Technical & operational evaluation report automated logistical robot on BUAS campus

Evaluation report automated logistical robot on BUAS campus | The Future Mobility Network | 8 February 2021 |

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Introduction

This report serves as an evaluation for the automated logistical robot pilot named LoWie (Logistiek op WIElen) from September 2020 till November 2020 on the Breda University of Applied Sciences (BUAS) campus. Multiple parties have participated and cooperated in the project: BUAS, Airlift Systems, The Future Mobility Network (FMN), students from BUAS, Hogeschool Rotterdam, and students from Hogeschool Amsterdam. The goal of the project focused on driving with an automated logistical robot on the BUAS campus to better understand its use for future implementations (it was the first-ever automated robot pilot in The Netherlands to run for at least 1 month on a semi-public road).

Figure 1: The automated logistics robot LoWIE (Logistiek op WIElen). Its presence is indicated using the signs with the text "Let op, proef met een zelfrijdende bezorgrobot. Geef ruimte!"

This document serves as the pilot evaluation report and focuses on all aspects (from preparation till the end of the pilot) with the purpose to learn from it for future use cases. Therefore, all lessons learned gathered during the project will be presented. The aspects to be evaluated are legal, technical, operational and business case.

The goals of the evaluation are:

- Provide better insight into the results of the BUAS project. The knowledge questions that have been made during the preparation of the project will be compared with the discovered findings/log files. There can be determined if all needed information is gathered or if we haven't measured everything we wanted to measure. Also, the measured factors will be evaluated to discuss if the factors had the expected/right outcome.
- Define lessons learned from the BUAS project
- Show how these lessons can be used to improve future use cases/robot projects

The evaluation report is drafted in cooperation with all stakeholders in the process to learn from our perspective and their perspectives. The lessons learned that have been gathered are of great value and can be used for future pilots and projects with deliveries/robots.

The project team would like to thank the contribution of direct stakeholders (City of Breda, Regio West-Brabant, Logistics Community Brabant, AON) for the realisation, execution and evaluation of this pilot. All involved partners for the success of this pilot are listed below.

Funding & research | Funding | Insurance provider | Road authority

Reading guide

The report has been organised in the following way.

Chapter one presents the findings and analysis of the research, focusing on four aspects: technical, legal, operational and business case. In each theme, the results of the research and its processes will be analysed. Also, the research questions will be answered and analysed.

Chapter two is concerned with the conclusions being drawn based on the findings and analysation.

The third chapter gives recommendations by defining the top 10 lessons learned for each phase of the project.

In addition, there is a second evaluation summary report drawn up by BUas about user experience, and added to the appendix.

1. Findings and analysation

The robot route is indicated in Figure 2. The goal was to support the three buildings on-campus: The Horizon building, the Frontier building, and the Ocean building. The consortium prepared the operational phase with the use of an operational plan, which consists of the following items:

- The project team and the specific roles;
- A health and safety plan;
- A contingency plan;
- The research questions.

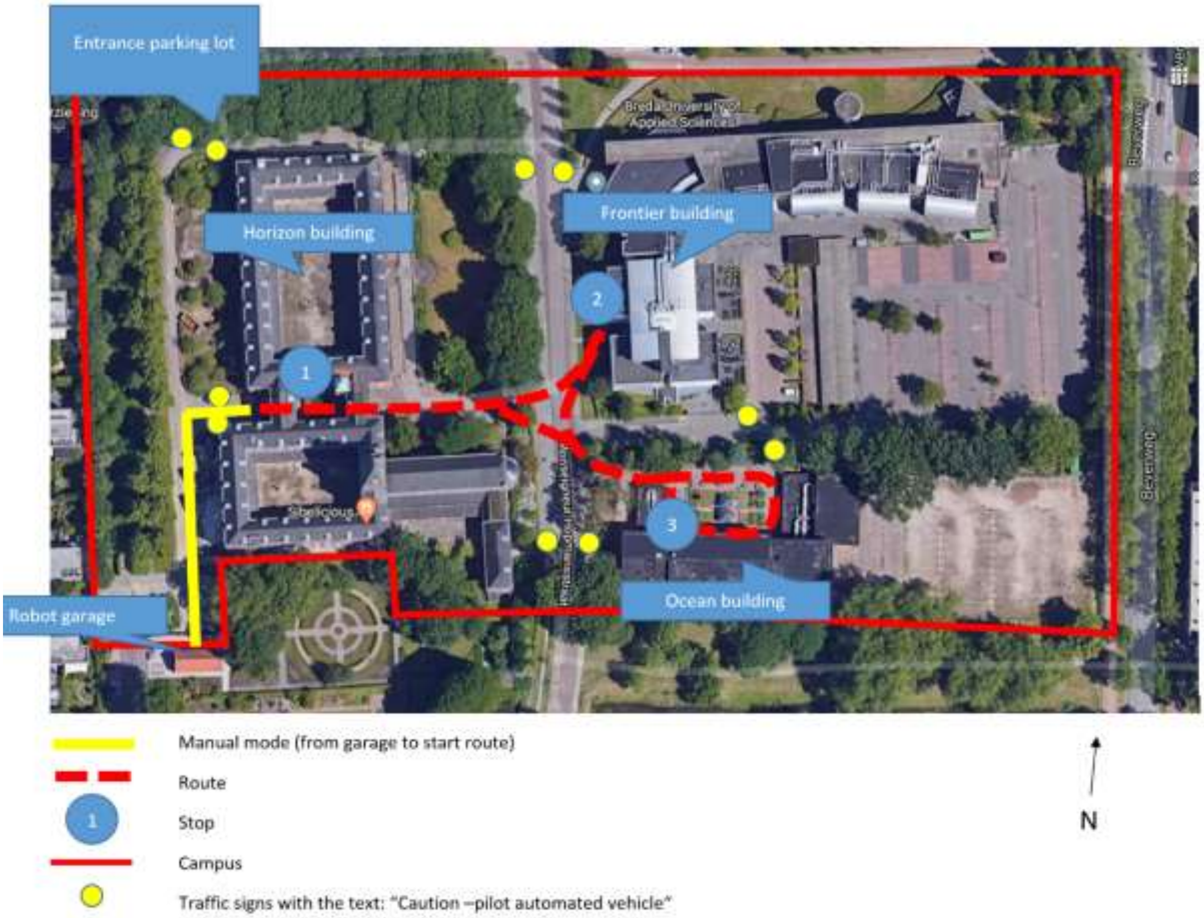

Figure 2: Top view of the route

In this evaluation report, the different research questions and the health and safety plan are addressed with a conclusion and motivation. Any additional findings during the pilot will be mentioned as well for future implementations. The research questions and the additional findings will be addressed from a technical, legal, operational, and business case point of view.

1.1 Technical aspects

The technical research questions are answered with the help of the log files data provided by Airlift Systems, see Appendix 1 for this. In table 1 down below will be discussed per research question what the outcome was.

Table 1: Research questions technical aspects

Technical aspect	
	Research question
1	What charging facilities does the robot need? Is the dockstock set up well enough?
2	How long does the commissioning of the robot take?
3	Can the robot be operational throughout the entire day? How long can the robot drive on a single battery?
4	How far does the operator need to be standing from the robot to be able to take over the kill switch within a few seconds?
5	How long does it take to reactivate the robot after the kill switch has been used and turn on the autonomous mode?
6	Can the robot deal with (heavy) rain/fog/extreme temperature in operation?
7	What is the frequency of maintenance intervals/technical errors; what was this about and how long did it take?
8	What are other relevant technical findings?

Assumptions/premises

The following assumptions/premises are used before the start of the project:

1. It is currently unclear to which extent the robot can drive autonomously in mixed traffic (i.e. without a safety operator walking next to it) on the BUAS campus. Is it capable of positioning itself on a so-called 'virtual rails' and is it able to perceive other road users potentially crashing into it? Theoretically, it should be possible, and this needs to be validated in practice.
2. The robot has been tested in Qatar in different weather conditions to drive in. The robot used in this pilot is a prototype robot not tested before in the Netherlands. It seems like the robot is waterproof and *therefore, the assumption is made that the robot can drive during not so heavy rain and operate except during heavy rain and extreme fog.*

Discussion of the research questions

Robot garage/dockstock

When the robot arrived on the BUAS campus, it had to be stored in a shack. This shack needed many adaptations because there was no router set up yet when the robot arrived. This was installed the day after arrival. Furthermore, the storage location also served as a workshop where the robot got set up, maintained, and repaired.

