Proceedings of the Hamburg International Conference of Logistics (HICL) – 32

Marko Thiel, Sandra Tjaden, Manuel Schrick, Kerstin Rosenberger, and Matthias Grote

Requirements for robots in combined passenger/freight transport

HICL

Published in: Adapting to the Future:
Carlos Jahn, Wolfgang Kersten and Christian M. Ringle (Eds.)
ISBN 978-3-754927-71-7, September 2021, epubli

Requirements for robots in combined passenger/freight transport

Marko Thiel[1], Sandra Tjaden[1], Manuel Schrick[1], Kerstin Rosenberger[1] and Matthias Grote[1]

1 – Hamburg University of Technology

Purpose: *Delivery robots promise to provide gains in logistics in many ways especially on short distances. However, there is a lack of orderly overview of requirements for their successful implementation. The aim of this paper is to generate a better understanding of how to implement delivery robots in public infrastructure.*

Methodology: *This paper follows an explorative, applied and interdisciplinary research approach based on the pilot project "TaBuLa-LOG". The results of a literature review were used as the foundation for thematically targeted expert workshops, interviews and desktop research. The individual approaches and outlined requirements are then combined and structured on the basis of a dependency model.*

Findings: *We discuss not only the independent solo autonomous use of delivery robots, but also the combined use, where the main run takes place in an automated passenger shuttle. The result of this paper is a comprehensive overview of the identified requirements structured along the developed dependency model.*

Originality: *When it comes to delivery robots there is limited uniform information about the implementation in real environments so far. This paper closes the gap by identifying requirements for implementing a delivery robot into a combined passenger and freight transport.*

First received: 10. May 2021 Revised: 29. Aug 2021 Accepted: 31. Aug 2021

1 Introduction

Delivery robots promise to solve various problems in logistics, especially on the last mile. Their use serves, for example, to reduce traffic, counteract environmental pollution and enable request delivery as well as contactless delivery (e.g. Figliozzi and Jennings 2020, University of Toronto Robotics Institute 2020). When the term delivery robot is used, it usually refers to small or micro vehicles that automatically transport only a small volume of goods, such as individual packages or small food deliveries. A classification option named in the literature relates to the transportation infrastructure used. On the one hand, there are road autonomous delivery robots (RADR) which travel roadways together with conventional motorized vehicles (Figliozzi and Jennings 2020). On the other hand, the more frequently discussed delivery robots are pedestrian-sized and use only sidewalks and pedestrian paths, the known as sidewalk autonomous delivery robots (SADR) (Figliozzi and Jennings 2020). This seems an appropriate classification when talking about delivery robots, since the implementation differs significantly from each other in many characteristics (e.g. grade of technology, complexity of automated control, moving between pedestrians or cars).

Limitations of sidewalk autonomous delivery robots are the low transport capacity and a small radius of action. But solutions to these limitations have already been discussed, for example, combining the robots with other means of transportation (e.g. Hoffmann and Prause 2018, Figliozzi and Jennings 2020). In comparison to road autonomous delivery robots, sidewalk autonomous delivery robots can be integrated in other transport modes for longer distances, like commercial vans or busses, we call this scenario combined transport. In the same way, however, the SADR can then also cover shorter distances independently, which we refer to as solo transport. The solo autonomous use is the independent operation of the robot on the first and last mile, while the main run takes place in an automated passenger shuttle. In this respect, the combination enables a more flexible use of the delivery robots. Therefore, the sidewalk autonomous delivery robots are the subject of this paper, in line with numerous pilot projects (e.g. Brandt et al. 2019, Jennings and Figliozzi 2019).

But when it comes to delivery robots there is limited uniform information about the implementation in the real environment so far. Therefore, the aim of this paper is to generate a better understanding of how to implement delivery robots in public infrastructure. The question to answer is what are the requirements for implementing a delivery robot and how can they be assigned into a distribution process. In this paper the term “requirements” refers to software and hardware features as well as characteristics of development and logistics processes that are necessary to successfully implement a delivery robot in distribution.

