Proceedings of the Hamburg International Conference of Logistics (HICL) – 27

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HICL

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Published in: Artificial Intelligence and Digital Transformation in Supply Chain Management
Wolfgang Kersten, Thorsten Blecker and Christian M. Ringle (Eds.)
September 2019, epubli

SmartAirCargoTrailer – Autonomous Short Distance Transports in Air Cargo

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Purpose: SmartAirCargoTrailers improve short-distance air cargo transports within airport premises. They create real-time-transparency between the partners in the transport chain and thereby reduces waiting times while at the same time increasing equipment utilization. An autonomous truck with swap bodies facilitates these short-distance transports.

Methodology: The SmartAirCargoTrailer system consist of an autonomous truck with swap trailers which is controlled by a cloud platform. To allow for real-time-transparency all shipments loaded onto the trailer are detected by a camera-based system.

Findings: To enable reliable scannings of AirwayBill numbers (AWBs) a system of multiple cameras was developed. Challenges arose from the big variationin shipment size and scanning in motion. While the truck could be triggered automatically based on time or filling level, also human interaction had to be integrated.

Originality: The system introduces a combined push-pull-algorithm to optimize the utilization of the autonomous trucks. The camera-based barcode scanning allows for shipment identification without interrupting the loading process. Autonomous driving in the mixed traffic environments of the landside airport premises is another innovative part of the project.

Keywords: Air Cargo, Camera-based Barcode Detection, Neural Networks, Autonomous Transports

First received: 19.May.2019 **Revised:** 27.May.2019 **Accepted:** 14.June.2019

1 Introduction

Air transport is an important part of global supply chains, particularly in view of decreasing lead times. Air cargo accounts for one third of the global cargo value exchange while at the same time representing less than 1% of the cargo volume (Shepherd, Shingal, and Ray, 2016). Global eCommerce is the main driving factor of future growth.[1] At present, the market for smaller packages and express shipments is being dominated by the leading Courier, Express and Parcel service providers (CEP). In an environment of increasing distance and decreasing lead time requirements, faster modes of transport have become more and more important. To meet those customer requirements and to better compete with CEP-providers, the industry, represented by the International Air Transport Association (IATA), aims at a significant acceleration of the overall transport time (IATA, 2018).

While increasing the speed of air transport seems to be neither economical nor technically unambitious, acceleration of the overall lead time within processes on the ground deserve all attention. Especially at hub airports, the links between continental forwarder networks and intercontinental airline networks provide potential for improvement. Typically, physical exchanges of shipments between forwarder hubs and air cargo handling facilities of designated airlines are executed via road transport. The covered distance is often less than a few kilometers. As a result, the process of delivering or receiving shipments between forwarder hub and air cargo handling facilities takes hours whereas the actual driving activity accounts for

[1] For further information on global supply chains and the impact of digitization on freight forwarding refer to Lehmacher, 2015 and Dietrich and Fiege, 2017.

a few minutes only. The purpose of the forwarder hub is to consolidate single shipments to achieve a better weight and volume mix and reduced kg-pricing for bigger shipments. As many shipments are last-minute-deliveries (or pick-ups from the shipper site) this consolidation is based on dynamic and experienced-based decision making. As the consolidated air cargo shipments have to be delivered prior to a Latest Acceptance Time (LAT) forwarders tend to deliver at the latest possible time to maximize the consolidation potential. However, in peak times the congestion of the air cargo handling facilities generates the decision problem regarding the right cut-off-time at the forwarder facility: Apart from the LAT and the transport distance the delay caused by the congestion has to be taken into account.

The aim of the SmartAirCargo trailer is to increase the transparency of the process by realizing a demand-driven transport concept. The autonomous transports are planned for August and September 2019. So far the basic functions and integration of camera-based barcode reading and the cloud platform are in workable conditions while the preparatory work on the autonomous transport is almost finished.

In the following, the paper gives a short review of relevant literature regarding air cargo processes, camera-based barcode identification, and autonomous transports (Chapter 2). Then, the air cargo supply chain is introduced in more detail (Chapter 3). Chapter 4 consists of the goals and a concept overview. Preliminary and expected results, but also limitations are detailed in chapter 5. At the end an outlook is given.

2 Literature Review

In this section we give a brief overview of the relevant and latest relevant publications While the section of air cargo provides an general overview of the area of application, the following sections highlight the current status in the area of autonomous vehicles in freight transport and camera-based barcode reading. The literature review on air cargo is the basis for the description of the air cargo supply chain and its challenges while camera-based barcode reading and autonomous vehicles are two central conceptual elements of the SmartAirCargoTrailer.