Commissioning of the robot

The commissioning of the robot took longer than expected (10 days), but this was due to the calibration of the sensors, this still needed to happen on-campus. Besides that, there were later deliveries of the LiDAR and batteries. The first LiDAR sensor had issues with high humidity condensated inside the sensor boards causing residue shorting. This was later rectified and prevented with a tighter seal. The theoretical 10 working days of commissioning and the number of commissioning days in practice will be discussed down below.

Commissioning duration in theory:
Ideally, the commissioning takes 10 working days for assembly of the robot, environment scanning, calibration and overall testing for safety and systems check.

Commissioning duration in practice:
In practice it took around 20 working days, which is longer than expected. This was due to multiple reasons:

- Shipping and custody challenges resulting in parts to be sent from different locations. This took longer than expected.
- The prototype was not fully equipped against the Dutch adverse weather conditions, which gave leaking troubles during the commissioning and required a change of parts and a tighter seal.
- Due to COVID and the resulting travel restrictions there was a severe lack of manpower from Airlift to speed up the process. None of the HQ staff in Qatar was able to travel and support the operations in the Netherlands. Only 2 people from Airlift were physically onsite with remote support from Qatar.

Battery usage per day

There were two swappable batteries available for the operational phase. During the operations and as can be seen in Appendix 1, it became apparent that the main batteries can be used for more than a day of operations in BUas. In appendix 1, auxiliary batteries (RC) systems batteries were charged which are easily swappable. Airlift opted to charge the main batteries during the breaks anyway. The robot was charged at least once a day for at least 30 minutes, during the day. Sometimes it was needed to charge it longer than that to be operational the entire day. After a day of operation, the robot was charged again.

Use of kill switch

The kill switch hasn't been used on-campus because there were no technical errors regarding the loss of control of the robot during the pilot. Besides that, the robot stopped rather fast when facing other obstacles or people on its route, which led to no need for using the kill switch during the pilot. To use the kill switch within a few seconds at least one of the safety operators needed to have sight on the robot during operation.

Reactivate kill switch

The kill switch hasn't been used during the pilot because there were no technical errors regarding the loss of control of the robot during the pilot. There hasn't been an occasion that needed reactivating the robot. This led to no extra delays in the process operationally. The switch was verified during the tests/commissioning phase but was not necessary during the pilot.

During this verification, the kill switch was tested with the operating laptop, the controller and de physical switch. After the ignition of the kill switch, it is possible to reactivate the robot in the time frame of a couple of minutes with the operating laptop.

Dealing with weather conditions

The weather conditions were good enough to operate most of the time. There was a maintenance stop needed when it had to operate in (not so heavy) rain. It seemed that the robot was not waterproof for these situations. The tests carried out in Qatar seemed to be unrepresentative (less extreme) for the weather in the Netherlands. As can be seen in the Operational Hazard Analysis and Risk Assessment (OHARA) in table 2 down below, the road and robot should have been assessed by the operator in advance.

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Table 2: Example of the Operational Hazards and Risks Assessment for rainy conditions

Hazard (*if …, then …*)	**Risk assessment** (*Risk*)	**Mitigation measurement** (*Action take to mitigate the hazard*)	**Risk assessment** (*Resulting risk*)
In case of rain, then the robot may not be able to drive	Unacceptable	• The road is assessed by the operator in advance • The control room is informed and required to help in the assessment • In case it is not possible to drive (due to KNMI advice code yellow), replacing transport can be arranged/delivery can be delayed	Acceptable

As can be seen in the OHARA, there were mitigation actions prepared in case the rain did not allow safe operation of the robot (e.g. no automated driving possible due to bad weather). This mitigation action did not consider the robot waterproofness.

Besides that, there were no other weather conditions during the operation, such as extreme temperatures, extremely rainy days or fogs. The robot could operate on all other days that there were no technical errors.

Maintenance intervals/technical errors

During the first week of the operation, the robot encountered a mechanical issue (6 October) where the drive differential system failed. The failure cause remained unknown as the failed piece was cast from strong grade metal which the supplier investigated immediately. Until Friday the engineering team was unable to source the failed part locally, therefore an order from the supplier was placed and there was opted for the fastest shipping option (ETA Wednesday the 14th) to resume operations at the earliest. Because of this incident, the robot wasn't in operation until Monday the 19th. During this period any media or visits had to be postponed. The robot could not get back into operation for almost three weeks. Airlift acted well on the repair by ordering the failed part immediately with the fastest shipping option, as can be shown in the OHARA in table 3 down below.

Table 3: Risk assessment of maintenance and technical defects

Hazard (*if …, then …*)	**Risk assessment** (*Risk*)	**Mitigation measurement** (*Action take to mitigate the hazard*)	**Risk assessment** (*Resulting risk*)
Maintenance or repair takes longer than initially planned	Undesirable	• The situation is assessed by the operator and discussed with other partners and control room • Replacing transport can be arranged or the schedule can be adjusted	Acceptable

It is however unclear what the scheduled maintenance intervals are and if these exist. It is currently unclear what aspects determine the maintenance interval. The mechanical failure that occurred during the pilot was not expected, not even from the supplier. The cause of failure could not be explained, and hence, there was no other option than to replace it. It took two working days to replace the part after its arrival.

Other findings

The robot was not capable of driving fully autonomous, as it suffered from calibration issues with the Lidar sensor. It could not properly localize itself in the environment nor could it detect obstacles on the right and left side of the robot. See an overview of the front view and top view of the robot in Figure 3. The LIDAR at both sides of the robot (where the green circle gets overlapped by the blue colour)

Furthermore, at some locations on the route, the GPS signal was too weak to ensure proper redundancy. This was especially the case at the entrance of the Horizon building when driving under the port.

The Lidar sensor on top of the robot was custom-made and its use was tested for the first time in this environment. The sensor was affected by high humidity in the air which reduced the efficiency in some situations. Its Field of View (FOV) can be dynamically adjusted and controlled. In most situations it functioned as expected.

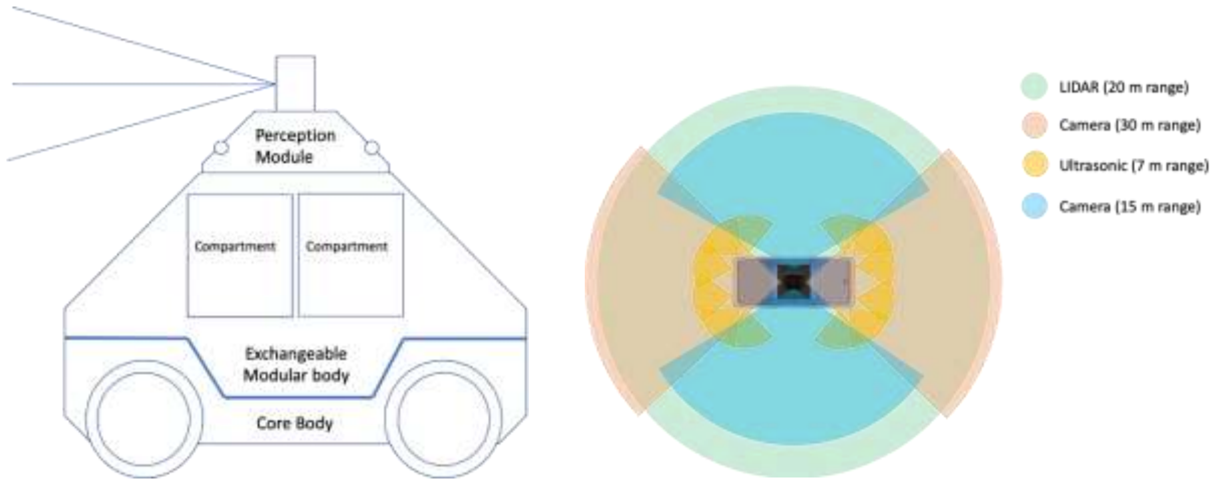

Figure 3: Front and top view of robot and systems

The consequence was the following:

1. The safety operators had to walk next to the robot to cover its blind spots. This had two functions: 1) to prevent the robot from drifting off the route and collide into an obstacle, and 2) prevent the robot from getting hit by an obstacle/another road user from the side.
2. Tests without the direct presence of safety operators could not be performed. The safety operator always had a direct line of sight to the robot.
3. Tests with the indirect presence of the safety operator (i.e. in the control room) were not performed.