For this purpose, a literature review will first be conducted to identify the areas from which requirements arise in the context of a delivery robot. The findings from the literature analysis are then used for our own methodological design. It is structured in several approaches focusing on operational, legal and technical issues. The identified requirements consist of an explorative mixed method approach in the sense of combining data from qualitative and technical sources by using a variety of different methods like expert workshops and interviews, desktop research as well as of a use case based on the pilot project “TaBuLa-LOG”. The individual results are then combined and the requirements systematized on the basis of a dependency model. Based on this the requirements for the implementation of a delivery robot are examined in more detail. The special characteristic of the consideration is that the delivery robot covers longer distances in an automated shuttle in a kind of "piggyback transport" and drives only the last mile to the end customer autonomously. This way, the range of the delivery robot can be extended. The shuttle is originally used for public passenger transport, but by taking the delivery robot with it, it then combines passenger transport with freight transport. The paper closes with a discussion and recommendations for actions to facilitate the integration of delivery robots into public infrastructure.

2 Delivery robots in literature

The literature was examined using the scoping approach, as according to Arksey and O´Malley (2005) this is appropriate, if fields of study are to be mapped and research gaps identified.

From a technical perspective in particular, there is of course a great amount of specific research on basic functionality such as mapping, localization and navigation. Since the adoption of these techniques is required for a wide range of autonomous robots and not limited to delivery robots, they are not considered in this literature review. Despite that, the literature shows different areas in which requirements are important with regard to the delivery robot.

Rubio et al. (2019) give a broad overview on the topic of mobile robots, not exclusively covering unmanned ground vehicles. They present and discuss the key technologies and methods in the areas of locomotion, perception, cognition and navigation.

Sindi and Woodman (2020) examine impacts and barriers for the use of autonomous vehicles for last-mile delivery on the basis of semi-structured interviews. The interviewed experts generally endorse the use of autonomous vehicles but also saw barriers, e. g. missing information regarding required infrastructural modifications.

Hoffmann and Prause (2018) concentrate on the regulatory framework of autonomous delivery robots for packages. They based their research on expert interviews, data analysis, and a case study. They have worked out that the two main challenges in the use of delivery robots will be liability and acceptance issues.

Pani et al. (2020) deal with the acceptance of autonomous delivery robots by the users to provide guidelines and recommendations for action to make delivery robots suitable for mass use over the last mile. They are focusing on decarbonizing the last mile, as this is where large savings can be expected according to Pani et al. (2020). Abrams et al. (2021) address the applicability of existing acceptance models to delivery robots. They introduce the idea of an "Existance Acceptance", which explicitly considers spontaneous or passive interactions. Kapser, Abdelrahman and Bernecker (2021) investigate the acceptance of delivery robots in last-mile delivery in Germany. They also study the influence of gender as a moderator. The results of their study point to a correlation of the gender of the participants and certain aspects of their acceptance of the robots. Furthermore, Baum et. al (2019) focused on the status of development, vehicle concept and the field of application. In line with Hoffmann and Prause (2018) they came to the point, that public acceptance is one key factor for successful implementation of autonomous delivery robots.

Also, Brandt et al. (2019) identified a need for regulatory action, in particular by examining what legal framework conditions are required. They examined the use of delivery robots in CEP delivery for a case study in the city of Hamburg, Germany.

Figliozzi and Jennings (2020) also examined sidewalk autonomous delivery robots which operate from a mothership van and identified them to be a feasible alternative to standard delivery vehicles in terms of reducing road miles travelled. In other sources as Hoffmann and Prause (2018) this kind of solution is called RoboVan and autonomous delivery robots that launch from trucks deliver shipments to customers. However, these savings then come at the expense of the sidewalk, which in turn can lead to new challenges such as pedestrian safety. In addition, Figliozzi and Jennings (2019, 2020) raise the issue that the additional mothership van needed might park longer and take up larger parking slots. Furthermore, Figliozzi and Jennings (2020) examined on the one hand the current capabilities of autonomous delivery robots and on the other hand the potential energy and emission reductions which they could bring. However, the analysis also shows that especially when it comes to energy consumption, emissions and parking space utilization, the use of road based autonomous delivery robots can be beneficial. Additionally, Figliozzi (2020) points out that the analysis, at least from an emission reduction perspective, has to take into account some requirements or factors such as the distance to be covered or the product size.