2.1 Air Cargo

Most publications related to air transport and airport operation focus either on passenger processes, airside ground handling or on network design. Feng et al. provide a literature review of air cargo operation studies (Feng, Li, and Shen, 2015). Lange has identified an increase in departure delays caused by cargo operations (Lange, 2019). Liu et al. specify this fact by developing a model to calculate costs of flight delays caused by late package deliveries (Liu, Yin, and M. Hansen, 2019). The airport classification defined by Mayer can be used to identify cargo hubs (Mayer, 2016). Selinka et al. provide an analytical solution for truck handling at air cargo terminals (Selinka, Franz, and Stolletz, 2016) while Azadian et al. formulate an algorithm to optimize air cargo pick-up and deliveries (Azadian, Murat, and Chinnam, 2017). Brandt and Nickel focus on the planning problem of air cargo (F. Brandt and Nickel, 2018). Bierwirth and Schocke have analyzed the status quo and challenges of digitization in the air cargo supply chain

(Bierwirth and Schocke, 2017). In summary, it can be stated that handling agents have to face various challenges heavily influencing costs and performance.

2.2 Autonomous Vehicles

In intralogistics, the use of AGVs (Automated Guide Vehicles) is common since decades (Schmidt, 2018 and Ullrich, n.d.). Applications in transport are rare as the use on public roads has some challenges regarding liability and regulations (Bartolini, Tettamanti, and Varga, 2017 and Hey, 2019). The AGVs of Container Terminal Altenwerder (CTA) in Hamburg are used for container transport between operate quay and staging area. Technology-wise they are centrally managed in a closed environment without other vehicles or humans beings around and they navigate with the help of transponders in the ground (Ranau, 2011). Today camera- or radar-based systems are applied and under further development (Dixon, 2018 and Meinel, 2018)

The interaction between human and AGVs or robots is under development. While research and experimental applications in warehouse and production environment focus on full automation (Bonini et al., 2015), flexible AGVs (Wurll, 2016) and interaction with workers (Neubauer and Schauer, 2017) and do not require fixed guiding infrastructures, the steering of autonomous trucks for road transport is more complex and therefore requires a different approach. Especially the navigation and docking or maneuvering of truck-trailer combinations is challenging.[2]

[2] For the docking process further information can be found in Clarembaux et al., 2016, David and Manivannan, 2014. For the special requirements on navigation refer to Stahn, Stark, and Stopp, 2007 and Kober, Huber, and Oberfell, 2017.

The current state and future visions for autonomous driving can be found in (Bäumler and Kotzab, 2017, Clausen and IVI, 2018 and Flämig, 2016). An overview of AGVs already applied can be found at (Kückelhaus, Zeiler, and Niezgoda, 2014). Pipp, Reiners, and Roesgen (2018) describes applications of autonomous driving in an airport environment. In (Parreira and Meech, 2011) autonomous haulage systems are discussed, but so far technical and regulative restrictions hinder the realisation. While platooning is conceptually designed (Kunze et al., 2011) and tested to increase efficiency on highways, autonomous trucks are deployed in on-site applications delivering goods from one building to another or in moving swap bodies (A. Brandt, 2018 or KAMAG, 2019).

2.3 Camera-based Barcode Reading

In general, camera-based barcode reading can be divided into two tasks: *detection* and *decoding*. Most work focuses on only one of these two tasks. For example, there are many commercial and free software libraries for decoding barcodes, such as *QS-Barcode SDK*, *QR-Code SDK*, *ZXing*, or *ZBar* to name a few. All these libraries can reliably decode a barcode if it can be seen in an image of sufficient quality, i.e. size, sharpness and orientation, otherwise they fail.

The size of the image area in which the barcode is visible is perhaps the most important aspect of camera-based barcode decoding. If the minimum thickness of a single bar of a barcode cannot be displayed correctly, the barcode cannot be decoded. Thus, a sufficient local resolution must be guaranteed by using a proper camera setup. Another important factor in camera-based barcode decoding, which can be corrected algorithmically to a certain extent, is the sharpness of the image containing the barcode. Beside defocusing, motion of the barcode recorded by the camera is an important reason for blur. The alignment of a captured barcode in an image is also critical, as most barcode decoding algorithms expect horizontally oriented barcodes, which cannot be guaranteed in practice. A reliable camera-based barcode reading system suitable for practical use must therefore be able to cope with the three problems just mentioned. Thus, beside reliable barcode localization, the deblurring of the image regions containing the barcodes and their proper horizontal alignment are important pre-processing steps before the actual decoding.