Furthermore, the robot possessed two compartments for storing parcels. One of these (for demonstration purposes) of an automated opening and closing system. This also worked with a QR code which was the same for all users. Also, the QR code didn't work at all times, sometimes it had to be opened by use of the laptop's system.

In this use case, placing an order was performed by sending a text message to the safety operator 30 minutes in advance. When the delivery is possible, you get a request conformation, and a text message will be sent to the receiver. When the robot is in front of the building the receiver will get another notification (including the QR code) of the robot's arrival. From this moment it is possible to collect the parcel. When the parcel will not be picked up, the robot will wait five minutes before he will return the package to the sender. For the use of the robot by the janitors this was sufficient but not efficient. Also, sending a text message and not working with an application is "old-school" and not user friendly enough.

Conclusion

It can be concluded that the technical part of the robot was of a significant level to perform the pilot, it could deliver packages on-campus without collisions. It could drive on-campus autonomously for almost all actions. Although, when the robot had to turn, manual control was needed because the robot could only drive in one direction. Besides that, the robot was not waterproof completely because, during the pilot, water piled up in the robot when facing not so heavy rain for a day. Also, when problems with the Lidar occurred, the safety operators had to walk next to the robot to cover its blind spots. The technical challenges faced during this pilot have been dealt with by immediate communication between the partners.

1.2 Legal aspects

For the legal aspects, multiple findings will be shown in this paragraph. Many legal aspects have to be taken into account when doing a project with multiple stakeholders from different countries with all different rules and demands. Besides that, letting a robot drive autonomously in a pilot for longer than one month hasn't been performed earlier in the Netherlands. This means, that everything must be taken care of before realisation.

Assumptions/premises

1. It is currently unclear whether the robot is a machine or a robot. This is a discussion that has been held on the Ministry level. The RDW, the national road authority, and the responsible entity for exempting pilots with innovative technical systems on the Dutch public road, currently does not possess a framework on which to assess whether LoWie is a vehicle or a machine. This discussion will not be solved in the short term, as an entire policy needs to be drafted for these systems. *Therefore, the assumption is made that an exemption by the RDW is not needed.* The discussion on the category in which the LoWie self-driving delivery robot falls, made it also challenging for the insurance.
2. Remote control during the pilot is not tested. This was the goal before the start, but due to technical problems with the robot, and due to a condition set by the insurance (see below), it was not fully feasible to test this feature.

Preparations

In preparing the pilot, many legal aspects had to be taken into account. This was a challenge since it was the first time an automated logistics robot would drive on the Dutch semi-public road.

- Draft of an implementation plan that serves as a basis for all legal permits and insurances, such as
  - A permit for doing a robot pilot on-campus: this was being handled by FMN and BUAS. The permit was given by the municipality of Breda.
  - The insurance for the robot.
  - A technical safety report of the robot before arrival.

Permit trajectory with the city of Breda

The permit was needed because of the fact that a local public road had to be closed for a certain period of time. The reason / argumentation for this closure should be organised within the existing (policy) frameworks in order to prevent loss of time.

The examined options that were considered:

- Event-permit (temporary) ("Evenementenvergunning")
- Temporary road closure ("tijdelijke verkeersmaatregel")

Ad. A

A lot of discussion (internally, between the municipality officers). There was discussion about the definition of 'event'. The local event-policy does not contain this kind of 'robot-events', but it is more about music-events and fairs, which is why this option turned out to have a 'dead end'. (question: must local policies anticipate on this kind of 'new-technology-events'?)

Ad. B

From the municipality of Breda's perspective planning- and accessibility-coordination ("planning- en bereikbaarheidscoordinatie") is a key-factor for temporary road-closures. All kinds of different activities (internal and external) are planned in one combined system in order to keep the city accessible and liveable. Because of the fact that this (short) piece of the street Mgn. Hopmannsstraat is not a vital part of the local infrastructure (for cars) this local road closure could easily be arranged. The traffic- and safety plan from BUAS described the assistance / presence of a 'host' / steward who would supervise the robot. This fact, combined with the suggested road signs convinced the municipality of Breda to agree with the proposal.

In addition (but actually really relevant): the appearance of the 'shared-space-campus-design of this part of het Mgn. Hopmannsstraat was already closed for car-traffic and mostly in use for students (on bikes and walking) who are familiar in this place.

Down below in figure 4 the BUAS campus can be seen. The whole campus was private terrain except the Monseigneur Hopmansstraat, the bicycle road in the middle of the campus. This is pointed out with the red line. Specifically for operating on this red line, the city of Breda granted the permit.

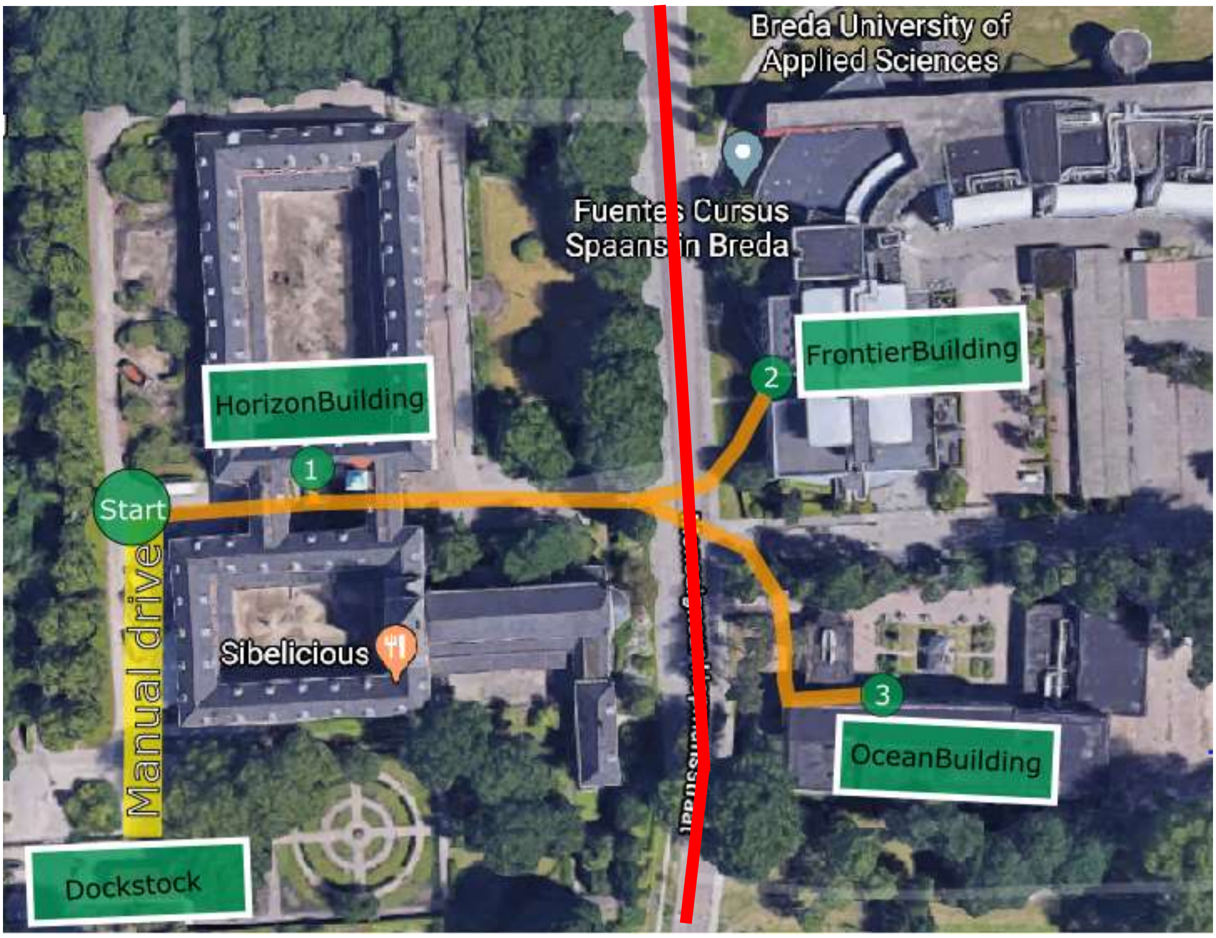

Figure 4: BUAS campus, private and public terrain

Insurance of the LoWie

Field tests with technology not ready for the public market can be dangerous, as it is not always certain how the system is going to behave in real-world conditions and in a mixed environment. For instance, it may occur that, even when the technology provider has thought of everything, the technology will fail and cause a severe accident.