Simoni et al. (2020) focus on the possibility of implementing an integrated truck-robot system for the last mile delivery. Based on a scheduling problem they show that robot-assisted last-mile delivery systems are quite efficient, when robots are employed in heavily congested areas. However, according to Simoni et al. (2020), one requirement for this would be the robot having several individual compartments. Boysen et al. (2018) studied this concept from an operations research perspective by addressing scheduling and routing issues.

Yu, Puchinger, and Sun (in press) also discuss the routing of van-robot systems and present an algorithm to solve these tasks. A case study modeling a realistic scenario is used to verify their findings.

Deng et al. (2020) model vehicle routing problems and also consider sidewalk delivery robots in the context of cooperative delivery schemes through movement synchronization between different delivery resources. Sidewalk delivery robots can bring cost savings compared to truck deliveries (Deng et al. 2020). Chen et al. (2021b) also investigate how to schedule vehicles and delivery robots as assistance for city logistics with the aim of minimizing total route time.

Marsden et al. (2018) present the BUGA:log project, in which they test the use of an automated transport system in a new living quarter as well as the BUGA 2019 (Bundesgartenschau – National Garden Festival) in Germany as part of a real-world laboratory.

Literature study shows that the development in the field of delivery robots is highly dynamic. But when it comes to the requirements that delivery robots should meet for proper implementation there is little information in the literature to date. Nevertheless, the questions addressed in the literature can be ordered into technical, legal and operational issues.

3 Research approach and methodology

This paper follows an explorative, applied and interdisciplinary research approach. Basis of our findings is a prototype study conducted as part of the research project “TaBuLa-LOG”. The aim of the project is to investigate and test the combined transport of passengers and goods in automated shuttles, with delivery robots performing the goods transport aspect. The interdisciplinary nature of our research requires knowledge of engineering, law, logistics, and transportation planning. For this reason, we decided to use an explorative mixed methods approach, which allows us to identify the diversified requirements for the development and implementation of delivery robots.

At the time of publication, the “TaBuLa-LOG” project is still ongoing. Hence our findings may change or expand as our research progresses. To address this limitation, we conducted a literature review in the form of a scoping study as mentioned above, both as a first starting point, as well as to complement our own findings. As shown in the previous section, the literature to date can be categorized into three areas: technical, legal and operational issues. As these appear to be the three most important areas in the implementation of delivery robots, it is necessary to identify requirements in each category. For this purpose, individual analyses are carried out in each area.

To identify operational requirements in distribution, an expert workshop was held to capture different experiences. The method of an expert workshop is a qualitative approach, which is used in an early state of research to find possible solutions for a given problem by integrating expert knowledge or the interested public (Häder 2015). The workshop incorporated knowledge of six participants, four from research with regard to engineering, transport and logistics and two from industry with an expertise in transport and logistics. In our workshop, operational requirements were identified by using an iterative process based on the World Café. The method was developed by Brown and Isaacs in 1995 with the aim of integrating different perspectives and views of all group members on a topic (Brown and Isaacs 2007).

Legal requirements were determined on the one hand by desk research and on the other hand by expert interviews. The desk research consisted of studying laws, regulations and standards in the development of delivery robots. Unanswered questions from the desk research and generic specifications were addressed in the interviews. The interview partner was an experienced auditor from TÜV Nord, an independent technical inspection and certification organization. As the approval and testing of the "TaBuLa-LOG" delivery robots takes place in Lauenburg/Elbe (Germany), the legal requirements refer to German law. However, since national law in many cases implement international legal provisions, transferability, at least in certain areas, is plausible.

Since the research and development of delivery robots is still at an early stage, it is difficult to obtain openly accessible information on technical requirements. For this reason, we held an expert workshop with five researchers from the fields of computer science, mechatronics, mechanical engineering and technical logistics. To provide a framework for this workshop, the operation of the delivery robot was modelled as a generalized transport process. The top level of abstraction is shown in Figure 1.

In addition to solo transport, optional combined transport, and (un)loading, the process model also includes multi-stage tours and passive waiting states. Any additional handling of goods is implicitly covered by the (un)loading step. This model was then used to identify, discuss, and group requirements along the transport process, providing a simple and intuitive workflow.

Finally, to structure the requirements identified, we introduce a dependency model that clusters the requirements based on their interdependencies.