State of the art localization methods such as (Gallo and Manduchi, 2011, Sörös and Flörkemeier, 2013, Creusot and Munawar, 2015, Yun and Kim, 2017 or Namane and Arezki, 2017), detect 1D or 2D barcodes from blurry, low contrast and low resolution images. However, all these methods require that the barcodes are very present in the image, i.e. the distance between camera and barcode is small and the barcode is aligned almost parallel to the camera image. In addition, they focus only on localizing barcodes, but do not correct their orientation or sharpen the image, both of which, as we have seen, are important for decoding. Katona and Nyúl, 2013 developed an algorithm to address some of these drawbacks by using morphological operations, but also does not consider small resolutions. More recent approaches based on deep learning proposed a barcode localization pipeline (see D. K. Hansen et al., 2017 and Zhang et al., 2018). The authors used a specialized neural network to locate barcodes and then rotate them to align them horizontally. However, The proposed approaches do not cope with motion blur. In (Yahyanejad and Ström, 2010) the authors presented a method for deblurring barcode images that are mainly affected by translational motion blur. A more recent neural network-based approach to sharpen barcode images was presented by Kupyn et al., 2018.

3 Air Cargo Supply Chain

For this paper, we focus on the processes between forwarder and air cargo handling agents. For a better understanding of the overall context we describe a generic air cargo supply chain from shipper to consignee first (see also Figure 1). We then highlight the relevant processes and describe them in more detail.

The air cargo supply chain starts with a shipper, usually a company, as air cargo is mostly used in the Business-to-Business (B2B) context. Based on a contract between shipper and consignee a forwarder is contracted by one of the parties based on the INCOTERMS agreed. The shipment is picked up by the forwarder and brought to a local forwarder facilities. From there, it is consolidated with other air cargo shipments and transported to the forwarder hub at the airport. There, all air cargo shipments with the same destination (airport-wise) will be consolidated. Part of the consolidation process at the forwarder hub is also the booking of airline capacity. As air cargo pricing is varying and multiple carriers and routings are available for almost all destinations, bookings are done at the latest possible point – ideally when all cargo is known and already at the hub. Then, shipments will be labeled with the airway bill (AWB) number according to a standardized format defined by IATA.

The consolidated shipments will then be transported to the airline air cargo handling facility. Typically, only home-base carriers operate their own facilities while most airlines use handling agents offering their services to multiple airlines. Transport from forwarder to airline, therefore, typically consists of multiple shipments to multiple destinations of multiple airlines. It is the handling agent who receives and consolidates all shipments of all forwarders for one flight. This process is called ”build-up”. The handling agent has his own cut-off-time for the transport from the handling facility to the plane. Depending on the airport and permissions, this is done by the handling agent or a ground handling agent. The cargo is then transported to the destination, sometimes with an additional handling process at the airline hub. After arrival at the destination airport the cargo follows the same processes only in reverse order. Most important is the customs clearance process as the shipments can only be processed any further after clearance. Usually, the forwarder will focus on a limited number of urgent shipments to be picked up from the handling agent immediately after clearance while the rest of the shipments will be processed later.

The physical exchange of shipments is accompanied by the exchange of transport documents. Although IATA and many companies try to digitize documents only slightly more than 50% of all shipments are transported with an electronic AWB (IATA, 2019). The handling agents try to improve transparency by implementing truck slot booking systems where the incoming or outgoing AWBs have to be listed. But for short distance transports those slots are booked either with no AWB information or just-in-time.

For shipments requiring special handling such as Dangerous Goods, Pharmaceuticals or Perishables, additional physical and documentary processes apply. However, this lies outside the focus of this paper.

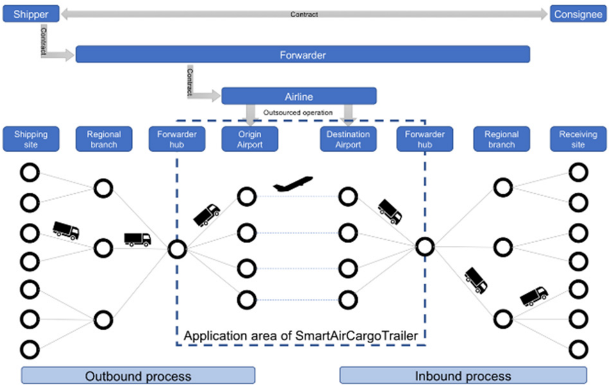

Figure 1: Simplified air cargo supply chain and application area of the SmartAirCargoTrailer.