In that case, being insured against accidents and liability is important to be covered for. For most insurance companies it seems to be too risky to insure these innovative pilots due to the high uncertainty, and the high costs involved. There is currently only one insurance company, AON, in the Netherlands to ensure these pilots.

AON assessed the risks of this implementation by evaluating the implementation plan set up by The Future Mobility Network. The insurance policy could only be drafted and agreed on under the following conditions:

1. The insurance was only covered under the condition that there was a direct physical line of sight by the safety operator to the robot, meaning that only monitoring from the control room was not allowed.
2. The mitigations as proposed in the implementation plan, i.e. the Operational Hazards and Risks Assessment (OHARA), the examination checklist of the robot, the checklist upon arrival of the robot, were act upon. For an overview of the checklists, see Appendix 2.
3. The insurance could only be held by a Dutch BV entity. Airlift Systems had a sister company in the Netherlands, Airlift Systems BV, that could handle this.

Technical safety

An OHARA according to the ISO26262 (ISO, 2018) standard was performed by Airlift systems with technical assessment by FMN. The OHARA had been made before leaving Qatar to give an overview of the risks and mitigation measures that would be taken. All identified risks had to be mitigated and ensure the quality and performance of the robot and its equipment during operation. These mitigation actions were verified during operations.

Remote control

While in operation the robot could not be left unattended even if the robot was able to drive by itself. Somebody needed to monitor the driving part to ensure the safety of the people on campus. The safety operator needs to have control of the three ways to use the kill switch, the physical switch, the controller and the laptop. The safety operator needs a fast way to take over the control of the robot, this also means that the safety operator is responsible for the robot in case of a collision or incident. Therefore, remote control from a control room was still not possible in this pilot.

Conclusion

It can be concluded that the legal part of the robot has been covered sufficiently during the pilot. Although, the effort for arranging the insurance and permit to drive on-campus took some weeks/months. This was especially because it is the first-ever pilot to drive on a semi-public Dutch road for minimally a month. The pilot was able to continue because the pilot conditions were met, and the insurance and permit were arranged in time. Furthermore, the RDW didn't interfere during the pilot which makes it probable that more pilots will be performed in the nearby future. From Airlift's perspective, strictly adhering to the safety guidelines and the insurance requirements was the highest priority for Airlift during the pilot. Having any incident occurring will not only result in material damage, it will also impact the credibility of the project partners and the industry as a whole.

1.3 Operational

Multiple findings regarding the operational aspects will be shown in this paragraph. During the operational phase, many aspects have to be considered. This is due to multiple deliveries the robot performs, and the multiple groups of people involved on-campus. The janitors, students, teachers, visitors, the safety operators and students involved in the project all play a part. It was the first time for most of these people to see a delivery robot operate and therefore it was new to everybody. The whole operation had to be filed and many research questions had to be answered, see Table 4. Under table X the knowledge questions will be answered. For an overview of the whole logbook, see the Excel file "Logbook Observation".

Assumptions:

1. The staff, students and all people on campus would use the service of the delivery robot. The robot will be used as a delivery service on-campus for goods and packages.
2. The users of the robot delivery service can easily arrange transport of their package.
3. A lack of students and staff members on-campus as a consequence of the COVID-19 policy made it challenging to perform the pilot in the intended way. It was not possible to perform a minimum number of deliveries and pickups without an intervention. Therefore, field tests had been simulated to acquire enough data for the research questions.

Table 4: Operational research questions

Operational aspect	
	Research question
1	What does the transport of the robot and all needed parts look like?
2	What is the targeted user group?
3	How can a package be submitted for delivery? Is there an app for this?
4	How long do the loading and unloading take at the buildings?
5	How long does an average, minimum and maximum delivery take?
6	What will happen if there are too many packages that have to be delivered on a day?
7	How many trips have been performed per day and how could this number be optimized? Will the janitors use the robot enough for deliveries on-campus?
8	Has there been on-time and enough communication with the users and janitors about the robot?
9	Will a too low or too high mental task load for the safety operator lead to distraction of the controlling job? And for a control room operator?
10	Will people on-campus treat the robot differently with the direct physical nearby presence of the operator than with the operator's absence?
11	Are people willing to pay for a robot package delivery service?

Transport of the robot and parts

The robot, its batteries and the LiDAR had to be transported from different locations to The Netherlands: the robot from Qatar, the LiDAR from Africa, and the batteries from Germany. This has been performed by flight and road. The road transport was also delayed from the airport of Schiphol to Breda because not all tools were available to make the transport to Breda ready. The robot arrived on the 16th of September, but the batteries arrived much later. The two batteries had to be sent separately by different transports and countries because of the safety, causing one battery to arrive later than the other. The LiDAR was delayed as well and therefore together with the batteries causing a delay in the start of the commissioning process.

The customs department at the airport had to ensure everything was properly documented and well checked. The robot got imported and exported as special carriage. Therefore, it was allowed to maximally stay abroad for 90 days from the Qatar headquarters. This constraint did not give much room for any delay in the project.

User groups

The intended user group were the janitors. The robot hasn't been used a lot by the janitors because they didn't find it useful for delivering packages for such short distances. Every building on the campus was already supplied with the necessary material (e.g. printing paper, pencils etc.) and every building already had its own restaurant. Therefore, the janitors felt forced to use the robot rather than seeing it as an opportunity, or, in layman terms, as "a workhorse".

After a while, the robot delivery services became accessible to all campus visitors. This has been communicated by placing a message on the campus' website.

Submitting a package for delivery

A package can be submitted by sending a text message to one of the Airlift Systems engineers. If the robot is available, the request would be answered by a go. The robot will drive towards the pick-up location and sends a text message again when it has arrived. The user needs to bring its package to the pick-up point within 5 minutes. Then, the robot drives to its destination and it sends a text message confirmation to the receiving party when the robot has arrived at its destination. There is no working app for this at the moment, the text message submission function works but needs to be optimised. Everybody should be able to use the robot easily. For an overview of the current user instruction, see Appendix 4.

Loading and unloading duration

The average loading time took around 1 minute and the average unloading time around 2 minutes, this included the waiting time. There had been informed before the delivery that the maximum waiting time after arrival was 5 minutes. A no-show would result in a cancellation of the delivery. Cancelling of the delivery was still performed manually. If the receiver didn't show up in 5 minutes, the robot drove back to the pick-up point. However, the robot waited longer than 5 minutes multiple times because a user (one of the janitors) didn't show up on-time. For an example overview of the logbook regarding each delivery, see Appendix 2. This logbook has been recorded for every delivery being performed but is shown only for the route of Horizon Building to Frontier Building.