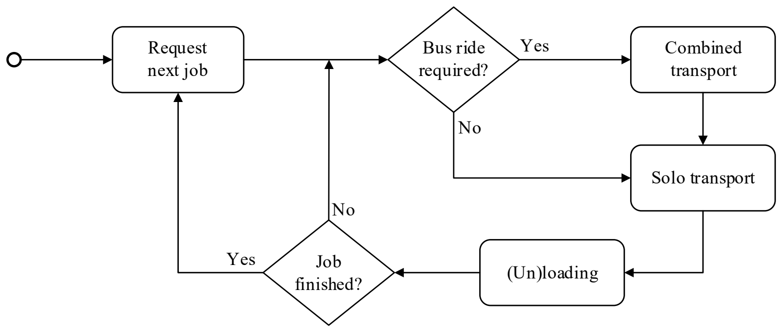

Figure 1: Flowchart of the generalized delivery robot transport process (own figure)

In summary, our approach consists of three main steps: the identification of requirement areas, the identification of requirements themselves, and the description along identified dependencies. The following Figure 2 summarizes our methodical approach.

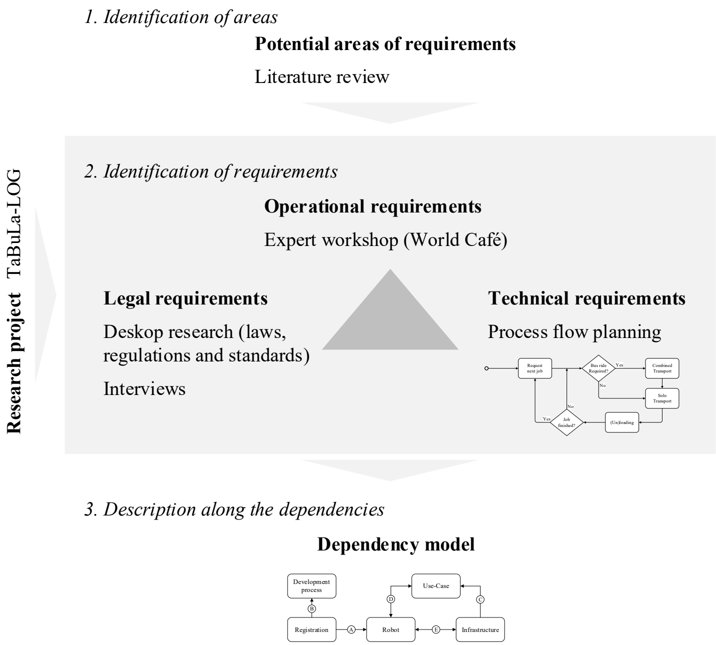

Figure 2: Illustration of the methodical approach (own figure)

4 Requirements along the dependency model

Our research showed that the requirements to be fulfilled when developing an autonomous delivery robot and implementing it into an (existing) supply chain can be assigned to one of the following aspects: registration, development process, robot, use case, infrastructure. For every identified requirement, one of these aspects can be considered the source. It imposes requirements upon another aspect, the target. Figure shows what hereafter we will refer to as the dependency model. It illustrates the aspects of development along the directions in which requirements are imposed depicted as arrows.

In the following, we will present the results of our research along the dependency model in that we will go through all aspects of development pairwise and list the requirements that arise in this relation. The order we will use is indicated by the letters on the arrows in Figure 3.

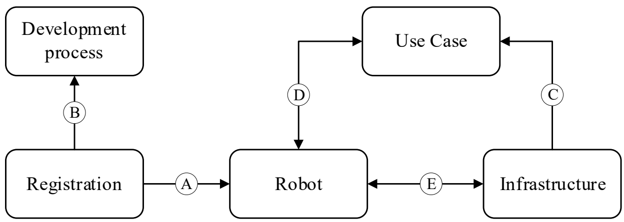

Figure 3: Dependency model with direction of imposed requirements (own figure)

4.1 Registration and Robot

Since the operational environment of the delivery robots are sidewalks, bike paths and streets in public space, it must first be determined which country-specific regulations such vehicles are subject to. This applies both to the use and behavior in road traffic as well as to the technical equipment of the robots. In Germany, small mobile robots are not explicitly covered by traffic law. Nevertheless, they are classified as motor vehicles under the German Vehicle Registration Ordinance (§ 2 FZV). Depending on the intended maximum speed, motor vehicles must undergo an official registration procedure. Vehicles with a maximum design speed of not more than 6 km/h are exempt from registration (§ 1 FZV). However, an additional permit might be required.