4 Methodology

4.1 From Gap Analysis to Goals

In chapter 2, the main deficits in the air cargo supply chain have already been identified, so the main goal of the presented concept can be easily deducted as the optimization of short distance transports in the air cargo supply chain. In more detail, this goal can be broken down into several sub goals:

- To increase truck and truck driver utilization and load factors
- To optimize the planning processes and to avoid of peaks by increasing the transparency
- To reduce congestion at the handling agent facilities
- To simplify import processes

4.2 Concept Overview

The concept of the SmartAirCargoTrailer rests on the following three elements which are illustrated in Figure 2:

1. Air cargo shipments which are ready to be transported to the next supply chain partner (outbound: the handling agent; inbound: the forwarder) will be loaded directly onto a trailer. The loading or unloading will be surveyed and steered by a camera-based barcode reading system.
2. The information about the shipments loaded onto the trailer will be shared between the parties involved, typically the forwarder and the handling agent. A cloud-based platform is serving as the enabling technology.
3. Transports will be executed by using trailers or swap-bodies with an autonomous truck managed by the cloud platform.

The shipment identification process is based on the existing AWB-Labels which usually provide a 1D barcode. The use of more modern identification technologies such as Radio Frequency IDentification (RFID) would be preferable, but the global scope and the volatile network structures circumvent the introduction of RFID tags early in the supply chain. What is more important, as machinery parts belong to the most shipped category, are the difficulties with too much surrounding metal that would also lead to detection rates well below 100%, but would require an extra process (tagging each piece). Labeling the piece with the AWB number is always necessary as not all facilities around the globe would be equipped with RFID readers. As the AWB-labeling is done after the booking, which – as mentioned above – comes after virtually consolidating the shipments, this happens shortly before these are transported to the handling agent. Therefore, it can be assumed that most labels will be placed on the outside of a pallet and can be decoded by a camera from one side or the top. Instead of consolidating the shipments in the warehouse in a dedicated staging area, the individual shipments are loaded directly onto the trailer. When identified, the information is sent to the cloud-based platform. The camera system is designed so that it can be integrated into the trailer and is compatible with all warehouses and facilities. The cloud-based platform receives the information from the camera system. Additionally, the consolidation plan will be provided by the forwarder. The system has to provide information to the operative staff about the loaded shipments and the number of pieces and missing shipments or pieces. The transport itself can then be automatically triggered by multiple events, which will be detailed below. Using an autonomous truck is possible as the transport is done on-airport premises in an infrastructure which is known and where many of todays obstacles to autonomous driving like pedestrians or cyclists may rarely interfere. As the truck only moves the swap bodies or trailers, waiting times are irrelevant.

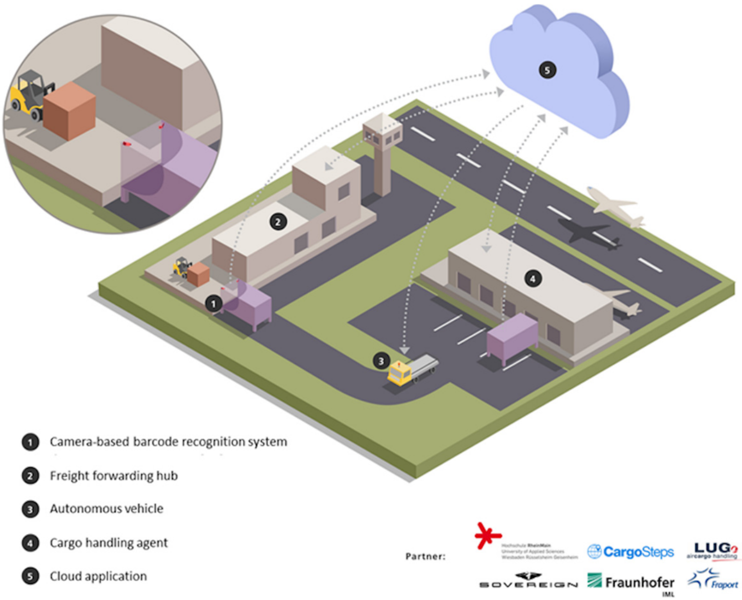

Figure 2: Elements and partners of the SmartAirCargoTrailer (Source: Sieke and Mehrtens, 2019).

5 Preliminary and Expected Results

As the testing of the autonomous vehicle will start this August, only the preparatory results are shown.

5.1 Process

As defined in the concept section, first the overall process with different use cases (or event-triggers) was developed. Up to 17 participants are involved in the air cargo supply chain from shipper to departure. At the beginning of a loading process, the transportation plan has to be uploaded to the system to ensure that the system can be identified correctly, i.e. intended AWB numbers with the right number of pieces as well as to identify and warn if wrong AWBs are loaded onto the trailer. To ensure compliance with safety and security regulation the swap body has to be closed and sealed before it is picked up by the AGV. After transport it has to be ensured that the swap body will be opened only after the AGV has finished its docking process. As for security regulation the intactness of the seal has to be checked.