Transit duration

Location	Avg. Transit time	Avg. loading time	Avg. unloading time	Avg. duration of stops	Total Transit time
Horizon - Frontier	00:03:12	00:00:41	00:02:59	00:00:03	0:06:55
Horizon - Ocean	00:04:01	00:00:21	00:00:41	00:00:02	0:05:06
Frontier -Horizon	00:02:51	00:00:15	00:02:28	00:00:16	0:05:51
Frontier - Ocean	00:02:25	00:02:18	00:01:01	00:00:00	0:05:44
Ocean - Horizon	00:05:25	00:01:26	00:02:25	00:00:09	0:09:24
Ocean - Frontier	00:02:36	00:00:49	00:01:31	00:00:12	0:05:07
Avg. times	00:03:25	00:00:58	00:01:51	00:00:07	00:06:21

Figure 5: Average duration routes

The average transit duration is around 3.5 minutes while driving on average 3-4 km/hour. The average speed is set low for safety and legal reasons. Multiple routes with all different distances had been driven on-campus. The longest route was from Horizon building to Ocean building (160 meters) and the other way around, which, according to the data, minimally takes 3.5 minutes. There is one outlier in the data with 9 minutes to drive this route. It took this long due to an operator stop when people walked in front of it and asked about the robot during the transport.

Number of packages

During the pilot, there were not too many orders because of the low demand for deliveries. In an ideal situation with much demand for transportations, it would be needed to have the robot decide what is the most efficient way of performing all transports that come in around the same time. It has to decide based on efficiency which order will be delivered firstly.

Number of trips

The number of trips performed was lower than we hoped for in advance. To improve the number of trips, there has been chosen to do some field tests for stimulating the number of orders. It led to the robot driving more routes on-campus and being seen by more campus visitors. Duet to COVID-19 there were fewer people on campus, this also has consequents for the research questions.

Communication with janitors and users

A meeting with the janitors was scheduled for Thursday the 22nd on the campus to explain the project in detail. It had been postponed to the 27th for the remaining janitors to be present as well. That week they started working with the janitors to test the system and start sending the logbook report. After this meeting, there were still not many orders coming in and therefore the communication with them should have been performed earlier to see if they would be using the robot for delivering packages.

The lack of orders from the janitors led to a message being placed on the digital infrastructure of BUAS to get students to participate in field-tests. The communication with the students went via BUAS coordinator Jeroen Wepner. Regarding the physical infrastructure, signs were placed to make the robot knowable towards its surroundings. Students, teachers, employees, bystanders and others were informed by them. A sign had to be placed at every possible location that entered the BUAS campus.

Mental task load safety operator/control room operator

The mental task load of the safety operators has to be determined in future use cases. In this use case, they were able to focus on the operational and technical part of the robot continuously, this was possible due to the low number of trips that the robot made daily. During the trips the safety operators had to turn the robot in the right direction because it could only drive from one side, the messages to receiver and sender had to be sent, the robot's hatch had to be opened manually and the robot's autonomous mode had to be put on to let it drive. The task load for the safety operators was relatively low due to the autonomous capabilities of the robot.

Figure 6: Example of a control room

The task load could increase in the future when the robot can be controlled from distance in a control room because the robots have to be watched continuously and maybe even multiple ones at the same time. When the robot's functionalities improve, the task load for the safety operator could decrease again.

A control room has not been used during this project because the safety operators had to walk next to the robot to cover its blind spots. As such, there were human resources left for the control room. The safety operator could be assisted by a control room operator in a future project. To move the safety operator's physical location to the control room, there needs to be an additional safety case. Besides that, the first step to take is working from a room that has a direct sight on the robot at all times and that is always accessible and available during operational hours. When it is completely safe to control the robot from a control room without direct sight on the robot, the next step can be taken. A control room has to be set up that meets all insurance conditions. ***Airlift is capable of showcasing the realtime and highly redundant tele-assist system that is not being used.***

<u>Physical interaction with other road users</u>
The first few weeks the interaction with other road users was low. As can be seen in the logfiles, only a few times the safety operators were addressed by campus visitors. In the first weeks, the Airlift safety operators and volunteers didn't keep a lot of distance from the robot. This didn't help in simulating a realistic situation between the robot and visitors on campus. This was discussed during the pilot and in accordance with the safety operators a bit of distance was kept from the robot while it was operational.

During the operation, you could see that more road users interacted with the robot because there was no group of people around it. This helped for a while and interaction was stimulated in this period, but after a while, the safety operators and volunteers did not keep enough distance again and interaction was decreased again.

Looking at the interaction and communication between the robot and the people it went through text messages. When a janitor/student wanted to send a parcel, they could send a text message 30 minutes in advance to the operator. When the delivery is possible, you get a request conformation, and a text message will be sent to the receiver. After this, the package can be placed in the robot. When the robot is in front of the receiving building, the receiver will get another notification (including the QR code) of the robot's arrival. From this moment it is possible to collect the parcel. The parcel can be collected when the QR code is showed before the camera and the hatch will open automatically. For the receiver, it was first hard to find the QR reading camera, but for a second time user, it was easy to find and execute by themselves. When the parcel will not be picked up, the robot will wait five minutes before he will return the package to the sender.

<u>Willingness to pay for the service</u>

If people are willing to pay for the service will be made clear from the questionary that has been made by the students at the BUAS campus. They shared a questionnaire with people visiting the campus, the results of the questionary are the following.

<u>Conclusion</u>
It can be concluded that the operational aspect of the pilot could be improved. The robot has driven less than was expected upfront. This was especially due to COVID-19 that caused fewer visitors, students, and staff members on-campus. Still, the number of orders increased after a while because field-tests were organised on-campus. Another reason for fewer orders than expected is the user digital interaction. Sending a text message 30 minutes in advance is not ideal for people who need to send their package right away. Besides that, sending a text message when needing your package picked up is "old-school" and therefore not user friendly enough. For future projects, an application should be used that is easily accessible to all its users.

To move the safety operator's physical location to the control room, the safety case needs to be further improved.

For the unloading and loading including waiting time process, the period of 5 minutes waiting time can be decreased. The unloading time took the longest and on average it took 1:51 min. Although, in this pilot, most of the orders came in during the field-tests, where the customers were close to the pick-up or drop-off point. In future projects, the average and maximum waiting time have to be measured when a customer is not close to the robot's pick-up/drop-off point. Then, there can be determined what should be the waiting time for the robot on customers.

1.4. Business case

The business case of self-driving logistics robots is theoretically present. By removing the steward and letting a control room operator monitor several self-driving robots, the operational costs should be reduced. Furthermore, self-driving robots theoretically have the capability to operate efficiently (using route optimization methods) and 24/7.

Assumptions:

1. The service was free of use.
2. The target group for this pilot was intended to be the janitors and reduce the distances they had to walk to get from building to building. Other users were not included.
3. The number of users and deliveries were expected to be significant to better understand the trends for a potential business case. However, due to the policy against COVID-19, almost 70% of the staff members and students were not allowed to come to the campus, which made the campus quiet. It was not possible to perform a minimum number of deliveries and pickups without an intervention. Therefore, field tests with dedicated student groups had been simulated to acquire enough data for the research questions. This data is not fully representative of a realistic situation.

Table 5: Business case research questions

Business case aspects	
1	What are the costs and revenues of the pilot?
2	Is it possible to make a business case with delivery robots?

Costs and revenues

This pilot has been funded by RWB and LCB for learning of the implementation of these self-driving systems. The costs involved are currently as follows.

Costs:

1. ***Costs for the storage location of the robot, including charging facilities*.** The storage also serves as a maintenance workshop for the robot. Charging facilities are straightforward, as the robot possesses swappable batteries that can be charged with a 220V power outlet.
2. ***The steward and the control room operator*.** The manhours needed to pay a steward and a control room operator. During the field test, we had two stewards. One of them could potentially work as an operator.
3. ***Infrastructural adjustments***: for this pilot, it was sufficient enough to inform the environment with the use of signs. These signs were made out of cardboard, and therefore, not costly.
4. ***The robot's leasing costs***. The use of the robot comes with a price, both for the costs of the robot, its maintenance, the setup costs, and any additional material costs, and also licensing costs for the use and update of the software for the autonomous driving and the user interface app.
5. ***Insurance costs***.
6. ***Project management costs***. The project management costs to prepare, implement, operate, and evaluate the pilot are included as well.
7. ***Event costs***. The grand opening as the start of the pilot project and its respective communication cost preparation time and materials.