A further consequence of a classification as motor vehicles is the technical equipment and design of the robots within the framework of the German Road Traffic Licensing Ordinance (§ 16 StVZO). Here, specific requirements are placed on the technical equipment and design of the robots, e.g. with regard to lighting, braking systems, design of protruding outer edges but also electromagnetic compatibility. The regulation also refers to the respective international legislation that must be implemented.

Despite a vehicle’s ability to perform an entire journey fully automatically, the German Road Traffic Act requires the presence of a driver. This driver must be able to override systems or switch off automated driving functions at all times (§ 1a StVG). With delivery robots, these cannot be drivers in the conventional sense, who monitor the movement from a position within the vehicle. It is therefore necessary to check whether country-specific legislation permits monitoring from the robot's immediate surroundings, or also from a remote control center.

Before delivery robots can be deployed, preparatory assessments and permits need to be obtained. As far as approval for operation is concerned, the country-specific regulations and processes must be taken into account. In Germany the exact steps and requirements depend on whether the robots are series production vehicles or prototypes. Importantly, even for research prototypes such as those being developed in the “TaBuLa-LOG” project, a technical expert assessment must confirm conformity with road traffic regulations. Only then can an operating permit be applied from the licensing authority. Furthermore, proof from an insurer is required. To operate robots on sidewalks, an additional exemption permit is required. If the delivery robots are to use public transport vehicles for part of their journey, expert assessments must also be obtained to confirm the safety of the robots and of the passengers during the journey.

4.2 Registration and Development Process

As outlined in the previous section, national laws reference international law, including UN/ECE regulations. These not only set out requirements for the technical design of vehicles, but also for the documentation and validation of the development and safety concept. The latter two are described in particular by two standards: ISO 26262 Road Vehicles Functional Safety and ISO 21448 Safety of the Intended Functionality. An important aspect of these standards is a structured, iterative approach to the development of safety-critical systems, including risk assessment, rigorous testing and validation.

4.3 Use case and Infrastructure

In order to allow customers to request deliveries, a server system needs to supply an application programming interface (API) with this functionality. A graphical user interface (GUI) is required that uses this API and allows users to specify the desired delivery. The server needs to keep track of incoming delivery requests and assign them to available robots.

For the combined transport to take place without the need of manual interventions, the shuttle needs to supply an API that allows the robot to query various information such as the shuttles current location as well as to instruct the shuttle to perform tasks such as halting at a specific bus stop, opening a door or extending a ramp. This kind of communication is referred to as vehicle to vehicle communication (V2V). It typically requires a network connection of both systems.

During solo transport, depending on the selected routes, the infrastructure may have to be equipped with a vehicle to X communication (V2X) system that allows, for example, traffic lights to broadcast signal changes. This, of course can be circumvented by choosing routes that do not require the robot to cross any roads.

4.4 Use Case and Robot

Due to their design, delivery robots have a limited transport capacity, both in terms of volume and payload. This has to be considered when designing the use case. Conversely, with a given geometry or weight of goods to be transported, the robots' cargo compartment and weight distribution needs to be chosen accordingly. Especially since the characteristics of the cargo can have a significant impact on the robots' driving stability. The robots may have to be equipped with further hardware components such as insulation, climate control or shock absorbers to preserve the cargo's integrity.

Depending on the size and characteristics of the chosen delivery area, a combined transport may be required in order for the robot to reach its destination. This requires the delivery robot to be able to enter and exit a bus or shuttle, safely navigate inside, as well as securely dock during the trip.

In order for the robot to autonomously enter and exit the shuttle it needs to be able to use the above-mentioned Shuttle API to initiate the opening of a shuttle door or the extension of a ramp.

As the robot moves in close proximity to other passengers, distinct human-machine interaction is a major consideration. The sensors installed on the robot should be configured in such a way that the immediate vicinity of the robot can be monitored right down to the ground. Furthermore, it must be verified whether the selected sensors and localization method allow for localization in such geometrically confined and changing environments. The environment is changing as the number of passengers, the presence of luggage or pets is not known in advance and varies from trip to trip.