Today's regulations require that a person presents the shipment related documents and that the identity and security status of this person, the driver, is verified. In the future, the projects propose the use of electronic seals which are also managed by the platform to lock the swap body or trailer and transport the documents inside. As the AGV and the status of the seal would be under 100% surveillance, as all motions would be tracked, this would enhance security. Any manipulation could be detected immediately.
With regard to triggering autonomous transports the following events have been defined:

- The basic push process is triggered by a full swap body. The loading status, or to be precise the empty loading meters, are monitored with an additional camera or an array of ultrasound detectors. To prevent a disruption of operation at the loading facility the AGV will be triggered before 100% capacity will be reached.
- Another trigger-event can be derived from the LAT of one of the shipments loaded. If one of the shipments comes close to its LAT,

the transport will be triggered and even if the loading is not complete, the operative staff would be requested to close the swap body. In this case a manual intervention – a rejection or approval – by the transport manager is necessary. The sending facility decides if they want to finish loading first and risk missing the LAT or if they would modify their transport plan.

- A pull request from the receiving side can be sent if the load of the shipment onto the trailer would be needed to optimize their workflow and processes although the trailer still has capacity left and also time-wise a transport is not necessary. This could be the case when heavy shipments which are handled first in the build-up process would be already processed at the forwarder, but as capacity in the trailer is still available and more shipments of the same forwarder are currently being handled in the forwarders facility, the forwarder intends not to transport those shipments. The handling agent on the other side would profit from those shipments as the build-up could start and other shipments which are at the handling agent's warehouse could be processed afterwards. Although this generates an additional transport, the overall process benefits from early delivery of the shipments (as build-up already started the peak load after LAT is significantly lower).
- A manual pull request could also be sent from the receiving side if it seems appropriate or beneficial to bring in available shipments. This could be triggered by free manpower or free truck docks at the receiving side, esp. if they expect upcoming peaks.
- For highly time-critical shipments such as urgently awaited imports an on-demand transport can be triggered automatically

once the shipment has been registered as being loaded onto the trailer.

- While the push of a trailer is triggered by reaching maximum capacity it could be that the cargo loaded is not time-critical and at the same time the receiving side is under peak load conditions or expects a peak soon. In this case, the receiving side could advise the AGV to transport the swap body to a staging area. As a consequence, the forwarder profits from being able to continue its operations while the handling agent can focus on time-critical shipments.
- To optimize work load, the transport manager of the handling agent could delay a transport that is generated by LAT if the manager decides that the shipments could be handled later, for example if the LAT-critical shipment is a small pieces which will be processed late in the build-up process. This would lead to fewer transports.

Generally speaking, to understand the roles and tasks of the different parties involved in transports seems to be of utmost importance:

- The operative warehouse staff should have a mobile device which shows them which shipments should be loaded, how many pieces have been loaded and wether any mistakes have occurred. They need options to modify the number of pieces detected (in case the barcodes of some pieces could not be read or any other detection error occurred).
- The transport manager is responsible for initially creating the transport list, but also for any updates and modifications. In case

a transport request is generated, the transport manager has the possibility to intervene. The transport manager could also send out a pull request.

- For the setup with multiple parties and AGVs an AGV manager is needed. The responsibilities of the AGV manager would be to monitor the AGV operation and solve conflicts, for example if not all transport requests could be served due to a limited number of operating AGVs.

5.2 Cloud-based Platform

The cloud-based platform links the elements of the SmartAirCargoTrailer concept, mainly the camera system, the autonomous vehicle and the user frontend. The architecture was developed based on the process and role models. The system is designed as a stand-alone solution, as previous experience with digitization and interfaces in the air cargo supply chain (see Bierwirth and Schocke, 2017 for details) showed that IT integration would be challenging and time-consuming. The web-based frontends would have to run on mobile devices as well as on stationary computers. While the camera system should provide AWB numbers and the responding number of pieces, the interface with the autonomous vehicle has to exchange status information as well as transport orders. For export or outbound shipments a transport plan (according to the consolidation) has to be provided by the forwarder.

