terminal.
ADV drives to the load/unloading area	The charging areas in the terminal shall not interfere with the flow of goods and with ADVs in operation.
ADV drives to the load/unloading area	The terminal logistics shall be designed to prevent queues in the terminal. The mission control system shall prevent queues in the terminal
ADV stops at the load/unloading area	The ADV shall have a visible ID.
ADV drives to the load/unloading area ADV stops at the load/unloading area ADV exits the Terminal	The ADV shall communicate its intentions (movements, missions etc.) to the surrounding: - ADV to be un/re-loaded (cargo) - ADV going to Stop - ADV going to move - Unplanned stop
Operator loads/unloads	The ADV shall indicate overload (of cargo)
Operator loads/unloads	The ADV shall have loading/unloading entries from the rear and from both sides.
Operator loads/unloads	The P-brake on the ADV shall be possible to activate manually.
ADV stops at the load/unloading area Operator performs vehicle diagnosis	The ADV shall communicate its mode to the surrounding: - Automation mode (on/off) - Unplanned stop - Load/Unload mode
Operator loads/unloads Operator performs vehicle diagnosis	The ADV should send information to the terminal in advance about: · ADV status (battery, defective sensors etc.) · Estimated time of arrival · Deviations in time of arrival
Operator performs vehicle diagnosis	The ADV shall have a digital ID.
Operator performs vehicle diagnosis	The ADV shall be possible to remove manually.
Operator loads/unloads	The box on the ADV shall be designed to prevent goods sliding and overturning during transport.
Operator loads/unloads	The box on the ADV shall protect the goods from theft.
Operator performs vehicle diagnosis	The terminal should have facilities for charging the ADVs.
Operator performs vehicle diagnosis	The terminal shall be designed to handle failing ADVs.

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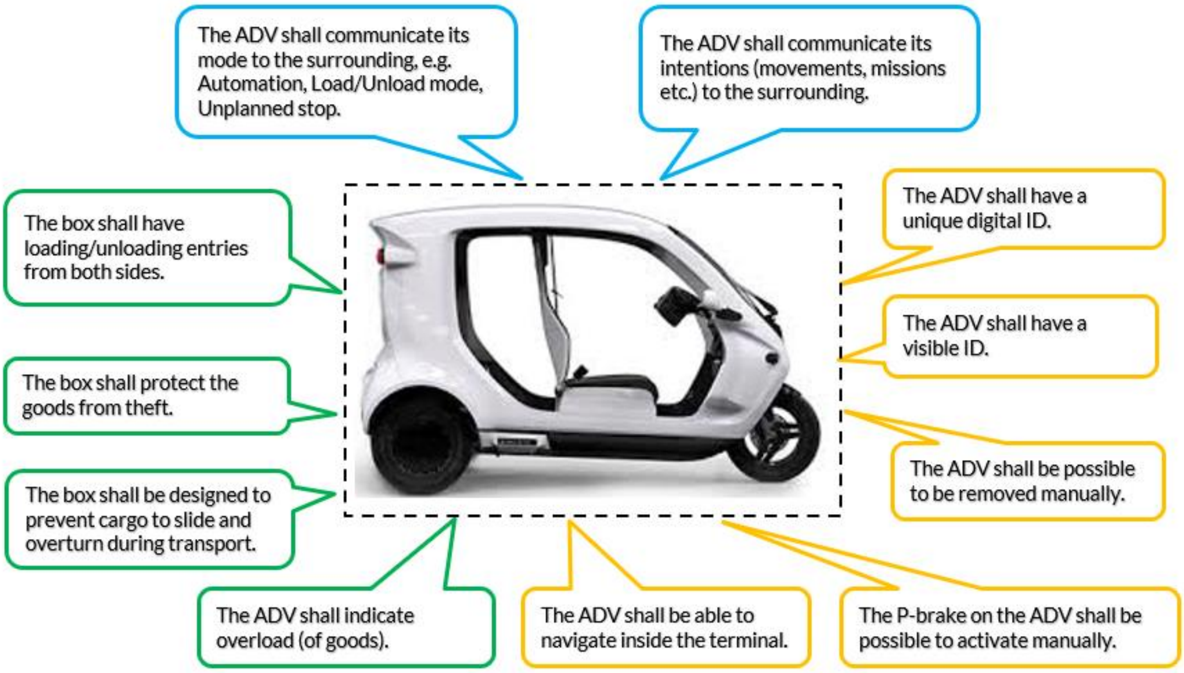