If the delivery robot is used in a regular public transport system, priority of passengers for transportation may have to be respected. This depends on the local conditions of carriage.

While riding the shuttle, the robot covers large distances in a short amount of time without being responsible for the motion. This has to be considered in the mapping process. Some parts of the recorded map may not have to be of the same level of detail as others. The robot may even have the ability to switch from one map to another.

Access to the cargo compartment should allow for easy and ergonomic (un)loading of the transported goods. The doors or flaps should open wide enough to accommodate larger items and the robot must be designed in such a way that partially removed load carriers or parcels do not cause the robots to tip over.

The robot must also ensure that only authorized customers get access to the cargo compartment. This may require an input device to be mounted on the robot.

4.5 Robot and Infrastructure

To enable regular operation of the delivery robots, it is necessary to set up a charging infrastructure on site. On the one hand, this concerns the charging stations themselves. On the other hand, this concerns the grid-side installations. The physical energy transmission interface of the charging station and robot have to be designed in such a way that it does not pose a risk to each other or people in close proximity. Depending on the location of the charging station, different weather conditions may have to be considered. In addition, the charging station needs features that render it recognizable by the robot for automated docking. The grid-side infrastructure must be capable of providing the necessary charging currents. A service station with tools, materials and spare parts is required to perform maintenance and repairs directly on site. This also includes a trolley for transporting the robot if inoperable.

In order for the robot to request its next job, it must be equipped with a network connection to be able to consume the above-mentioned server API. Subsequently, the robot must be able to deduce from a given job whether or not a combined transport is required.

Delivery robots are a classic example of mobile robots in outdoor environments and thus during solo transport are subject to typical challenges: Localization, typically with respect to a given map, path finding within predefined operating areas, and obstacle avoidance. As stated earlier, since these aspects not solely apply to delivery robots, this is why they were not considered in our research.

Depending on the robots' physical configuration it may require the infrastructure to be barrier-free. This includes entering and leaving the shuttle, accessing buildings, and traveling on public infrastructure. For a robot deployment, these infrastructural adjustments must be made in advance. However, the selection of certain robot configurations such as a legged robot that provide it with specific locomotion capabilities that render these requirements unnecessary.

Depending on the robots' routes, it may be required to engage in the above-mentioned V2X-communication in order to, for example, receive the status of traffic lights and cross roads safely.

During the combined transport, the robot must not roll, slide or tip over. This applies to regular travel as well as during emergency maneuvers of the shuttle. To secure the robot, structural modifications to the shuttle may be necessary.

When it reaches its destination, to start the (un)loading process, the robot has to notify the recipient of the transported goods. This may require the server system to send notifications to customers.

Figure 4 gives an overview of all identified requirements.

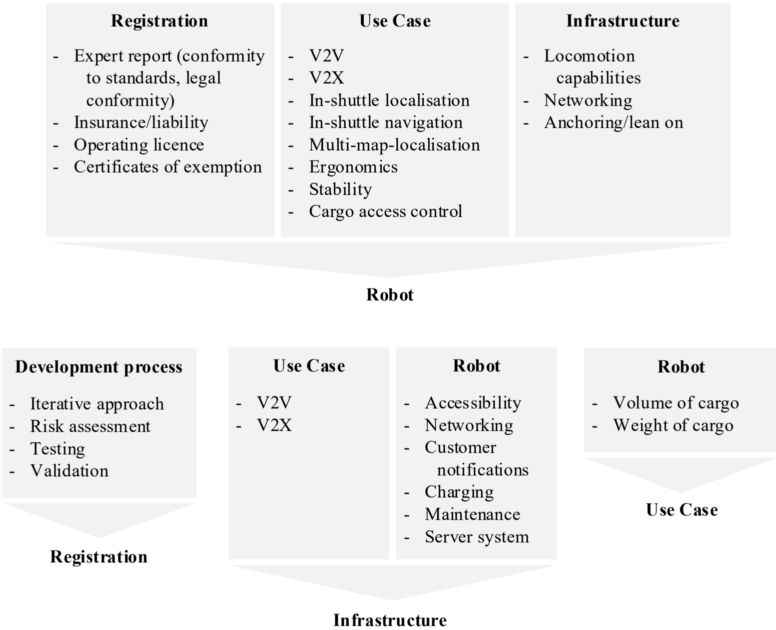

Figure 4: Overview of the identified requirements (own figure)

5 Conclusion

The aim of the paper was to generate a better understanding of the development of delivery robots and their implementation into public infrastructure and transport. To achieve this, we conducted a literature review to identify areas in which requirements arise using a scoping approach. The results were used as the foundation for thematically targeted expert workshops, interviews and desktop research.