The core of the platform is the algorithm which automatically manages the autonomous vehicle based on multiple triggers detailed above. As the automatic triggers are time-driven the algorithm has to take into account the process time of the vehicle operation. To increase or maximize the vehicle utilization the vehicle may perform other transport orders and has to drive to the forwarder facility first. After the swap body is closed and a starting signal is given – at least to ensure the closing of the swap body – the transport is performed and the swap body arrives at the handling agent. So depending on the current position of the AGV the total transport time has to be considered to ensure that the transport arrives prior to LAT. The platform consists of a server application (backend) and a web application which serves as the frontend. The cloud application platform Heroku is used to provide a highly scalable infrastructure. Programming is done using Python and the framework Django. The platform uses a Postgresql database, while the transport orders are managed with the help of a worker process. The interfaces with the AGV and the camera system use a REST API.

The web frontend is programmed in responsive HTML5 using the JavaScript Framework Angular.js and websocket connections which enables instant updates. The web site offers a login to ensure security and user role selection. The current status of the transportation plan is displayed for the operative staff. Single entries can be modified by the user in case of reading errors. Completed shipments will be indicated in green, incomplete shipments with an orange indicator and wrong shipments shown in red. Shipments which are missing completely are shown in grey.

To generate input data prior to finishing the interface with the camera system a web-app for Android was developed. Based on the basic barcode reading capabilities of smart phones AWB numbers could be scanned and the information processing could be tested. User role models, IT security and specific processes, e.g. to ensure that the swap body is closed, will be added in later stages.

5.3 Autonomous Transport

For autonomous transports we decided to use swap bodies in combination with swap body trans- porters upgraded with AGV capabilities (see Figure 3). The AGV was already successfully tested at closed cross-docking facilities. The guidance of the vehicle is GPS- and camera-based so no modification of infrastructure is needed.

Figure 3: AGV swap body truck (Source: KAMAG, 2018).

The internal airport roads were originally designed to allow for the operation of all ground handling equipment with a lane with of 5 m, the movement of the swap bodies with an additional width due to the down-folded legs will be possible. As airport roads are private roads they allow the operation of vehicles without legal permission (Straßenverkehrszulassung) and a license plate with the approval of the airport operator only. The speed limits on these roads is 30 km/h. The area is connected to the public road system via two gates. Although the area is accessible to everyone who wants to enter, the registration procedure or the need of an airport ID ensures that the roads are not used by misguided passenger cars or through traffic.

The final system test is planned for several weeks, but prior to that the autonomous vehicle has to be adapted to the special conditions of the airport premises. Prior to that, the routing will be tested with a conventional swap body transporter. The swap body will contain the camera system which then will be battery-powered. As the sites of the handling agent and the forwarder were those of the project partners, the preferable routing had to be chosen taking into account that both intersections and turns or changing lanes and possible interferences with normal traffic do create additional problems. Occasionally, trucks and other vehicles stop or even park at the roadside which can pause problems. Figure 4 shows the chosen route which contains two right and two left turns where the right of way has to be given. To gain experience and avoid peak traffic hours the tests with the AGV will not be conducted neither during shiftover times (7-9 am and 4-6 pm) nor during cargo traffic peak times.

Figure 4: Chosen AGV-routing (Source: Own representation based on Fraport, 2019).

5.4 Camera-based Barcode Reading

The two biggest challenges in decoding barcodes using conventional camera systems during air cargo loading are the large field of view that needs to be covered and the rather difficult lighting conditions in the vicinity of the loading ramp. The latter often lead to blurred images. In the following, we describe our camera setup, with which we try to ensure that we can capture as many barcodes as possible. Furthermore, we present our approache to deal with the large field of view and blurred image regions containing barcodes.

Figure 5 shows the proposed camera-setup, which fits the typical dimensions in the surrounding of a loading ramp. The load is on a standard pallet moving through an archway with a size of approximately 3m 2.8m into a trailer. Our camera arrangement consists of cameras at the corners and upper center of the archway to cover all sides of the pallet. All cameras are hardware synchronized, which guarantees that alle images are taken at the same time. This allows to filter out barcodes that are seen simultaneously in different camera images.

Despite a well-thought-out optical setup, based on several synchronized cameras, the reliable recognition of the barcodes in the camera images and, above all, their subsequent decoding poses a major challenge. To meet these challenges, our camera-based system for reading barcodes essentially consists of the three successive stages (see also Figure 6).