The exact costs of these respective items are not clear, but the entire funding for the pilot was approximately €150.000,-

Revenues

During the pilot, there were no revenues made. As mentioned in the assumptions, the use of the robot was free of charge. Also, there were no other sources of income except for the funding scheme. Therefore, there are no findings to be mentioned. Theoretically, potential revenue streams could come from:

1. Sponsoring deals (licensing deals for logo's etc.)
2. Income per delivery
3. Data sell to third parties

Business case

For such a pilot to be profitable, there have to be more people on-campus and the way to use it should be made more easily. On the BUAS campus, at first, there were not many people aware of the robot and how to use it. It was specially made for the janitors to use it. After a while, all people on-campus could use it, but this did not reach the number of people that was intended. For transporting packages from one building to another, there is too little demand by all these other people.

The business case depends on different aspects. Not only does it depend on the costs and revenues, but it also depends on the state of the technology and the intended target group. The state of the technology is clearly outlined in Section 1.1. The intended target group was supposed to be the campus janitors. Because they were responsible for the logistics onsite, it was logical to start with them.

However, during the operations, it became clear the janitors were not the right target group. The three buildings were already individually supplied, which made the remaining outdoor last-mile logistics for the school materials unnecessary. As a result, the janitors did not feel the need to use the robot for supplying the different buildings, and they did not see themselves as early adopters of this service.

Since the aim was to learn from this pilot, it was necessary to gather data differently. Therefore, the target group got expanded. All people on-campus were allowed to use the robot. They got instructed with the help of the flyer as indicated in appendix 4. Due to COVID-19, there were not many staff members and students on-campus. The robot was expected to reduce human interactions, and therefore, help during the pandemic in the reduction of the spread. However, the number of people on the campus as a result of COVID dropped even more, which made it highly unlikely to gather a sufficient amount of data.

As a consequence, the partners had no choice but to set up a specific student target group and perform field tests (see the evaluation of BUas).

Conclusions

The business case of a self-driving robot cannot be validated yet after this pilot. There are yet too many unknowns to implement these robots effectively, such as:

1. ***Price per delivery.*** It is unclear what price should be requested per delivery, and whether this should be requested per kilometer/minute/delivery.
2. ***Target group.*** Currently, the initial identified target group did not seem to get attracted by the use of the robot. Whereas it is an interesting concept to insert into the supply chain, this cannot be done so easily without changing the existing supply chain.
   Furthermore, it is also unclear what other target groups and potential delivery products could be of interest. Are these self-driving robots only intended to deliver parcels, or are these self-driving robots also useful for the delivery of for instance books? In that case, what would the conditions be for the service to become profitable?

3. ***The state of technology and user acceptance***. With the introduction of self-driving robots, the introduction of human-machine interactions (HMIs) becomes apparent. Even though HMIs do not directly fall under the business case analysis, they do have a big impact on the success of the business. After all, if the 'customer' does not like the product, he/she will not use it.
   The conclusions based on the state of the technology and user acceptance are already included in Section 1.1 and 1.3.

2 Conclusions

The Future Mobility Network, Airlift Systems, and Breda University of Applied Sciences have had the intention to perform the first pilot in the Netherlands with a self-driving automated. The intention is to use this pilot as a basis for future implementations, with the goal to learn from each new pilot, and eventually, exploit these robots and make these more visual on the public road. Before the start of the project, the consortium drafted the following goals:

- What is the effect of using a delivery robot on CO2 emissions, costs and safety in a public environment?
- What does a business case for a single shop or city management cooperation look like? What is the balance between costs for deployment/exploitation versus the efficiency in the logistical process?
- What kind of conditions (technical, spatial or juridical in terms of regulations and law) are needed to operate delivery robots safely, quickly and secure?

Effect of using a delivery robot on CO2 emissions, costs, and safety in a public environment

The self-driving delivery robot is electrically driven, making it a sustainable form of transport, and does not increase further CO2 emissions.

It is not fully clear what the effects on costs are from this pilot, as the robot got implemented in an existing environment. The supply chain process on-campus was fixed, and it is believed there is room for optimization. The testing time was not long enough to change the environment and validate a new supply chain process. Therefore, the effects cannot be scientifically proven to exist.

The safety of the robot was considered to be well. It was programmed to behave defensively in mixed traffic, such that it would always stop for an obstacle. It can be considered as a non-aggressive robot in mixed-traffic that delivers the parcels. However, with the technical defects experienced during this pilot, it cannot be left fully alone. A safety operator needs to be in the physical presence of the robot. Therefore, it can be concluded that the robot can be safely implemented in a public environment but in quiet locations with little mixed-traffic.

Business case

The business case of a self-driving robot cannot be validated yet after this pilot. There are yet too many unknowns to implement these robots effectively, such as:

1. ***Price per delivery.*** It is unclear what price should be requested per delivery, and whether this should be requested per kilometre/minute/delivery. This is because the use of the robot was free of charge.
2. ***Target group.*** Currently, the initial identified target group did not seem to get attracted by the use of the robot. Whereas it is an interesting concept to insert into the supply chain, this cannot be done so easily without changing the existing supply chain and validate this. Furthermore, it is also unclear what other target groups and potential delivery products could be of interest.
3. ***The state of the technology and the user acceptance***. With the introduction of self-driving robots, the introduction of human-machine interactions (HMIs) becomes more important. Even though HMIs do not directly fall under the business case analysis, they do have a big impact on the success of the business. After all, if the 'customer' does not like the product, he/she will not use it.
   The conclusions based on the state of the technology and the user acceptance are already included in Section 1.1 and 1.3.

The impact of COVID-19 was significantly. During this research project, the aim was to gather data to better understand the abovementioned topics (price per delivery, target group, state of technology and user acceptance). However, with the low number of people on-campus, the robot could not be tested in realistic real-world conditions.

Conditions

Safe, quick, and secure implementation of delivery robots can be successfully concluded for this pilot. FMN, Airlift, and BUas have proven in the implementation plan that safe implementation can be worked out in advance. During the pilot, no accidents have occurred, and the technical safety case, with the right insurance, permit, and communication have proven to be successfully working. The conditions are as follows:

1. Set up a proper technical safety case of the system.
2. Write an implementation plan that covers the safety case, the communication and contingency plan in case of calamities, the insurance, the operator's role, the required permit, and the research plan.
3. Set up the preparations for the actual implementation.
4. Technical commissioning of the robot.
5. Examinate the robot after commissioning.
6. Start the operation.
7. Weekly log files for better understanding. If the situation requires better safety, then react and improve.
8. Enjoy the achievement.

From a legal perspective, it is currently unclear whether self-driving delivery robots are considered vehicles or machines. This discussion is on a ministry level and it is unclear when this discussion will get an answer. The courage by and the belief in this pilot by the city of Breda made it possible to implement this pilot on the semi-public road. However, not all governmental institutes will do this. Therefore, a policy needs to be made for these type of systems in order to upscale the product.

Final conclusion

It is rather difficult to fully draw conclusions from this pilot. There seems to be potential to implement self-driving robots for upscale at other use cases. However, the upscale to other locations comes with a side note:

- There needs to be clarity on the legal framework of these self-driving delivery robots. If this is not the case, an upscale cannot easily be performed.
- The state of the technology needs to be enhanced for better operation. The autonomy of the system seems to be working well, but needs further development. Furthermore, the user interface requires more development to make it more accessible. Ordering and communication with the robot by the end user is still a point of attention for proper operation.
- Finally, better insight is needed in the user acceptance and the target group. This insight is needed to better understand the supply chain process in which the robot should be integrated, and ultimately the business case. New use cases on other locations will be required to gather data from different target groups, different supply chains, and different operation processes and times.

3 Recommendations

In this chapter, the lessons learned will be presented for the situations in different domains. The domains are categorised in deployment, impact, technical and human behaviour. These are also listed under the different project phases. The phases are categorised in preparation, implementation and realisation.

The top 10 experiences and learned lessons can be found below. The goal of this is to learn from these experiences for future project. The lessons learned serve as the recommendation for future project. The complete lessons learned document can be found in Appendix 5.