Using this explorative mixed methods approach, legal, technical and operational requirements were identified and augmented with the help of the pilot project “TaBuLa-LOG”. In this project, an autonomous delivery robot is implemented into an existing shuttle operation in order to achieve a combined passenger and freight transport system. Afterwards, the requirements were structured on the basis of a dependency model developed specifically for this purpose. This model is integral for obtaining a deeper understanding of the wide range of requirements and their interconnectedness. A structure of this kind has not been proposed in literature yet.

Our research yielded numerous requirements for the development and implementation of delivery robots. We close this paper by giving a comprehensive overview of the requirements identified along the structure introduced with the dependency model.

Recommendations for action can be derived from the findings. Currently, German traffic law does not explicitly cover delivery robots. General requirements can be inferred from the Road Traffic Licensing Regulations, but specific standards are not yet included. In the past, extensions have been made for new vehicle categories, such as electric scooters. This should also be pursued with a focus on delivery robots.

In general, a delivery robot can be used for various applications, e.g. delivery of mail, food or pharmaceuticals, which presupposes that the transport containers are adaptable and modular. Also, standardization of packaging sizes and shapes is important for better capacity planning as well as easier handling. For these two reasons, we encourage the adoption of standardized, modular norm containers.

For widespread use of delivery robots, it is necessary to consider their use in future transport and urban planning and thus the needed infrastructure (V2X-communication, barrier-free accesses). However, in line with Hoffmann and Prause (2018), it is also important to strengthen the acceptance among the population.

As the development and operation of delivery robots in public infrastructure and transport is a very young field of research, this paper is not free of limitations. Due to the limited amount of information, we resorted to qualitative methods like expert workshops and interviews, which are common practice at early research stages. These methods are based on individual experiences and estimates, which is why the results may not be exhaustive.

In addition, our analysis is based on a prototype consideration, which means that some requirements, most notably the ones addressing and originating in the registration process, might still have to be adjusted in the case of series production. The same applies when fleets of delivery robots are used.

Moreover, the analysis was almost exclusively based on German law and standardization, which must be taken into account when using the identified requirements.

It is noteworthy that the literature almost exclusively considers use cases in the parcel or food delivery sector. Further research is therefore needed to identify other areas of application. It might also be beneficial to expand the currently used terminology of “delivery robots” in literature to “transport robots” to open up the field of research.

All in all, it can be stated that future research will increasingly focus on digitalization and automation. In this context, policymakers should focus their attention on a holistic view of the transport system to better exploit the individual advantages of different modes of transport.

Financial Disclosure

This article is based on research that was undertaken in the project “TaBuLa-LOG - Kombinierter Personen- und Warentransport in automatisierten Shuttles” sponsored by the German Federal Ministry of Transport and Digital Infrastructure between 2020 and 2021.

References

Abrams, A. M. H., Dautzenberg, P. S. C., Jakobowsky, C., Ladwig, S. and Rosenthal-von der Pütten, A. M., 2021. A Theoretical and Empirical Reflection on Technology Acceptance Models for Autonomous Delivery Robots. In: ACM/IEEE, Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction. Boulder, CO, USA, 8-11 March 2021. New York: Association for Computing Machinery.

Arksey, H. and O'Malley, L., 2005. Scoping studies: towards a methodological framework. International Journal of Social Research Methodology, [e-journal] 8(1), pp. 19–32.

Baum, L., Assmann, T. and Strubelt, H., 2019. State of the art - Automated micro-vehicles for urban logistics. IFAC-PapersOnLine, [e-journal] 52(13), pp. 2455–2462.