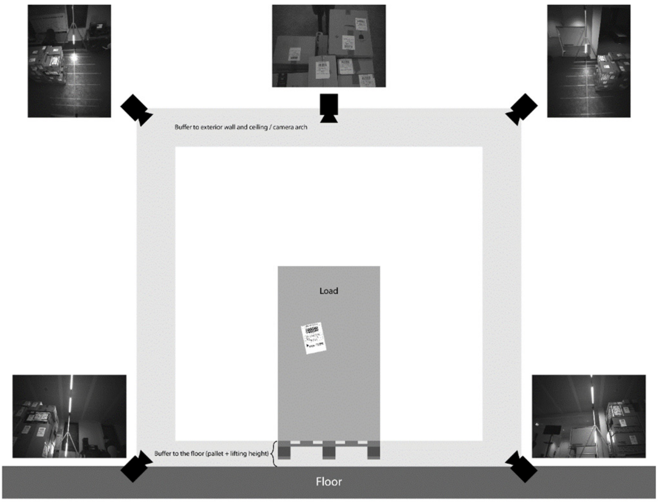

Figure 5: Camera arch equipped with synchronized cameras.

1. *barcode detection*, where image regions that contain barcodes are marked,
2. *image region enhancement*, where the image regions containing barcodes may be sharpened and, above all, aligned horizontally, and finally
3. *barcode decoding*, where the detected and aligned barcode is decoded.

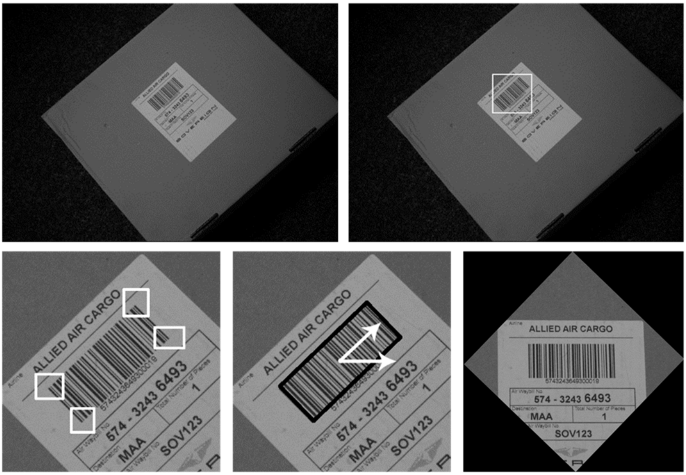

Figure 6: Top row: Original camera image and barcode detected with *Barcode-YOLO*. Bottom row: Corners of the barcode detected with *Corner-YOLO*, determined orientation, and aligned image region that is used to decode the barcode.

The aim of the first stage of our system is to recognize all relevant barcode candidates in each of the camera images (see Figure 7). This step is based on the real-time object detection system YOLO (see Redmon, Divvala, et al., 2016 and Redmon and Farhadi, 2017), a neural network that outputs bounding boxes for objects it detects in real-time. Since YOLO is a deep neural network, it requires a lot of training data to work properly. However, there are pre-trained variants of YOLO that can be adapted to specific problems. We have customized such a pre-trained network for the task of barcode detection using 300 manually labelled images of barcodes. In the following we will refer to this network as Barcode-YOLO.

Figure 7: From left to right: Original camera image, detecting relevant barcodes (ignoring others) and decoded barcodes.

In the second step we estimate the alignment of the detected barcodes (see Figure 6). For this step we use another YOLO network (which we call *Corner-YOLO*) that we have trained to recognize the corners of a barcode. As illustrated in Figure 6 the input for *Corner-YOLO* is a cropped area of the original image based on the prediction boxes of *Barcode-YOLO*. Creating a rotated minimum rectangle over the centers of the detected corners of the boxes, we can estimate the rotation of the barcodes.

The last step is the decoding of the barcodes. For this step we use the 1D/2D barcode image processing library ZXing[3]. As already mentioned, the decoding rate can be further improved by first deburring the rotated image area containing the barcode. It turned out that neural network-based approaches such as the one presented in (Kupyn et al., 2018) are not suitable for deblurring as they provide visually very appealing results but hallucinate false lines leading to incorrect barcodes. Thus, algorithms such as the one presented in (Yahyanejad and Ström, 2010) should be used for deblurring.

[3] ZXing speaks ”zebra crossing”. You can find it at: https://github.com/zxing

5.5 Limitations

Although the overall concept is applicable to air cargo supply chains in general, some limitations have to be considered.