Figure 9, *High level requirements addressing the ADV. Please note, the ADV in the picture is not designed for goods deliveries, but for passengers and was used as an ADV-prototype in the study.*

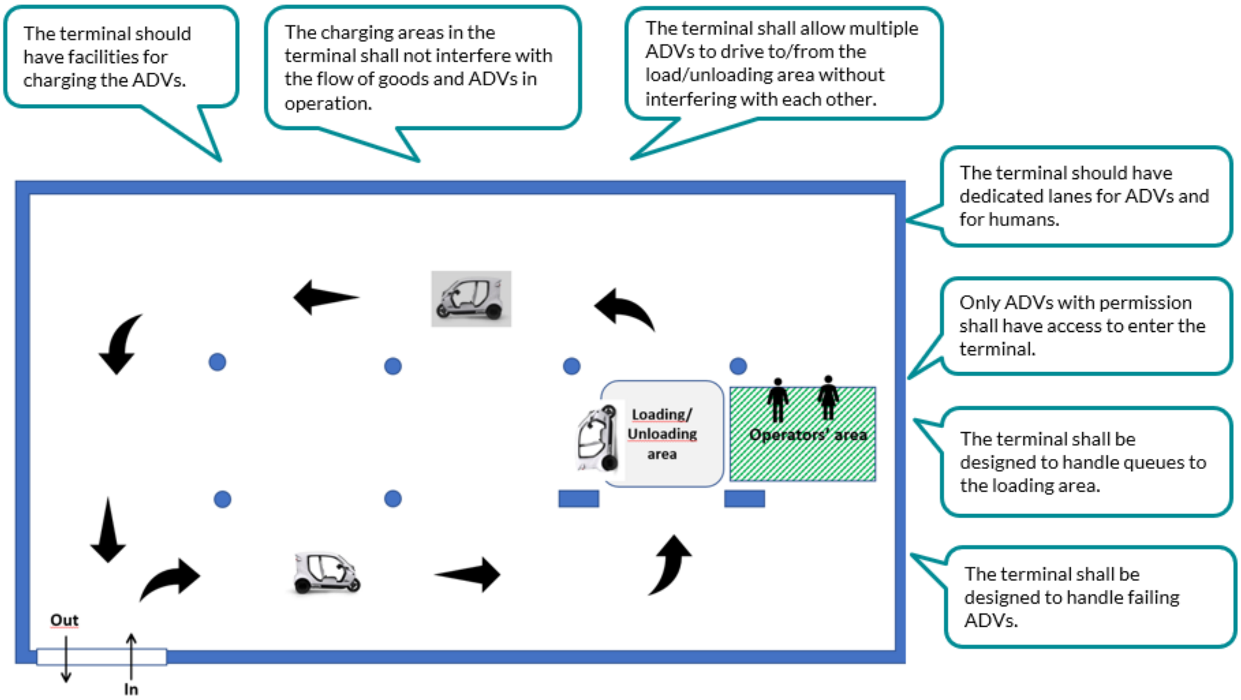

Figure 10, *High level functional requirements addressing the terminal.*

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5 Discussion

5.1 Method

Due to the outbreak of COVID19, the planned workshops for data collection were reorganized to be carried out online. Compared to a workshop in-real-life (IRL) there are several advantages with a workshop in-real-life where the participants are in the same room which makes the discussions direct and multi-dimensional body language and facial expressions. The participants can also interact with artefacts by showing, pointing, demonstrating etc. However, the main objectives with the workshops were largely accomplished. The usage of the video shown in the workshops seemed to have provided satisfactory information about the use cases in general and about the ADVs' operations in the terminal in specific. The communication platform and the digital whiteboard made it possible for the participants to discuss the use cases, write notes and read the other's notes simultaneously. The lessons learned from the workshops carried out online are summarized below:

Advantages:

- Documentation: The scenario and the use cases as well as the participants' notes on the digital whiteboard were organized, documented and saved simultaneously.
- Repetition: During the workshops the recorded use cases could be viewed repeatedly, stopped at specific moments on request and studied in detail.
- Accessibility: The material for the workshop as well as the documented material were accessible to the project team members after the workshops.
- Flexibility: The material can be used and re-used in different ways and adapted to different conditions. In this study the material was adapted to the different prerequisites in the two workshops.
- Sample: The participants could participate regardless of their geographical location, which made it possible, and easier, for the participants to participate and to contribute with their input.

Disadvantages:

- Communication: The dialogue between the participants may have been hampered because the participants did not see their co-participants (everybody did not use cameras). Generally, online communication is less dynamic compared to IRL since the communication is mainly limited to verbal communication without the cues from facial expressions and body language.
- Interaction: It was not possible for the participants to interact with the ADV, to point at and try specific features or to move around in the terminal.
- Technology: The communication platforms (Zoom, Teams) require updated software, fast internet connections, functioning microphones and cameras etc. It is difficult to carry out a workshop online if these are not working properly.
- Sample: The technical prerequisites for online workshops can hinder people from participating.

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The digital whiteboard was useful for the affinity diagram analysis. The participants could contribute and assess the clustering and relationships of the data and add information also after the workshops, since the whiteboard was accessible online. The results from the workshops and the affinity diagrams provided feasible information to formulate preliminary functional requirements regarding the ADV and the terminal.

The collected data was retrieved from a limited number of participants in the workshops. A larger number of participants, especially in the workshop with terminal workers, would have given more insights into the conditions in a terminal and strengthened the results.

5.2 Results

The objectives of the study were (i) to gain understanding of the interactions between the ADV and human operators in the terminal, and (ii) to identify high-level functional requirements for safe and efficient deployment of ADVs in terminals.

The high-level functional requirements for the ADV are useful for the design of ADVs. The high-level functional requirements that address the terminal are also useful as they provide contextual matter that needs to be considered. The terminal and the ADV should, therefore, be regarded as parts of a system and not as two separate elements. For example, the terminal and the ADV should be able to handle multiple ADVs operating in the terminal at the same time, and to prevent congestion in the terminal.

Moreover, human operators will most likely have important roles in delivery chains with ADV, such as loading and unloading of goods, as well as managing problems the ADV cannot solve, for example removal of failing ADVs. Humans are expected to manage critical situations in automated systems, for example monitoring that the automated system is operating correctly and to take-over control in situations the automation system is failing [9]. The high-level functional requirements indicate that goods handling personnel have a key-role and that human - ADV interactions will be critical from safety and efficiency points of view.

The results also suggest that communication between the ADV and the goods handling personnel is important and that ADVs should have a clear communication scheme, or external HMI (eHMI), i.e. visual signals or indicators that communicates the ADV's mode (autonomous, mission etc.), state (safe, not safe to approach etc.) and its intentions (start, stop, turn etc.) to the goods handling personnel for safe co-existence in the terminal and efficient working routines.

6 Conclusions

ADVs can play an important role in a delivery chain of smaller goods. However, the design of the ADVs and the design of the terminals are critical for safe and efficient interactions with goods handling personnel. The identified problems and the goods handling personnel's needs and requirements were clustered in four groups: (i) the design of the ADV for goods delivery, (ii) the ADV operating in the

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terminal, (iii) goods handling personnel's interactions with the ADV (goods handling and vehicle diagnosis) and (iv) deviations from normal operations (loss of signals, damages on the ADS, theft etc.).

The study indicated that goods handling personnel are key stakeholders and will have an important role in terminals that are operated by ADV as long as there are manual tasks involved, e.g. loading and unloading goods and managing faulty ADVs a. Therefore, it is important to take the human – ADV interaction matters into account as well as the logistics of goods handling when designing ADVs. The high-level functional requirements for the ADV and the terminal can serve as a basis for designing safe and efficient interactions between ADVs and human operators in a terminal context.

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