PHASE	SITUATION	LESSON LEARNED	DOMAIN
Preparation	The Wi-Fi strength was not checked at the BUAS storage. This was ultimately too weak.	Checking the Wi-Fi strength beforehand.	Deployment
Preparation	After the robot was released at customs, no thought was given to transport it to the location and for unloading at the location.	Record who provides transport and how the robot can be unloaded on-site (use of a ramp).	Deployment
Preparation	The commissioning phase lasted more than 10 days because all sensors still needed to be calibrated. And the robot was too sensitive and stopped too many times.	This can be done shorter (10 days expected) if this is done in advance instead of on location. The calibration should have been done earlier. The system could be more plug and play, this saves more time during the commissioning phase.	Impact
Preparation	The expectations of the functions of the robot where higher than expected.	The TRL level should be mentioned and is essential before starting such a project. So, all parties know what they can expect. The safety case is not proven yet, because the operator is still needed next to the robot.	Technical
Implementation	A meeting was held once a week, but not after the operational plan. As a result, the planning was not kept and not all things were arranged at the end.	Plan in a fixed moment to deal with the operational plan so that there will be progress.	Human behaviour
Realisation	Janitors did not use the robot.	Janitors did not use of the robot. For them, it was unnecessary and not timesaving. They might not be the right group to target and train for these types of projects.	Human behaviour
Realisation	The robot made fewer deliveries daily because there were not enough people on campus and there were not enough orders placed. Therefore, the is a lack of collectable data. This was caused by COVID.	Organize field tests to simulate certain situations in operation and to be able to collect enough data with help of students. COVID had a much greater impact on this part of the project than expected.	Impact
Realisation	Water enters the LiDAR and the compartments of the robot.	The robot is designed in Qatar and therefore not properly tested for a rainy environment, which makes it not waterproof. The robot should be tested with a rain simulator or at simulator conditions.	Technical
Realisation	To receive the packages, messages are sent manually by the safety operator. And the QR-code used to open the compartment was always the same code.	Sending messages can be done by the use of an app, but the robot did not yet possess this featured. They used SMS for notifying. The QR code should be changing every delivery.	Technical
Realisation	The routes between the buildings can be driven autonomously, but the robot still had to be turned manually, so the front side was towards the right direction on arrival. And this had to be done before departure.	This is still a labour-intensive process and should be avoided in future projects.	Technical

Table 6: Top 10 Lessons Learned

Appendices

Appendix 1: Logfiles Airlift Systems

Name		28.10 Wednesday	29.10 Thursday	03.11 Tuesday	06.11 Friday
Battery usage per day					
State of the charge in the morning	%	100	100	75,7	57,2
State of the charge end of the day	%	75,3	81,5	0	53
Distance travelled per day					
Total distance driven per day (mtrs)		0	0	1352	2863
Driven trajectory per day					
Performed trips per day					
Horizon to frontier	number of trips	3	1	4	3
	average time per trip	4,14	3,18	2,15	5,13
frontier to horizon	number of trips	1	1	2	3
	average time per trip	3	2,37	2,44	8,15
horizon to ocean	number of trips	1	1	1	4
	average time per trip	6,08	3,55	3,18	8
ocean to horizon	number of trips	1	0	1	5
	average time per trip	8,59	0	2,17	11
frontier to ocean	number of trips	0	1	2	3
	average time per trip	0	2,43	2	4
ocean to frontier	number of trips	0	1	1	4
	average time per trip	0	2,54	3,14	4,62
Speed and stops					
Average speed per day		3km/h	4km/h	3km/h	3km/h
Number of stops		8	1	5	11
Number of emergency stops		1	0	0	0
Driving time per day		25	0	0	0
Maintenance					
Number of maintenance intervals occurred during the day		2	2	1	1
Nature of maintenance intervals		Charge batteries, maintenance steering motor	Charge batteries, waterproofing check	Charge batteries	Charge batteries
Total duration of maintenance during the day		30	45	45	60

Table 7: Logfiles Airlift Systems

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Appendix 2: Logfiles BUAS

	28-10-2020			29-10-2020	03-11-2020			
Trip number	1	2	3	1	1	3	9	11
Morning/Afternoon	Morning	Afternoon	Afternoon	Afternoon	Morning	Morning	Morning	Morning
Name	Dmitry.A	Dmitry.A	Dmitry.A	Dmitry.A	Dmitry.A	Dmitry.A	Alem.A	Alem.A
Week	44	44	44	44	45	45	45	45
Weather conditions	Dry	Light rain	Light rain	Dry	Dry	Dry	Dry	Dry
Temp.	11	11	11	12	9	9	9	9
Campus density	Calm	Calm	Busy	Busy	Calm	Calm	Calm	Calm
Duration	00:01:59	00:02:08	00:03:05	00:03:18	00:02:15	00:02:14	00:02:14	00:02:17
Number of packages	1	0	1	10	1	1	1	1
Type of package	From janitors = 1x Pen	N/A	From janitors = Box (35 x 5 x 5)	Books	Air	Box	Book	Beer crate
Loading time (min)	00:01:00	/	00:01:00	00:00:05	00:00:10	00:02:26	00:01:20	00:00:06
Unloading time (min)	00:11:02	/	00:17:00	00:00:26	00:00:20	00:02:59	00:04:25	00:00:19
Number of stops	0	0	3	0	0	0	0	1
Duration of stops	/	/	00:00:02	/	/	/	/	00:00:02
Reason for stops	N/A	0	alking in front of it and interest from an i	NA	NA	NA	NA	Jeroun sticked out his leg
Robot driving mode	Autonomous	Autonomous	Autonomous	Autonomous	Autonomous	Autonomous	Autonomous	Autonomous
observations about loading moment	fast	N/A	Quick	N/A	N/A	N/A	N/A	N/A
observations about unloading moment	g waiting time, and phone not answered by the recie	N/A	N/A	N/A	N/A	N/A	N/A	N/A
number of people asking about robot	0	4	4	0	0	0	0	0
peoples reaction to robot	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
number of people challenging the robot	0	1	0	0	0	0	0	0
Other observations	Smooth drive during the whole transit	Stops straight away when senso	ed in the robot getting too close to a wall and thereby making it stop again.					N/A

Table 8: Logfiles BUAS

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Appendix 3: Legal preconditions for operation

Checklist arrival BUAS

Section	Description	Satisfactory	Comments
Airlift Systems (ALS) robot specifications	Arrived undamaged (no significant damages)	☐	
	Wrapping fulfilled well	☐	
	Unwrapping fulfilled well	☐	
	4 wheels available and filled with air	☐	
	2 available compartments	☐	
	Front and rear lights available	☐	
	Front and rear blinkers available	☐	
	Camera available	☐	
	GPS receiver/tracker on the robot	☐	
	Spare parts available: • Spare wheels • Spare brakes • Spare sensors	☐	
	Kill switch is available	☐	
	Safety switches stationed on the robot	☐	
	Saving data availability (SD card or just USB input)	☐	
Dockstock/ docking station/ control room	Location matches with the project plan	☐	
	The robot can be stored in a secured location at the dock stock when not in operation	☐	
	The robot and its batteries can be charged at the dock stock	☐	
	The robot can be filled with parcels and packages here, that fits the requirements	☐	
	Necessary tools (laptop) to monitor the robot with real-time telemetry data is available	☐	
	A fire extinguisher is available	☐	
	All sandwich plates/signs are available	☐	
	Safety vests available	☐	
	All needed instruments available to drive with the robot	☐	
Risk management	Risk control plan has been shared and approved with and by the insurance company	☐	