- The concept is only applicable for cargo hub airports where short distance transports between on-airport forwarder hubs and handling agent facilities exist. Furthermore, the concept requires designated truck doors for swap bodies or trailers during loading processes which are longer than at present. As for the handling agents, their number is usually limited, in most cases less than 10, but sometimes even below 5. As for the forwarders the concept has been designed to serve the 5 to 10 biggest players on a specific airport. If the number of truck doors is identified as a limiting factor the concept of AGV based swap body positioning at cross docking facilities could be applied.
- The camera system is trained and developed based on the IATA AWB standard with some optional modification by the forwarder. As the labels are not 100% standardized, the system would have to be slightly modified and trained to read new partners labels.
- A mobile internet connection is necessary to ensure near-time communication with the platform and to provide timely feedback to the operator while loading. The information of the identified shipments has to appear on the mobile device within seconds so the operator can modify or rescan the shipments if errors occur.
- The autonomous transport relies on the operation of an unregistered vehicle within a gated airport area with almost no through-traffic and no pedestrians or cyclists. To transfer the results to

other airports additional requirements may have to be considered. The system is designated for airports with multiple facilities, forwarder hubs and handling agents. At some airports there is either one common building or buildings are connected so transports are done with forklifts or tow tractors. The basic principles of the cloud-based platform, the steering algorithm, and the camera-system can be used, but other types of trailers and AGVs have to be used.

- The autonomous transport may encounter difficulties in certain road conditions (e.g. snow or heavy rains) which are unknown as of today.

6 Managerial Implications and Outlook

The SmartAirCargo trailer concept is meant to improve short distance transports. While the outbound operation of the forwarder remains unchanged, handling agents gets additional information about upcoming shipments and options to optimize workload at the truck gates and in the build-up process by pulling useful shipments from the forwarder. The inbound process is accelerated by pushing all shipments which passed customs to the forwarder. By means of an automatic trigger urgent shipments can be processed without any delay.

Overall the systems helps to overcome the LAT-driven export peaks and to come to a more demand- driven supply chain optimized process flow with more dynamic LATs.

The use of swap bodies (or trailers) increases truck utilization as loading or unloading does not require a truck and its driver to be present any more. By using an AGV, manpower costs could be eliminated. In view of the current truck driver shortage the deployment of AGVs seems to offer a most adequate perspective. The camera-system ensures the completeness of shipments by providing a piece count and minimizes the chances of loading wrong shipments. In combination with the platform the workload of the transport manager is reduced as the system ensures punctual delivery.

The main investments required to make such a concept operational stem from the AGV and the camera system. On the other hand, the following cost savings can be achieved:

- Manpower costs (mostly truck drivers). As hub airports operate 24/7 – even if a night curfew exist – for the continuous operation of one truck a minimum of 5 drivers are needed.
- Quality costs which consist of penalties for missed flights, rebooking or paying for unused capacity, cost of last-minute actions to deliver missing pieces, cost of searching or even cost for unjustified claims.

With the achieved transparency, currently existing buffer times can be reduced which makes it possible to shorten lead times, so cargo could either be picked up later or delivered earlier. Also the throughput of the facility can be raised.

Attention ought to be given to the following issues for future research and developments:

- Air cargo transports should be tested with trailers as they provide more capacity, particularly mega-trailers with less limitations regarding shipment size. Even as trailers are used in closed areas they would have to be connected to the braking and electric systems of the tow truck. Using an AGV would require an automatic connection for both systems.
- The power supply for the camera-system in the trailer has to be changed, as the current battery-based power supply is not capable of a 24/7 operation. Two options exist: Either the system is charged by a connection to the truck while being transported or the charging takes places while being connected to a truck gate.
- Overall, it would be preferable to change the AGV to a e-mobility version. As total payload is seldom used, the speeds are rather low and as the total distance travelled is low only a limited battery capacity is needed while charging options could be provided at the facilities.
- An integration with cargo community systems (CCS) and the warehouse management systems (WMS) has to be developed, to make use of truck slot booking systems, but also to integrate the information flow to make sure that transport plans are automatically uploaded and updated from the WMS.
- The security of the outbound process has to be developed in more detail with the regulation being modified, to allow for a non-human transport and handover of secured shipments. Therefore electronic seals have to be added to the system and security-related alerts and monitoring has to be programmed. The approval

from the responsible authority, the Luft- fahrtbundesamt (LBA), is required prior to a day-to-day-operation.

- A method of automated image processing meant to detect any damages has to be developed to be used for a better claims management.
- The camera system could also be used to verify dimensions.
- Once data from regular operations is available the transport planning algorithm can be optimized with AI and predictive analytics. [4]

[4] Kappel et al., 2019 describes potential use cases for AI in autonomous driving.

Acknowledgements

The authors would like to thank our project partners Sovereign Speed, CargoSteps, Fraunhofer IML, Fraport, LUG aircargo handling, KAMAG and the associated partners Dachser and QuickCargoService.

Financial Disclosure

This project (HA project no. 575/17-57) is funded in the framework of Hessen ModellProjekte, financed with funds of LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz, Förderlinie 3: KMU-Verbundvorhaben (State Offensive for the Development of Scientific and Economic Excellence).

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