Boysen, N., Schwerdfeger, S. and Weidinger, F., 2018. Scheduling last-mile deliveries with truck-based autonomous robots. European Journal of Operational Research, [e-journal] 271(3), pp. 1085–1099.

Brandt, J. C., Böker, B., Bullinger, A., Conrads, M., Duisberg, A. and Stahl-Rolf, S., 2019. Fallstudie: Delivery Robot Hamburg für KEP-Zustellung. <https://www.bmwi.de/Redaktion/DE/Downloads/C-D/delivery-robot-hamburg.pdf?__blob=publicationFile&v=4> [Accessed 30 May 2021].

Brown, J. and Isaacs, D., 2007. Das World Café: Kreative Zukunftsgestaltung in Organisationen und Gesellschaft. Heidelberg: Auer.

Chen, C., Demir, E., Huang, Y. and Qiu, R., 2021b. The adoption of self-driving delivery robots in last mile logistics. Transportation Research Part E: Logistics and Transportation Review, [e-journal] 146, p. 102214.

Figliozzi, M. and Jennings, D., 2020. Autonomous delivery robots and their potential impacts on urban freight energy consumption and emissions. Transportation Research Procedia, [e-journal] 46, pp. 21–28.

Häder, M., 2015. Empirische Sozialforschung: Eine Einführung. 3rd ed. Wiesbaden: Springer Fachmedien Wiesbaden; Imprint: Springer VS.

Hoffmann, T. and Prause, G., 2018. On the Regulatory Framework for Last-Mile Delivery Robots. Machines, [e-journal] 6(3), p. 33.

Jennings, D. and Figliozzi, M., 2019. Study of Sidewalk Autonomous Delivery Robots and Their Potential Impacts on Freight Efficiency and Travel. Transportation Research Record: Journal of the Transportation Research Board, [e-journal] 2673(6), pp. 317–326.

Kapser, S., Abdelrahman, M. and Bernecker, T., 2021. Autonomous delivery vehicles to fight the spread of Covid-19 – How do men and women differ in their acceptance? Transportation Research Part A: Policy and Practice, [e-journal] 148, pp. 183–198.

Marsden, N., Bernecker, T., Zöllner, R., Sußmann, N. and Kapser, S., 2018. BUGA:log – A Real-World Laboratory Approach to Designing an Automated Transport System for Goods in Urban Areas. In: IEEE, 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC). Stuttgart, Germany, 17-20 June 2018. IEEE.

Miguel A. Figliozzi, 2020. Carbon emissions reductions in last mile and grocery deliveries utilizing air and ground autonomous vehicles. Transportation Research Part D: Transport and Environment, [e-journal] 85, p. 102443.

Pani, A., Mishra, S., Golias, M. and Figliozzi, M., 2020. Evaluating public acceptance of autonomous delivery robots during COVID-19 pandemic. Transportation Research Part D: Transport and Environment, [e-journal] 89, p. 102600.

Puyuan Deng, Glareh Amirjamshidi and Matthew Roorda, 2020. A vehicle routing problem with movement synchronization of drones, sidewalk robots, or foot-walkers. Transportation Research Procedia, [e-journal] 46, pp. 29–36.

Rubio, F., Valero, F. and Llopis-Albert, C., 2019. A review of mobile robots: Concepts, methods, theoretical framework, and applications. International Journal of Advanced Robotic Systems, [e-journal] 16(2).

Simoni, M. D., Kutanoglu, E. and Claudel, C. G., 2020. Optimization and analysis of a robot-assisted last mile delivery system. Transportation Research Part E: Logistics and Transportation Review, [e-journal] 142, p. 102049.

Sindi, S. and Woodman, R., 2020. Autonomous Goods Vehicles for Last-mile Delivery: Evaluation of Impact and Barriers. In: IEEE, 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC). Rhodes, Greece, 20- 23 September 2020. IEEE.

University of Toronto Robotics Institute, 2020. Making Sense of the Robotized Pandemic Response: A Comparison of Global and Canadian Robot Deployments and Success Factors. <https://arxiv.org/abs/2009.08577> [Accessed 30 May 2021].

Yu, S., Puchinger, J. and Sun, S., (in press). Van-based robot hybrid pickup and delivery routing problem. European Journal of Operational Research. (Accepted for publication June 2021).