Table 9: Checklist arrival BUAS

Checklist examination BUAS

Section	Description	Satisfactory	Comments
Testing environment	The BUAS campus has been released by the municipality of Breda (the road authority)	☐	
	Not driving on (semi) public road during the examination	☐	
	All needed sandwich plates/signs are placed	☐	
Risk management	Control measures of the risk control plan have been performed	☐	
	The operational plan is submitted and approved	☐	
Participants	All participants have a safety vest, the students that work on this project, safety operators and others	☐	
	Participants have been informed about research scenarios/goals	☐	
Safety operators /stewards	Safety operators know their job proceedings/need to be certified	☐	
Visitors BUAS-campus	Visitors have been informed about the pilot	☐	
Airlift Systems (ALS) robot specifications	Batteries delivered and installed	☐	
	The robot can be turned on	☐	
	Front and rear lights work	☐	
	Front and rear blinkers work	☐	
	Robot brakes properly	☐	
	The robot can move without collision	☐	
	The robot detects pedestrians/obstacles	☐	
	Robot stays in its lane, except when dodging obstacles or pedestrians	☐	
	Camera for real-time feedback works	☐	
	All possible data is saved/logged	☐	
	GPS receiver/tracker on robot and working	☐	
	Dead reckoning working	☐	
	Path planning in a confined environment working	☐	
	Safety systems are active	☐	
	The robots speed limit is 5 km/h	☐	
	Kill switch is working and can be used by the safety operator within 2 seconds	☐	
	Safety switches on the robot are working	☐	

	The robot can be taken over by the safety operator within 2 seconds	☐	
	The inside of the robot looks good, no wires are laying on each other	☐	
Dockstock/ docking station/ control room	The robot can be driven to the docking station manually	☐	
	Batteries charge when plugged in	☐	
	Call tree available by safety operators	☐	
	The robot opens up at pick-up point autonomously	☐	
	The robot opens up at arrival point autonomously	☐	
	Necessary tools (laptop) can monitor the robot's real-time telemetry data	☐	
	Break stop/location for safety operator with toilet and coffee	☐	

Table 10: Checklist examination BUAS

Appendix 4: User instruction flyer

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Appendix 5: Lessons learned

In this Appendix, the lessons learned have been presented for the situations in all domains. The phases are divided in preparation, implementation and realisation.

PHASE	SITUATION	LESSON LEARNED	DOMAIN
Preparation	The Wi-Fi strength was not checked at the BUas location. This was ultimately too weak.	Checking the Wi-Fi strength beforehand.	Deployment
Preparation	After the robot was released at customs, no thought was given to transport it to the location and for unloading at the location.	Record who provides transport and how the robot can be unloaded on-site (use of a ramp).	Deployment
Preparation	At the moment, two people are needed for commissioning of the robot.	This should be made easier in the future and be performed by 1 person.	Deployment
Preparation/ Implementation	There was no clear schedule. Airlift does not have a clear schedule till finalization, so it is unclear where they are in the process.	Getting a schedule from Airlift beforehand.	Deployment
Preparation	New batteries and LiDAR are not yet available before needing them for programming.	More time needed to program because they were not used to it, after installing these parts the robot became heavier as well and it became more difficult to drive up a slope.	Impact
Preparation	The commissioning phase lasted more than 10 days because all sensors still needed to be calibrated. And the robot was too sensitive and stopped too many times.	This can be done shorter (10 days expected) if this is done in advance instead of on location. The calibration should have been done earlier. The system could be more plug and play, this saves more time during the commissioning phase.	Impact
Preparation	The batteries were shipped separately and through different countries, causing one battery to arrive sooner than the other.	Send the batteries earlier to prevent delays in the process due to delay in transport.	Legal
Preparation	No thought is given to the weight distribution (vehicle dynamics), which means that there is a great chance of imbalance (in the load of parts).	Parts can't handle the load/break more quickly. Vehicle dynamics should be taken into account.	Technical
Preparation	No consideration is given to possible height differences, which creates extra ballast on the front axle and other parts.	Parts can't handle the load/break more quickly. Height differences should be part of the tests performed by the robot.	Technical

Preparation	There was no kill switch when the robot arrived. As a result, it had to be made on location, resulting in even greater time pressure.	The kill switch must already be equipped on the vehicle as a strict requirement before reception/commissioning.	Technical
Preparation	Most spare parts are available at arrival, but not all. We are not confident enough to say if the pilot can start on the right day.	Clearly state that the spare parts should be available on time, make good appointments about this. The parts should be sent earlier.	Technical
Preparation	The location was not ready for commissioning, so it was not possible to start immediately.	Before the commissioning takes place, there should be done a final check on the location.	Technical
Preparation	After the arrival of the robot on-campus, there were no proper tools available, which made it difficult to remove the robot from the transport box.	Create a fixed package containing basic tools when going to a location to do an unboxing. Think of a cordless drill, crowbar, hammer and screwdrivers.	Technical
Preparation	The expectations of the functions of the robot were higher than delivered	The TRL level should have been discussed before starting the project. So all parties know what they can expect.	Technical
Implementation	A meeting was held once a week, but not necessarily about the operational plan. As a result, the planning was not kept hard and not all things were arranged at the end.	Plan in a fixed moment to deal with the operational plan so that there can be anticipated on more fiercely.	Human behaviour
Implementation	The calibration process must take place right next to the robot with a good Wi-Fi connection available.	This should be performed otherwise, and it must be defined in advance. If necessary, the sensors should be removed from the robots to be able to calibrate at another location so that it gets more dynamic. This must also take place before commissioning.	Technical
Implementation	The robot is considered to be driveable on both sides, therefore it must be possible to drive it going back and forth.	The colouring of the lamps is not very convenient (red at the back, white at the front). The choice has been made to let the robot drive in only one direction. This has been done especially given the load on the axles and the weight distribution.	Technical
Realisation	The LiDAR sensor had to be reset because the brakes stopped the robot too fast when an object was in front of it.	Better communication with FMN for findings of the earlier projects with the shuttles would have saved time.	Deployment

Realisation	Janitors do not use the robot.	Janitors are reluctant to use the robot because they indicate that they consider it unnecessary and not timesaving.	Human behaviour
Realisation	Unknown how the robot can drive without LiDAR. What if no distance determination can take place, e.g., on a pasture? If the LiDAR is absent or broken, the robot can't work anymore.	Find out whether the robot can drive without the help of the LiDAR.	Impact
Realisation	Too few people on campus.	Because of COVID19, there are fewer students/staff on campus. This reduces the demand for orders.	Impact
Realisation	Airlift's hardware is located in a BUas area where Airlift is not authorized to enter. As a result, Airlift cannot access their belongings.	Make a separate room available for Airlift where they can safely store their belongings.	Impact
Realisation	The robot makes fewer or no transports daily because there are too few people on campus and too few orders are placed. Therefore, the is a lack of collectable data.	Organize field tests to simulate certain situations in operation and to be able to collect enough data with help of students.	Impact
Realisation	You have to walk next to the robot at all times.	Because of this, you can't simulate a real situation where you can see the reaction of people.	Legal
Realisation	The LiDAR was delayed and does not have a certificate required for insurance.	Transport the LiDAR sooner to avoid delays in the process and make sure all certificates for insurance are available.	Legal
Realisation	Airlift would like to do remote control from a room on the campus, but this is not legally possible, because there are too many blind spots and the connection is probably too poor.	In advance, there should be a check for the possibilities of remote control in a room with a direct view on the robot.	Legal
Realisation	Water enters the LiDAR and the compartments of the robot.	The robot is designed in Qatar and therefore not properly tested for a raining environment, which makes it not waterproof. The robot should be tested in a region with rain.	Technical
Realisation	To receive the packages, messages are sent manually.	Sending messages can be done by for example use of an app, but this robot wasn't that far in development yet.	Technical

Realisation	The routes between the buildings can be driven autonomously, but the robot still has to be turned manually with the front side towards the right direction on after arrival and before departure.	This is still a labour-intensive process and should be avoided in future projects.	Technical
Realisation	After putting in the package, the hatch cannot close autonomously.	The hatch must be closed manually, this should be avoided in future projects.	Technical
Realisation	The QR-code used to be able to open the hatch of the robot is the same for every package/customer.	Someone else might take your package accidentally or on purpose. This should be avoided by sending different QR codes to customers.	Technical
Realisation	The passage to the compartment is smaller than the compartment itself. As a result, smaller packages than possible fit in.	Make the passage the same size as the compartment.	Technical
Realisation	The routes between the buildings can be driven autonomously, but the robot still has to be turned manually with the front side towards the right direction on after arrival and before departure.	This is still a labour-intensive process and should be avoided in future projects.	Technical

Table 11: Lessons learned